

RENEWABLE DIESEL, BIODIESEL, AND PETROLEUM DIESEL: COMPARING PRODUCTION, PERFORMANCE, AND ENVIRONMENTAL IMPACT

This paper compares renewable diesel, biodiesel, and petroleum diesel using U.S. government publications and published research, with a focus on the U.S. market. The comparison examines production methods, chemical composition, fuel properties, engine performance, environmental impacts, cost, and availability. Petroleum diesel is refined from crude oil, while biodiesel and renewable diesel can be produced from oils and fats through different chemical processes. Renewable diesel contains hydrocarbons and can be used in conventional diesel engines. Biodiesel contains fatty acid esters, and its use requires attention to blend level, cold-weather performance, and storage conditions. The reviewed research indicates that both renewable alternatives can reduce life cycle greenhouse gas emissions compared with petroleum diesel, although the reductions depend on feedstocks, production methods, and land-use impacts. Cost comparisons also depend on location, fuel availability, and energy content per gallon. Overall, choosing among these fuels requires balancing potential environmental benefits with practical operating needs. The most suitable option depends on the equipment, climate, local fuel supply, and operating costs.

Introduction

Diesel fuels play an important role in transportation and industry, powering trucks, buses, and agricultural and construction machinery. The main type used in these applications is petroleum diesel, which is refined from crude oil [1]. Biodiesel and renewable diesel can be produced from vegetable oils, animal fats, and recycled cooking oil. Although they can use similar raw materials, they are distinct fuels with different production methods and chemical compositions [2, 3].

Comparing these fuels requires consideration of both their environmental benefits and their practical limitations. Studies show that biodiesel and renewable diesel can reduce life cycle greenhouse gas emissions compared with petroleum diesel, although the reductions depend on the raw materials, production processes, and land-use impacts considered [4]. Fuel properties, engine compatibility, cold-weather performance, cost, and availability also need to be considered for a fair comparison. This paper examines renewable diesel, biodiesel, and petroleum diesel across these areas to compare their advantages and disadvantages and identify the conditions under which each fuel may be most suitable.

Production Methods and Chemical Composition

Most diesel fuel produced and consumed in the United States is refined from crude oil [1]. During refining, crude oil is heated and separated into fractions according to their boiling points. Heavier fractions can undergo cracking, which breaks large hydrocarbon molecules into smaller ones [5]. Refiners also use catalytic hydrotreating to remove sulfur. This process treats the fuel with hydrogen in the presence of a catalyst, reducing its sulfur content [6]. Diesel sold for road vehicles in the United States is ultra-low sulfur diesel (ULSD), with a sulfur content of 15 parts per million or less [1]. The Department of Energy lists petroleum diesel components containing 8–25 carbon atoms [7].

Biodiesel is synthesized from raw materials such as plant oils, recycled cooking grease, and animal fats. These oils and fats react with an alcohol, usually methanol, in the presence of a catalyst. This reaction is called transesterification (Equation 1). When methanol is used, the reaction produces fatty acid methyl esters (FAME), which make up biodiesel, and glycerol as a coproduct. This conversion also reduces the viscosity, or thickness, of the original oils and fats to values closer to those of conventional diesel fuel [8].

Triglyceride + 3 methanol ⇌ 3 FAME + glycerol (1)

The double arrow indicates that the reaction is reversible, so excess methanol is used to drive it toward FAME [8].

Renewable diesel can be manufactured from fats, oils, and greases, but its production process differentiates it from biodiesel. Instead of undergoing transesterification, renewable diesel is commonly produced through hydrotreating, which uses hydrogen and a catalyst to process these materials at elevated temperatures and pressures [3, 9]. The resulting fuel contains hydrocarbons rather than the fatty acid esters found in biodiesel.

In commercial production, hydrotreating is commonly followed by isomerization, which converts straight-chain hydrocarbons into branched hydrocarbons. This lowers the cloud point and allows producers to adjust the fuel's cold-weather performance. Renewable diesel made from fats and oils is also commonly called HVO or HEFA [9]. Renewable diesel meets the ASTM D975 specification used for petroleum diesel in the United States and can replace petroleum diesel or be blended with it in any proportion [3].

- **Biodiesel's methyl ester structure:** $R–C(=O)–O–CH_3$
- **A straight-chain hydrocarbon structure found in renewable diesel:** $CH_3–(CH_2)_n–CH_3$

Here, R represents a hydrocarbon chain, while n indicates the number of repeating CH_2 groups. The ester group contains oxygen; the hydrocarbon contains only carbon and hydrogen. These simplified structures illustrate the chemical difference between the fuels. Renewable diesel also contains branched hydrocarbons [8, 9].

Figure 1 compares the raw materials, production methods, and final product for the three fuels. Although biodiesel and renewable diesel can use similar raw materials, transesterification produces fatty acid esters, while hydrotreating produces hydrocarbon fuels.

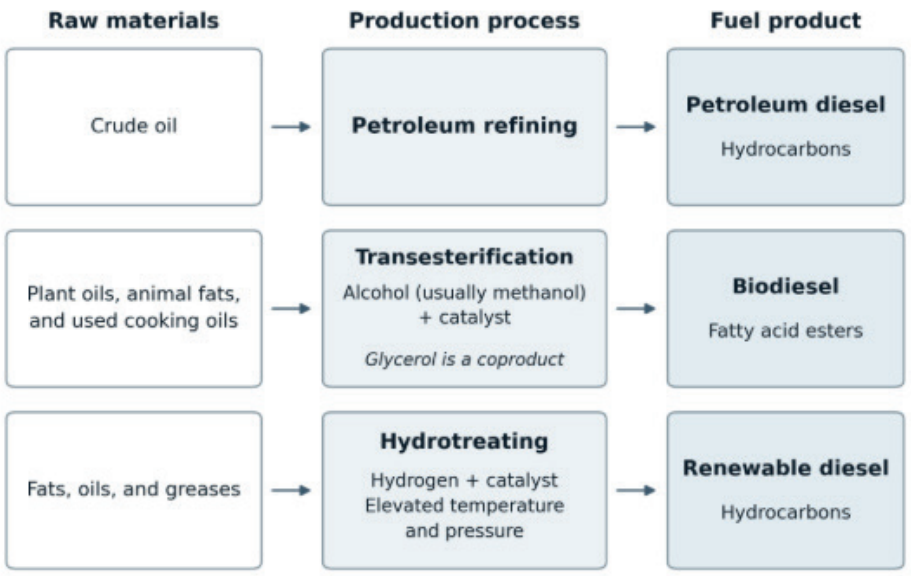


Figure 1: Production Pathways for Petroleum Diesel, Biodiesel, and Renewable Diesel

Diagram based on [1, 3, 8].

Fuel Properties and Engine Performance

Energy content describes the heat released when a fuel burns. It is measured here in British thermal units per gallon (Btu/gal), so a higher value means more energy in each gallon [8]. The lower heating value is the heat released when the water formed during combustion remains as vapor. The Department of Energy lists lower heating values of 128,488 Btu/gal for petroleum diesel, 119,550 Btu/gal for pure biodiesel (B100), and 123,710 Btu/gal for pure renewable diesel (RD100) [7]. Calculated from these values, biodiesel contains approximately 7% less energy per gallon than petroleum diesel, while renewable diesel contains approximately 4% less. If an engine converted each fuel's energy into work with equal efficiency, a lower-energy fuel would require more gallons to perform the same work.

B20 contains 20% biodiesel and 80% petroleum diesel by volume. Using the heating values above, B20 contains approximately 1.4% less energy per gallon than petroleum diesel [7]. This small difference often produces little or no noticeable change in fuel economy, with differences comparable to those between summer and winter diesel fuels [8].

Energy per gallon depends on both fuel density and energy per kilogram. Density describes how much mass a given volume contains. In the samples tested by McCormick et al. [10], biodiesel was denser than petroleum diesel but released less energy per kilogram. Its higher density partly offset that lower energy content. Renewable diesel showed the opposite pattern: it released slightly more energy per kilogram, yet its lower density meant that each gallon contained less energy [10]. These sample results illustrate the relationship; the 7% and 4% differences above were calculated from the separate Department of Energy values [7].

Cetane number is another important property that measures ignition quality. Higher values indicate a shorter delay before combustion begins. This property impacts cold starting and combustion smoothness [8]. According to the Department of Energy, cetane numbers range from 40–55 for petroleum diesel, 45–65 for biodiesel, and 70–85 for renewable diesel [7]. Renewable diesel therefore has the highest listed ignition-quality rating. These comparisons show that a fuel can have less energy per gallon while still having better ignition quality, because the two measurements describe different properties.

Indicated cetane number (ICN) is a laboratory measure of fuel ignition quality. In the study shown in Figure 2, it was measured in a constant-volume combustion chamber using ASTM D8183 [10]. Conventional cetane number uses a different test: a Cooperative Fuel Research (CFR) engine operated under ASTM D613. The two measures are correlated but not interchangeable, so the ICN values in Figure 2 should not be compared directly with the cetane ranges given above. Figure 2 shows that increasing biodiesel content decreased the indicated cetane number of the renewable diesel blends but caused little change in the petroleum diesel blends tested [10].

Cold-weather performance affects all three fuels because crystals can form as the fuel cools and clog fuel filters. The temperature at which these crystals first become visible is called the cloud point [10]. Cold filter plugging point (CFPP), measured using ASTM D6371, provides another way to assess whether cooled fuel can pass through a standardized filter [8, 11]. Biodiesel's performance depends on its feedstock, blend percentage, and the petroleum diesel used. Lower biodiesel concentrations generally perform better in cold weather. For example, B5, which contains up to 5% biodiesel, typically performs similarly to No. 2 diesel [2]. Biodiesel made from tallow or palm oil generally has a higher cloud point than soy biodiesel because it contains more saturated methyl esters, which crystallize at higher temperatures [10]. Renewable diesel's cloud point can be adjusted during production through isomerization, which creates branched hydrocarbons and improves cold-weather performance [9]. However, it does not always have a lower cloud point than petroleum diesel. In the samples listed in Table 1, renewable diesel had a lower cloud point than biodiesel but a higher cloud point than petroleum diesel [10]. The petroleum diesel sample in [10] had a cloud point of −26.2 °C, which is much lower than that of typical No. 2 diesel, so this ordering should not be generalized to all petroleum diesel.

Engine compatibility depends on the fuel and blend level. Blends that contain 6–20% biodiesel, known as B6-B20, can be used in many diesel applications with minor or sometimes no equipment changes. ASTM D975 covers diesel containing up to 5% biodiesel (B5) [12], while ASTM D7467 covers blends containing 6%–20% biodiesel (B6–B20) [13]. ASTM D6751 sets the requirements for pure biodiesel (B100) used as a blendstock [10, 14]. However, blends above B20 may require special handling or modifications [8].

Renewable diesel meets ASTM D975, the U.S. specification used for conventional petroleum diesel. This permits it to be used in existing diesel engines and fuel infrastructure, either as a replacement fuel or blended with petroleum diesel [3].

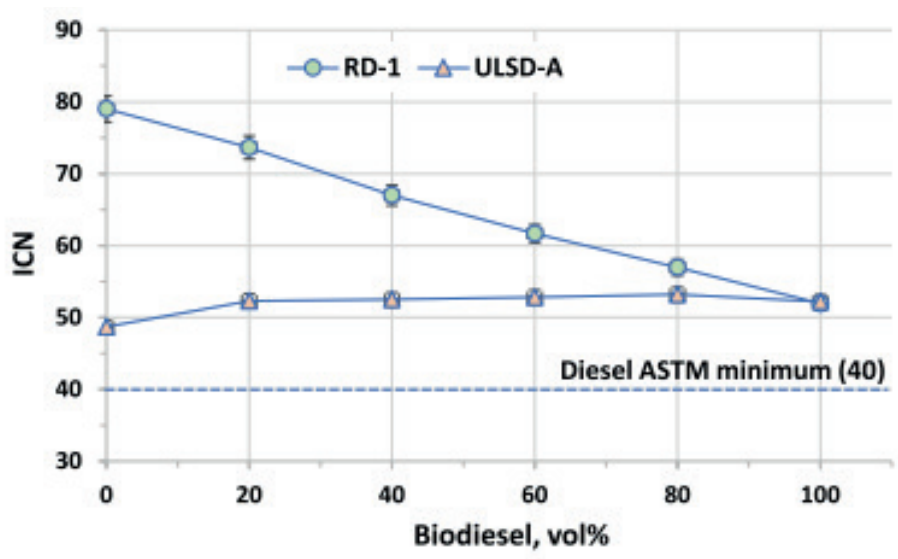


Figure 2: Indicated Cetane Numbers of Biodiesel Blends with Renewable and Petroleum Diesel

From McCormick et al. [10]. © 2024 the authors. CC BY 4.0.

Table 1. Selected Properties of Petroleum Diesel, Biodiesel, and Renewable Diesel

Property	Petroleum diesel	Biodiesel (B100)	Renewable diesel (RD100)
Lower heating value, Btu/gal [7]	128,488	119,550	123,710
Cetane number [7]	40–55	45–65	70–85
Cloud point,°C—sample values [10]	−26.2	−0.6	−19.6
Density at 15°C, g/mL—sample values [10]	0.843	0.884	0.780
Approximate oxygen content, mass % [2, 7, 9]	0	11	0
ASTM specification [10]	D975	D6751 (blendstock)	D975
Example life cycle carbon intensity, g CO_2e/MJ [4]	≈90	≈30	≈33

Note. Cloud point and density represent specific samples tested in [10]. The oxygen content listed for biodiesel applies to FAME and varies slightly with feedstock. Carbon-intensity values for biodiesel and renewable diesel represent soybean pathways using GREET default land-use-change estimates in [4]. Actual properties and emissions vary with feedstock and production conditions.

Environmental Impacts

Environmental comparisons should consider both life cycle emissions and tailpipe pollution. A life cycle analysis follows emissions from feedstock production or collection through processing, distribution, and vehicle use [4]. Carbon intensity expresses greenhouse gas emissions per unit of fuel energy, commonly in grams of carbon dioxide equivalent per megajoule (g CO_2e/MJ). The lower the value, the fewer greenhouse gas emissions for the same amount of fuel energy, allowing fuels with different energy contents to be compared [8]. For comparison, the petroleum diesel baseline used by Xu et al. was approximately 90 g CO_2e/MJ [4].

Xu et al. [4] estimated that oilseed-based biodiesel and renewable diesel pathways could reduce life cycle greenhouse gas emissions by 40%–69% compared with petroleum diesel, depending on the feedstock and land-use-change estimates. Pathways using tallow, used cooking oil, and distillers corn oil showed larger reductions of 79%–86%. A 40% reduction means that a pathway produced approximately 60% of the petroleum diesel emissions for the same amount of fuel energy.

Production practices and modeling assumptions strongly influence these results. Fertilizer-related emissions, processing energy, and chemical inputs contribute to the totals. Estimates also depend on changes in land use and how upstream emissions are assigned to waste and byproduct feedstock. As a result, environmental performance depends on how a fuel is produced as well as whether it is classified as biodiesel or renewable diesel [4].

Pollutants that are directly released through a vehicle's exhaust are known as tailpipe emissions. In older diesel engines, without advanced emissions controls, increasing biodiesel content can reduce carbon monoxide, unburned hydrocarbons, and particulate matter. Biodiesel's effect on nitrogen oxides (NOx) emissions in these older engines is mixed, with reported results ranging from small increases to no significant change [8]. Modern diesel engines use diesel particulate filters (DPFs) to trap soot and selective catalytic reduction (SCR) systems to reduce nitrogen oxides. With these controls, differences in tailpipe emissions between petroleum diesel, biodiesel, and their blends are often small [8].

Renewable diesel has also shown benefits in older engines. Tests of heavy-duty vehicles without advanced exhaust-treatment systems reported significant reductions in engine-out particulate matter and NOx emissions with renewable diesel compared with petroleum diesel [9]. These exhaust-pollution results should be considered separately from life cycle greenhouse gas emissions.

Cost and Availability

Fuel prices depend on the location, purchase date, and blend being sold. In the Department of Energy's April 2026 survey, petroleum diesel averaged $5.55 per gallon nationally. B20 averaged $5.30 per gallon, while B99/B100 averaged $5.28. B99/B100 contains approximately 99%–100% biodiesel [15].

Price per gallon does not account for differences in energy content. A diesel gallon equivalent (DGE) represents the energy in one gallon of petroleum diesel. Comparing prices per DGE therefore shows the cost of buying the same amount of fuel energy. Using the report's conversion factors, B99/B100 cost $5.80 per DGE, compared with $5.55 for petroleum diesel [15]. In this survey, B99/B100 was therefore cheaper per gallon but more expensive for the same amount of energy. Using the heating values in [7] instead gives approximately $5.67 per DGE ($5.28 × 128,488 / 119,550). The difference comes from the two sources' energy-conversion factors [7, 15]. Figure 3 shows the report's historical comparison of B99/B100 and diesel prices.

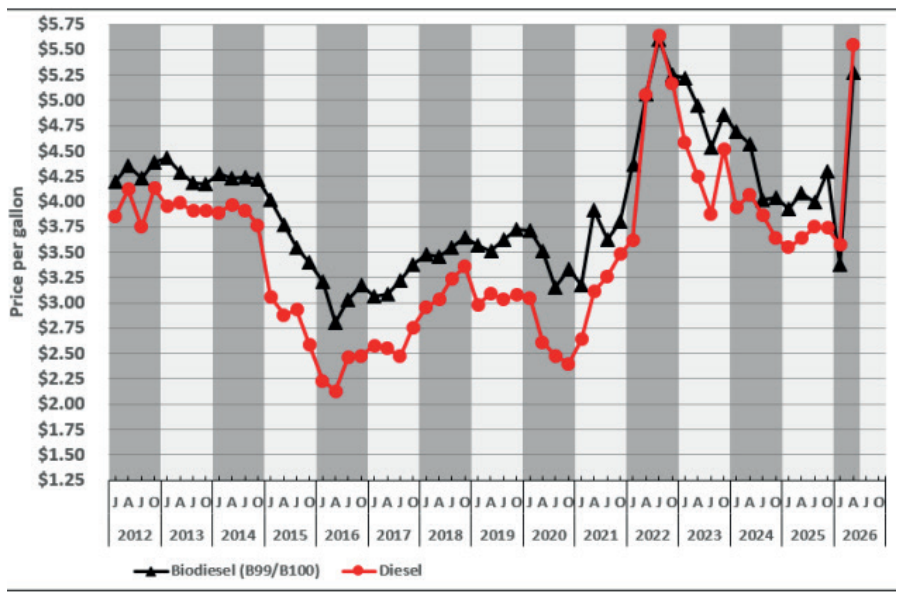


Figure 3: Historical Prices of Biodiesel (B99/B100) and Petroleum Diesel

From U.S. Department of Energy [15]

Renewable diesel prices were evaluated separately for California. During the same survey, average California prices were $7.50 per gallon for renewable diesel and $7.42 for petroleum diesel, a difference of eight cents per gallon. This regional comparison should be kept separate from the national biodiesel average [15].

Government incentives also influence the prices and availability of biodiesel and renewable diesel. Qualifying fuels can generate Renewable Identification Numbers (RINs), which are tradable credits under the federal Renewable Fuel Standard [16]. Eligible domestic producers may also claim the federal Section 45Z Clean Fuel Production Credit [17]. California's Low Carbon Fuel Standard provides additional incentives for lower-carbon fuels, helping explain why the state is an important market for renewable diesel [3]. Pump prices therefore reflect policy incentives alongside production costs and other market conditions.

Production costs also depend on the facilities used to make the fuel. McCormick et al. [10] note that biodiesel is less expensive to produce than renewable diesel in standalone production facilities. Much of the difference disappears when renewable diesel is produced in a petroleum refinery. This shows that production costs cannot be judged solely by the fuel's name. The way a production plant is built and integrated with existing operations also matters.

Availability of fuel is another practical consideration. McCormick and Moriarty [8] describe established distribution supply chains for biodiesel blends used in road vehicles. Renewable diesel can use existing diesel engines and fueling infrastructure, although the Department of Energy identifies feedstock and production costs as challenges to expanding its supply [3].

Challenges and Recent Research

Maintaining fuel quality during storage is an important challenge, particularly for biodiesel. Oxidation occurs when fuel reacts with oxygen and can lead to acids, increased viscosity, and deposits that clog filters. Exposure to air, heat, light, and certain contaminants can accelerate deterioration. Antioxidant additives can improve storage stability, but they work best before substantial degradation occurs. They cannot remove acids or sediments that have already formed [8].

Fuel-system materials also require attention when using high biodiesel concentrations. Prolonged contact with B100 can damage certain hoses, gaskets, and seals, making it necessary to check equipment compatibility before use [8]. Water contamination presents a broader concern because microbial growth can occur in any fuel when water is present. Keeping storage tanks dry and monitoring contamination therefore remain important regardless of the fuel being used [8].

Like ULSD, renewable diesel has low natural lubricity and generally needs additives to meet the lubricity requirement in ASTM D975, which sets a maximum HFRR wear scar diameter of 520 µm at 60 °C [12]. Lubricity is evaluated using the high-frequency reciprocating rig (HFRR) test under ASTM D6079 [9, 18]. Its low aromatic content presents another consideration: some older nitrile seals previously swollen by petroleum diesel may shrink after switching to renewable diesel, potentially causing leaks [9]. Biodiesel can help improve lubricity. Blending about 2% biodiesel (B2) into ULSD is often enough to provide adequate lubricity [8].

Research has examined the limitations of using higher biodiesel concentrations in both petroleum diesel and renewable diesel. McCormick et al. [10] evaluated blends containing 20%–80% soy-derived biodiesel and identified cloud point, viscosity, boiling behavior, and oxidation stability as potential constraints. These properties matter because they can affect fuel flow, the breakup of injected fuel into small droplets, and evaporation inside an engine. However, the study measured fuel properties rather than directly demonstrating engine problems, and the authors called for further research into these potential effects.

Several approaches could help address these limitations. Heated fuel systems and blending with lower-cloud-point fuels, such as No. 1 diesel or kerosene, can improve cold-weather operation. However, the benefit of these blending components decreases at very high biodiesel concentrations. McCormick et al. also recommended investigating engine settings designed for biodiesel blends and improving methods for assessing storage stability. Further engine and field studies would help establish suitable operating conditions for higher blends and determine which adjustments provide reliable performance [10].

Conclusion

Compared with petroleum diesel, pure biodiesel (B100) contains about 7% less energy per gallon, while pure renewable diesel (RD100) contains about 4% less. Renewable diesel's higher cetane range of 70–85, compared with 40–55 for petroleum diesel, gives it an ignition-quality advantage. The modeled life cycle greenhouse gas reductions ranged from 40% to 86%, depending on feedstock, production methods, and land-use assumptions.

Lower prices per gallon do not always mean lower costs for the same amount of energy. In the April 2026 survey, which is a snapshot of pump prices that change quickly, B99/B100 was cheaper per gallon but cost $5.80 per diesel gallon equivalent, compared with $5.55 for petroleum diesel, using the report's conversion factors. Fuel selection should therefore consider energy-adjusted prices and life cycle emissions alongside engine compatibility, storage requirements, and cold-weather performance.

Each fuel therefore suits different conditions. Renewable diesel is the most direct replacement where drop-in compatibility, high cetane number, and lower life cycle emissions are priorities and where supply is available, as in California. Biodiesel blends up to B20 are practical where existing infrastructure and incentives favor them, provided that cold-weather performance, storage stability, and material compatibility are managed. Petroleum diesel remains the default where alternative supply is limited or where very low temperatures and long storage periods constrain the use of higher biodiesel blends.

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