

# Biodiesel: An Overview

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## ABSTRACT

Biodiesel, a renewable and environmentally friendly alternative to conventional diesel fuel, has garnered significant attention due to its potential to address pressing energy and environmental challenges. Biodiesel is a biofuel derived from organic materials, typically vegetable oils, animal fats, or recycled cooking oils, through a process known as transesterification. During this process, these feedstocks are chemically converted into biodiesel and glycerol using alcohol and a catalyst. The resulting biodiesel can be used as a drop-in replacement for conventional diesel fuel, either in pure form (B100) or blended with petroleum diesel (e.g., B5, B20). Biodiesel is also known for its compatibility with existing diesel engines and infrastructure, which facilitates its adoption without significant modifications. However, challenges such as feedstock competition with food crops, energy balance concerns, and land-use change associated with biodiesel feedstock cultivation must be considered. Additionally, ongoing research focuses on improving the production process, exploring alternative feedstocks, and optimizing engine performance. Biodiesel represents a promising solution to reduce the environmental impact of the transportation sector and enhance energy security. Its advantages in emissions reduction, compatibility, and renewability make it a crucial player in the transition to cleaner and more sustainable energy sources. Addressing challenges while continuing to advance the state of the art in biodiesel production and application is essential for its successful integration into our energy landscape.

**Keywords:** Biodiesel, Renewable Energy, Biofuel, Transesterification, Green House Gas Emissions

## INTRODUCTION

The global energy landscape is at a pivotal juncture, driven by the urgent need to address the twin challenges of environmental sustainability and energy security. The conventional use of fossil fuels, such as diesel, has been a primary contributor to greenhouse gas emissions and air pollution. To mitigate these environmental concerns and reduce the world's dependence on finite and geopolitically sensitive energy sources, renewable and sustainable alternatives have become a critical area of research and development. Biodiesel, an eco-friendly and domestically producible fuel, has emerged as a prominent candidate in the global quest for cleaner, greener energy solutions [1].

Biodiesel, as a renewable energy source, is produced through the transformation of various feedstocks, primarily vegetable oils, animal fats, and waste oils, into a cleaner-burning alternative to diesel fuel. The key driver behind biodiesel's appeal lies in its potential to reduce greenhouse gas emissions, enhance air quality, and decrease reliance on non-renewable fossil fuels. As the global community grapples with the consequences of climate change and endeavors to transition to more sustainable energy sources, biodiesel offers a ray of hope [1].

The goal of this comprehensive literature review is to delve into various facets of biodiesel, spanning its production processes, advantages, disadvantages, the current state of the art, applications across diverse sectors, and, ultimately, to present an informed synthesis of the most recent research findings. This article aims to

provide an in-depth exploration of the biodiesel landscape, elucidating its potential while recognizing the associated challenges.

## **DISCUSSION**

### **Production Of Biodiesel**

The production of biodiesel is a multifaceted process that involves the transformation of various feedstocks into a cleaner-burning alternative to conventional diesel fuel. This section explores the intricacies of biodiesel production methods, with a focus on the latest developments and technologies as reported in recent literature. To comprehend biodiesel production fully, one must understand the following key elements [2]:

#### **1. Feedstock Selection**

Biodiesel can be produced from various feedstocks, including vegetable oils (e.g., soybean, canola, and palm oil), animal fats, and waste oils. The choice of feedstock significantly influences the overall sustainability and economic viability of biodiesel production. Recent studies have emphasized the importance of selecting feedstocks that are not in direct competition with food production and that have favorable energy balances. Advanced research is continually evaluating alternative feedstocks, such as algae and jatropha, with an emphasis on maximizing productivity and minimizing environmental impacts [2].

#### **2. Transesterification**

Transesterification is the most common method for converting feedstocks into biodiesel. This chemical process involves the reaction of triglycerides (found in oils and fats) with an alcohol (usually methanol or ethanol) in the presence of a catalyst, typically sodium or potassium hydroxide. The result of this reaction is the production of biodiesel (fatty acid methyl or ethyl esters) and glycerol, a valuable byproduct. Recent research in transesterification has focused on optimizing reaction conditions, enhancing catalyst efficiency, and exploring novel catalysts that reduce waste and improve yield [3].

#### **3. Enzymatic Processes**

Enzymatic processes are an alternative to traditional chemical transesterification. These processes use lipase enzymes to catalyze the reaction between triglycerides and alcohol. Enzymatic biodiesel production has gained attention for its potential to reduce energy consumption, offer high specificity, and minimize the formation of unwanted byproducts. Researchers have been exploring novel enzyme sources, immobilization techniques, and reaction conditions to improve the efficiency of enzymatic biodiesel production [3].

#### **4. Supercritical Transesterification**

Supercritical transesterification is an innovative approach that involves using supercritical fluids, typically supercritical methanol, to accelerate the transesterification reaction. This method offers the advantage of reduced reaction times and lower energy consumption. Recent studies have investigated the use of supercritical fluids and co-solvents to optimize the process and enhance biodiesel yield [2].

#### **5. Waste-to-Biodiesel**

The utilization of waste oils and fats from restaurants, food processing plants, and other sources has garnered considerable attention in biodiesel production. Waste oils can be an environmentally sustainable source of biodiesel, as they divert waste from landfills and reduce the need for virgin feedstocks. Recent research in this area has focused on improving the collection and pretreatment of waste oils to enhance their suitability for biodiesel production [3].

#### **6. Catalyst Development**

The choice of catalyst is a critical factor in transesterification reactions. Recent research has explored the development of heterogeneous catalysts, such as solid acids and bases, as alternatives to traditional homogeneous catalysts. Heterogeneous catalysts offer the advantage of easier separation and reuse, reducing waste and production costs [4].

#### **7. Waste Utilization**

The glycerol byproduct generated in biodiesel production has applications

beyond disposal. Recent research has examined various ways to utilize glycerol, including its conversion into value-added products such as chemicals, pharmaceuticals, and biofuels [4].

Biodiesel production is a dynamic field with ongoing developments aimed at making the process more sustainable, cost-effective, and energy-efficient. Researchers are continually exploring novel feedstocks, improving reaction methods, and optimizing catalysts. Understanding these advancements is crucial to comprehending the potential and limitations of biodiesel as a renewable energy source. The evolution of biodiesel production methods plays a pivotal role in determining its viability as a green alternative to conventional diesel fuels [5].

### **Advantages Of Biodiesel**

Biodiesel, as a renewable and sustainable energy source, offers a multitude of advantages that make it an attractive alternative to conventional diesel fuel. In this section, we will explore these advantages in greater detail, considering the most recent research and findings from reliable sources. The key advantages of biodiesel include [6]:

#### **1. Greenhouse Gas Emission Reduction**

Biodiesel is considered a cleaner-burning fuel as it produces fewer greenhouse gas emissions, particularly carbon dioxide (CO<sub>2</sub>), compared to petroleum-based diesel. This reduction in emissions is primarily attributed to the carbon-neutral nature of biodiesel feedstocks, which absorb CO<sub>2</sub> during their growth, thus offsetting emissions during combustion. Recent studies have quantified these emission reductions, highlighting biodiesel's role in mitigating climate change [6].

#### **2. Air Quality Improvement**

Biodiesel combustion emits lower levels of harmful air pollutants, such as sulfur oxides (SO<sub>x</sub>) and particulate matter, which are known to contribute to respiratory problems and air quality degradation. The decreased emission of nitrogen oxides (NO<sub>x</sub>) in

biodiesel combustion also results in lower levels of smog-forming pollutants. Recent research has emphasized the role of biodiesel in improving urban air quality and its potential for use in urban fleets to reduce particulate matter pollution [7].

#### **3. Domestically Produced and Reduces Energy Dependency**

Biodiesel can be produced domestically from various feedstocks, reducing a nation's dependence on imported petroleum. This energy security advantage has significant economic and geopolitical implications. Recent studies have assessed the economic benefits of biodiesel production, job creation, and its contribution to energy independence [7].

#### **4. Compatibility with Existing Infrastructure**

Biodiesel can be used in existing diesel engines and infrastructure with little to no modifications. This compatibility reduces the barriers to adoption and eases the transition to cleaner fuels. Recent research has focused on optimizing engine performance and ensuring that biodiesel blends meet industry specifications for quality [8].

#### **5. Renewable Feedstocks**

Biodiesel feedstocks, such as vegetable oils, animal fats, and waste oils, are renewable resources. Their production can be sustained over time, unlike finite petroleum reserves. Research has explored various feedstock options and their potential to provide a consistent and sustainable source of biodiesel [8].

#### **6. Local Economic Development**

Biodiesel production can stimulate local economies by creating jobs in agriculture, feedstock processing, and biofuel manufacturing. Recent studies have examined the economic impacts of biodiesel production on rural and agricultural communities [9].

#### **7. Biodegradability and Reduced Spill Risks**

Biodiesel is biodegradable and less toxic than petroleum-based diesel, reducing the environmental impact in case of spills or

leaks. This characteristic has been highlighted in recent research that assesses the environmental risks associated with biodiesel use [9].

### **8. Flexibility and Blend Compatibility**

Biodiesel can be used as a pure fuel (B100) or blended with petroleum-based diesel in various proportions (e.g., B5, B20, B50). The flexibility to use biodiesel in blends allows for a gradual transition to cleaner fuels. Recent studies have examined the performance and emissions characteristics of different biodiesel blends [10].

### **9. Reduced Engine Wear and Maintenance**

Biodiesel's higher lubricity can result in reduced engine wear and maintenance costs. Research has delved into the impact of biodiesel on engine longevity and maintenance requirements [10].

### **10. Carbon Sequestration**

Biodiesel feedstock crops, such as soybeans and rapeseed, capture carbon dioxide during their growth. This carbon sequestration aspect further contributes to the overall reduction of greenhouse gas emissions. Recent research has explored the carbon balance of biodiesel feedstock production [10].

Biodiesel offers a range of compelling advantages, with a clear focus on reducing greenhouse gas emissions, improving air quality, enhancing energy security, and stimulating local economies. These advantages make biodiesel a viable and attractive option for addressing environmental and energy challenges. The continued exploration of biodiesel's benefits is essential for informed decision-making and policy development, as it plays a pivotal role in the transition to more sustainable and cleaner energy solutions [11].

### **Disadvantages Of Biodiesel**

While biodiesel presents a range of advantages, it also comes with a set of disadvantages and challenges that need to be considered in its adoption and production. In this section, we will explore these disadvantages in greater detail, drawing

from the most recent research and findings from reliable sources. The key disadvantages of biodiesel include [12]:

#### **1. Feedstock Competition**

The production of biodiesel competes for agricultural land and resources with food crops and other agricultural products. This competition can lead to increased prices for these resources and concerns about food security [12]. Recent research has assessed the potential impacts of biodiesel production on food production and land use [13].

#### **2. Energy Balance Concerns**

The net energy balance of biodiesel production has been a subject of debate. The energy input required for planting, harvesting, and processing feedstocks can, in some cases, approach or even exceed the energy output in biodiesel. Recent studies have examined the energy efficiency of various biodiesel feedstocks and production processes [14].

#### **3. Land Use Change and Deforestation**

The expansion of biodiesel feedstock cultivation, particularly in regions like the Amazon rainforest and Southeast Asia, has been associated with deforestation and land-use change. This has raised concerns about biodiversity loss and ecosystem destruction. Recent research has investigated the environmental consequences of land-use changes driven by biodiesel production [14].

#### **4. Food vs. Fuel Debate**

Biodiesel production's reliance on edible feedstocks has raised the "food vs. fuel" debate, as it diverts crops that could be used for food into biofuel production. This debate poses ethical and social questions about the allocation of resources. Recent literature has explored the ethical implications of biofuel production [15].

#### **5. Cold-Weather Performance**

Biodiesel can suffer from cold-weather issues, including gelling and cloud point problems, which can lead to engine and fuel system difficulties in colder climates. Recent studies have focused on the formulation of winter-grade biodiesel and its performance in cold temperatures [15].

#### **6. Technical Compatibility**

While biodiesel can be used in existing diesel engines, it may require modifications in certain cases. In older diesel engines, biodiesel use can lead to clogged filters and fuel system problems. Recent research has assessed the compatibility of various engine types with biodiesel and the necessary modifications [16].

### **7. Stability and Storage Challenges**

Biodiesel can have stability issues during storage, leading to degradation and the formation of sediments. These challenges can result in quality issues over time. Research has explored methods to improve biodiesel storage stability and extend its shelf life [16].

### **8. Water Contamination**

Biodiesel production can produce waste byproducts, and if not managed properly, these byproducts can potentially contaminate water sources. Recent studies have examined the environmental impacts of biodiesel production waste and ways to mitigate contamination risks [17].

### **9. Economic Viability**

The economic viability of biodiesel production is influenced by factors such as feedstock prices, government incentives, and the availability of infrastructure. Recent research has assessed the economic sustainability of biodiesel production in various contexts [17].

### **10. Greenhouse Gas Emissions from Land Use Change**

While biodiesel itself can reduce greenhouse gas emissions, the land-use changes associated with feedstock cultivation, especially in ecologically sensitive areas, can release stored carbon and result in increased emissions. Recent studies have investigated the full life-cycle emissions associated with biodiesel production [18].

Biodiesel, while offering several environmental and economic advantages, is not without its disadvantages and challenges. It's essential to weigh these drawbacks against the benefits to make informed decisions about its production and utilization. Addressing these disadvantages

through technological innovation and sustainable practices is a key focus of ongoing research in the biodiesel industry. Understanding and mitigating these challenges is critical to the responsible and sustainable growth of biodiesel as a cleaner energy alternative [18].

### **State-Of-The Art Of Biodiesel**

The biodiesel industry is continually evolving, driven by a combination of technological advancements, regulatory changes, and the global transition toward cleaner, more sustainable energy sources. In this section, we will explore the current state of the art in biodiesel research and development, focusing on the latest breakthroughs in feedstock selection, catalyst development, and the optimization of biodiesel production processes. Additionally, we will examine recent advancements in the use of algae-based biodiesel, which holds significant promise in revolutionizing the industry [17].

#### **1. Advanced Feedstock Selection**

- a. Researchers are continually exploring alternative and non-food feedstocks, such as algae, jatropha, and camelina, which can potentially offer higher yields and reduce the competition between food and fuel production.
- b. Genetic engineering and selective breeding techniques are being employed to enhance the productivity and suitability of feedstock crops.
- c. Research is focused on improving the cultivation and harvest methods for these feedstocks, aiming to increase yields and reduce resource inputs [19, 20].

#### **2. Catalyst Development and Novel Reactors**

- a. Recent research has focused on developing heterogeneous catalysts with enhanced catalytic activity, stability, and reusability. Solid acid and base catalysts are being investigated as alternatives to traditional homogeneous catalysts.

- b. Advances in reactor design and engineering have optimized transesterification processes, resulting in faster reaction times and higher conversion rates.
- c. The use of non-conventional catalysts, such as ionic liquids and enzymes, is being explored for greener and more efficient biodiesel production [21, 22].

### **3. Enhanced Process Efficiency**

- a. Process optimization, including reaction parameters such as temperature and pressure, has been a focal point in recent biodiesel research.
- b. Supercritical transesterification has gained attention for its potential to accelerate the reaction rate, reduce energy consumption, and simplify the purification process.
- c. Research into continuous and continuous-flow processes is underway, with a focus on scalability and improved process control [21, 22].

### **4. Algae-Based Biodiesel**

- a. Algae-based biodiesel represents a cutting-edge development in the field. Algae are highly productive and can be cultivated in a wide range of environments, including wastewater treatment facilities and non-arable land.
- b. Advances in algae strain selection, growth optimization, and lipid extraction techniques have significantly improved the feasibility and yield of algae-based biodiesel.
- c. The integration of algae-based biodiesel production with CO<sub>2</sub> capture from industrial processes holds promise for further reducing greenhouse gas emissions [23, 24].

### **5. Analytical Techniques and Quality Control**

- a. Biodiesel quality control is crucial for ensuring optimal engine performance and environmental benefits.
- b. Advanced analytical techniques, including high-performance liquid chromatography (HPLC) and mass spectrometry, are being used to monitor

biodiesel quality and assess the presence of contaminants.

- c. The development of rapid and accurate quality control methods is ongoing to maintain the industry's reputation for high fuel quality [21, 22].

### **6. Life Cycle Analysis and Sustainability Assessment**

- a. Researchers are conducting comprehensive life cycle assessments (LCA) to evaluate the environmental impacts of biodiesel production, from feedstock cultivation to end-use.
- b. Sustainability certification programs, such as the Roundtable on Sustainable Biomaterials (RSB), play a pivotal role in ensuring that biodiesel production meets strict sustainability criteria.
- c. Sustainability metrics are being refined and updated to address evolving environmental and social concerns [23, 24].

The state of the art in biodiesel research is characterized by innovation in feedstock selection, catalysis, and production processes. The development of algae-based biodiesel and the pursuit of greener and more efficient production methods hold the potential to reshape the biodiesel industry. Research continues to be driven by the need for sustainability, reduced greenhouse gas emissions, and improved fuel quality, making biodiesel a dynamic and evolving field with significant potential to contribute to a more sustainable and energy-secure future [25, 26].

### **Applications of Biodiesel**

Biodiesel's versatility and compatibility with existing infrastructure have paved the way for its application across various sectors, including transportation, agriculture, power generation, and more. In this section, we will explore the latest developments in the utilization of biodiesel in these sectors, considering engine performance, compatibility, and the economic feasibility of its widespread use. Additionally, we will discuss the aviation industry's adoption of

biodiesel as a sustainable aviation fuel [25, 26].

### **1. Transportation Sector**

- a. Biodiesel can be directly used in diesel engines with little to no modification, making it a practical choice for road transportation. Research has focused on optimizing engine performance and emissions characteristics when using biodiesel blends, such as B5, B20, and B100. Studies have examined the impact on engine wear, fuel consumption, and emissions control systems, ensuring that biodiesel remains a viable choice for various road vehicles.
- b. Biodiesel is also applicable in rail transportation, where diesel engines are common. Recent research has investigated the compatibility of biodiesel with locomotive engines and its performance under various operating conditions.
- c. The maritime sector is exploring biodiesel as a cleaner-burning alternative for shipping vessels. Research has assessed the feasibility of using biodiesel in marine engines and its environmental benefits in reducing emissions in ports and coastal areas [25, 26]

### **2. Agriculture**

Biodiesel has gained traction in the agricultural sector, particularly for powering tractors, harvesters, and other farm machinery. Research has explored the economic and environmental implications of using biodiesel on farms, including fuel cost savings, reduced emissions, and the potential for on-farm biodiesel production using locally sourced feedstocks [23, 24].

### **3. Power Generation**

Biodiesel can be utilized in diesel generators to produce electricity. This application is particularly relevant in off-grid and remote areas where access to conventional fuels may be limited. Recent research has examined the technical aspects of using biodiesel in power generation and its

economic viability as an off-grid energy source [27, 28].

### **4. Sustainable Aviation Fuel (SAF)**

The aviation industry is increasingly exploring the use of biodiesel as a sustainable aviation fuel (SAF) to reduce carbon emissions. Biodiesel-based SAF can be blended with conventional jet fuel to reduce the aviation sector's environmental impact. Research has focused on SAF production methods, feedstock selection, and the compatibility of biodiesel-derived SAF with aircraft engines [25, 26].

### **5. Industrial and Commercial Applications**

Biodiesel is employed in a range of industrial and commercial applications, such as heating and as a source of backup power. Research has investigated the use of biodiesel for these applications, including the development of specialized biodiesel blends for heating purposes and emergency backup generators [27, 28].

### **6. Emerging Markets**

The use of biodiesel in emerging markets and developing countries is a growing area of interest. Researchers are examining the economic and environmental implications of biodiesel use in regions where energy security and environmental sustainability are of utmost importance [27, 28].

### **7. Blending and Compatibility Research**

Ongoing research is dedicated to understanding the blending characteristics of biodiesel with petroleum-based diesel and other biofuels. Studies aim to ensure that blended fuels meet industry specifications and maintain engine performance and emissions control [29, 30].

### **8. Economic Feasibility**

Research in this area delves into the economic feasibility of widespread biodiesel use. This includes assessing the cost-effectiveness of biodiesel production, fuel pricing, government incentives, and subsidies, as well as their impact on the economics of biodiesel utilization in various sectors [29, 30].

Biodiesel's application is not limited to a single sector; it spans transportation,

agriculture, power generation, aviation, and more. Its adaptability to existing engines and infrastructure, coupled with its potential to reduce greenhouse gas emissions, positions biodiesel as a versatile and sustainable alternative fuel. Ongoing research and practical applications are instrumental in evaluating the real-world potential of biodiesel in addressing energy and environmental challenges across a range of sectors [29, 30].

## CONCLUSION

In conclusion, biodiesel stands as a viable and sustainable alternative to conventional diesel fuel, with numerous advantages including reduced carbon emissions and enhanced energy security. However, it is crucial to consider the complex landscape of biodiesel production, its advantages, and disadvantages. The state of the art in biodiesel research continues to evolve, with new feedstocks, technologies, and applications emerging on the horizon. As biodiesel continues to be refined and adopted on a global scale, it is essential to stay informed about the latest advancements and potential challenges that the biodiesel industry may face.

### Declaration by Authors

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