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Biomass-Based Diesel

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A MARKET AND
PERFORMANCE ANALYSIS



Tristan R. Brown, J.D., Ph.D.

Assistant Professor & Lawyer, SUNY College of Environmental Science & Forestry

Tristan Brown is an Assistant Professor of Energy Resource Economics at The State University of New York College of Environmental Science and Forestry. His research focuses on renewable fuels markets, the economic feasibility of renewable fuels pathways under uncertainty, and energy policy. He has authored two books and more than 30 papers on these subjects since 2009.

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Introduction

This report provides a comprehensive overview of U.S. biomass-based diesel (BBD) markets and performance. BBD is defined here as biodiesel (fatty acid methyl esters, or FAME) and renewable diesel (hydrocarbons) that are derived from lipid feedstocks.

This report's primary purpose is to summarize and evaluate the major attributes of the U.S. BBD sector at every stage of the supply chain, including production, transportation, distribution, and consumption. It is divided into four sections that focus on the following topics:

1. **Section 1. BBD supply and demand and their drivers;**
2. **Section 2. Variations in BBD blending patterns and their contributing factors;**
3. **Section 3. The technical and environmental performance characteristics of BBD fuels and BBD blends; and**
4. **Section 4. BBD production and demand economics, both in the presence and absence of government subsidies and other types incentive programs.**

The motivation behind this report is the large increase in BBD production and consumption that has occurred over the last decade in the U.S. The diesel fuel that is used by motor vehicles in

the country contained an average BBD content of approximately 5% by volume (vol%) in 2018 compared to 0.5 vol% in 2010. That number is on track to increase to 10 vol% as early as 2022 as new capacity in the form of renewable diesel facilities comes online, making BBD one of the country's most widespread alternative fuels.

The full report reviews and analyzes the available data on each covered BBD subject in detail. This executive summary presents the major findings of each of the full report's sections and briefly discusses their implications. The full report's subsections (e.g., Section 1.1, Section 1.2, etc.) are cited within the executive summary to permit easy reference to the relevant data and analysis. Citations are not included in this executive summary for readability purposes but can be found in the corresponding sections of the full report. Units are presented in the executive summary and full report present data according to SI system, but with two main exceptions for the purpose of readability: volumes are presented in gallons and temperatures are presented in degrees Fahrenheit. Finally, both the executive summary and the full report frequently refer to the U.S. Petroleum Administration for Defense Districts (PADD) as a geographical representation. The PADD regions largely align with the major U.S. geographic regions (i.e., the Eastern seaboard; Midwest; Gulf Coast, Mountain West, and Western seaboard). [Figure 1-1](#) presents the PADD region boundaries. [Appendix I](#) and [Appendix II](#) present PADD-level BBD supply and demand data, respectively. [Appendix III](#) reconciles the different nomenclatures that are employed in the data sources that this report frequently references.

SECTION 1.

Overview of Biomass-Based Diesel Supply in the U.S.



Section 1. Overview of biomass-based diesel supply in the U.S.

Biomass-based diesel (BBD) is commonly produced in one of two forms by U.S. producers: (1) biodiesel and (2) renewable diesel.* Biodiesel is the more developed of the two biofuel types, pre-dating even the invention of the diesel fuel engine. Renewable diesel has experienced very rapid growth over the last decade, however, and is on pace to pass biodiesel production in the U.S. within the next five years. This section defines both types of biofuel, summarizes their respective production pathways, and details the sources of production that are supplied to the individual U.S. Petroleum Administration Defense District (PADD) regions (see Figure 1-1). An appendix to the full report discusses the different definitions for both fuels that are used by various data sources in greater detail.



Figure 1-1. Map of U.S. Petroleum Administration Defense District regions.¹

1.1. Biodiesel

* A common theme in this report will be the lack of uniformity in the nomenclature on biomass-based diesel and that absence extends to the term “biomass-based diesel” itself. While biomass-based diesel can technically refer to any biomass-derived diesel fuel or diesel fuel substitute regardless of feedstock, the U.S. Environmental Protection Agency (EPA) has adopted it to refer strictly to those diesel fuels and substitutes that are derived from lipid feedstocks. This report employs the EPA’s narrower definition throughout.

Biodiesel, despite its name, is not a hydrocarbon fuel like petroleum-derived diesel fuel (“petrodiesel”). Rather biodiesel is a fatty acid methyl ester (FAME) or fatty acid ethyl ester (FAEE), depending on whether it is synthesized from methanol or ethanol, respectively. FAME and FAEE both are capable of being used in diesel engines, most commonly as a blend with petrodiesel. They are not true hydrocarbons, though, and contain approximately 11% oxygen by weight in addition to hydrogen and carbon.² This oxygen causes biodiesel to have an energy content that is approximately 7% lower by volume than its major petrodiesel counterpart in the U.S., No. 2 ultra-low sulfur diesel (ULSD). Biodiesel’s technical and environmental profiles differ from those of diesel fuel as well (see Section 3 for more details.)

Most biodiesel is produced via the reaction of an alcohol (methanol or ethanol, although the former is most common) with lipid feedstocks as part of the pathway known as transesterification. Two categories of lipid feedstocks are commonly utilized: (1) fats and (2) oils. Both fats and oils contain saturated and unsaturated fatty acids, although they have important differences. Fats are usually derived from animal sources and have higher saturated fatty acid contents that cause them to take solid form at room temperature. Oils, which are not to be confused with the popular word for petroleum, are usually derived from plant sources and have higher unsaturated fatty acid contents that cause them to take liquid form at room temperature.

The reaction of fatty acids with methanol or ethanol causes the triglyceride’s individual chains to split from their propane backbone, forming alkyl esters (biodiesel) and the transesterification byproduct glycerol. The resulting biodiesel is soluble with petrodiesel at all blend levels, permitting the sale of biodiesel blends ranging from so-called “B1” (1 vol% biodiesel and 99 vol% petrodiesel) to “B99” (99 vol% biodiesel and 1 vol% petrodiesel). Bases such as sodium methoxide are used to catalyze the transesterification reaction and solvents such as tetrahydrofuran are frequently employed to increase the reaction rate.

Base catalysts are preferred for feedstocks with low free fatty acid (FFA) contents (<1.5 wt%) such as refined vegetable oils due to their high activity levels and a lack of corrosivity compared to acid catalysts.³ Base catalysts are less suited for feedstocks with high FFA and/or moisture contents, such as used cooking oil (UCO) and animal processing residues,⁴ since they can cause the triglycerides to hydrolyze into soap rather than FAME. In addition to hurting process efficiencies, soap formation can result in a lowering of biodiesel fuel quality. The employment of mineral acid catalysts with high-

FFA feedstocks convert the fatty acids to biodiesel instead of soap via an esterification step, enhancing process yields and fuel quality. It is not uncommon for biodiesel facilities to publicly list their feedstock requirements as “high FFA”, “low FFA”, or both since the technical requirements imposed by the feedstock’s FFA content is more important as an indicator of processing requirements than is the specific source of the feedstock (see Table 1-1).⁵ While high FFA feedstocks do incur additional process steps and consequent expenses compared to low FFA feedstocks, they have the advantage of often being waste products that are available at lower cost to the biodiesel producer than are unrecycled vegetable oils.

Table 1-1. Typical moisture and FFA contents of major BBD feedstocks.⁶

Feedstock	Canola oil	Distillers’ corn oil	Soybean oil	Tallow	UCO	White grease
Moisture (wt%)	0.085	0.153	0.029	0.051	0.242	0.218
FFA (wt%)	0.34	12.22	0.07	1.61	2.72*	0.61

The transesterification process yields a blend of biodiesel and glycerol. The two products are separated via settling and centrifuge, at which point the biodiesel is purified to remove any remaining water, alcohol and other contaminants. Most of the alcohol, base catalyst, and contaminants are found in the glycerol phase. The alcohol is removed from the glycerol phase for re-use and the base catalyst is neutralized, resulting in a glycerol co-product that is sold for use in the food and pharmaceutical industries. While glycerol is not an especially valuable product, its production and sale does offset some of the biodiesel pathway’s process costs (see Section 4.1).

Biodiesel supply – U.S. capacity

The U.S. hosted 2,450 million gallons of operational biodiesel production capacity that was registered with the U.S. Environmental Protection Agency (EPA) as of December 2018.^{7,8} An additional 1,200 million gallons of capacity is unregistered and/or inactive, bring total existing U.S. capacity to 3,650 million gallons.⁸ Total operational registered capacity has only increased by 17%

* UCO’s FFA content is highly sensitive to the type of cooking oil used, the cooking process employed, and seasonal variations, the combination of which can cause reported FFA contents to range as high as 20 wt% or more.⁴

since 2011 due to the intensive build-out that occurred during the previous decade. Demand for new capacity has been limited by the mandated blending volumes under the U.S. Renewable Fuel Standard (RFS) of 2,100 million gallons for all biomass-based diesel (BBD) in 2018 and 2019, targets that are easily met by current U.S. operational and registered capacity even before accounting for imports.

All five of the U.S. PADD regions host active biodiesel capacity, although the amounts vary widely across the country. The PADD 2 region, which encompasses the Midwest states, contained a majority (56%) of U.S. capacity at 1,355 million gallons per year (MMGY) in 2018 (see Figure 1-2). This was followed by the PADD 3 region at 26%, the PADD 5 region at 9%, the PADD 1 region at 7%, and the PADD 4 region at 2%, respectively, of total U.S. capacity. The heavy concentration of active biodiesel capacity in the Midwest and South-Central agricultural states reflects the presence there of large volumes of traditional biodiesel feedstocks such as soybean oil and corn oil. Less than 50% of the U.S. population lives in the PADD 2 and 3 regions, though, creating a disconnect between regions of biodiesel supply and potential demand within the country. This disconnect has widened over time: capacity in the PADD 1 region declined by 70 million gallons between 2011 and 2018 due to unfavorable economics (see Section 4) even as it increased by 300 million gallons in the PADD 3 region.

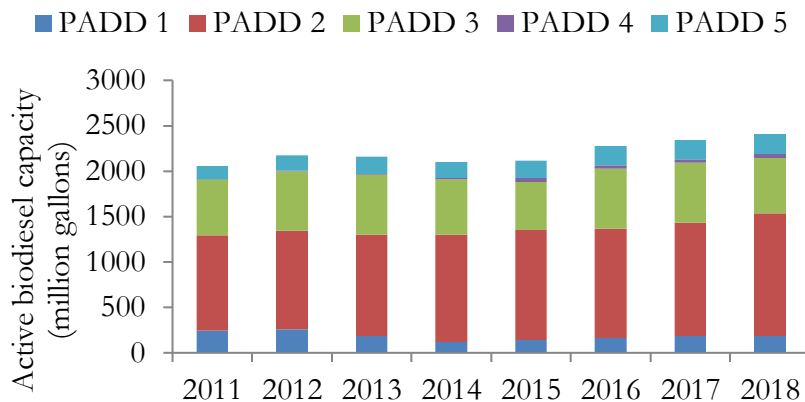


Figure 1-2. Operational and registered biodiesel capacity in the U.S. by PADD region, 2011-2018.⁷

There were 96 registered biodiesel facilities within the U.S. in 2018 with an average production capacity of 25.1 MMGY.⁷ Both the number of facilities and their average capacities vary across

PADD regions. The profiles of biodiesel production capacity and volumes in each PADD region are provided in Appendix I.

Biodiesel supply – U.S. feedstocks

U.S. operational biodiesel production increased from 515 MMGY in 2009 to 1,855 MMGY in 2018 even though active U.S. biodiesel production capacity increased by 349 MMGY over the same period. Production volumes have been able to increase due to the large amount of domestic production capacity that was already in existence in 2009. A legacy of the high petroleum prices and global concerns about peak petroleum supply that prevailed before 2009, this capacity was poorly utilized, having a national annual utilization rate of just 17% in 2010 (see Figure 1-3). The utilization rate has steadily increased over the last decade and reached an all-time high of 77% in 2018.

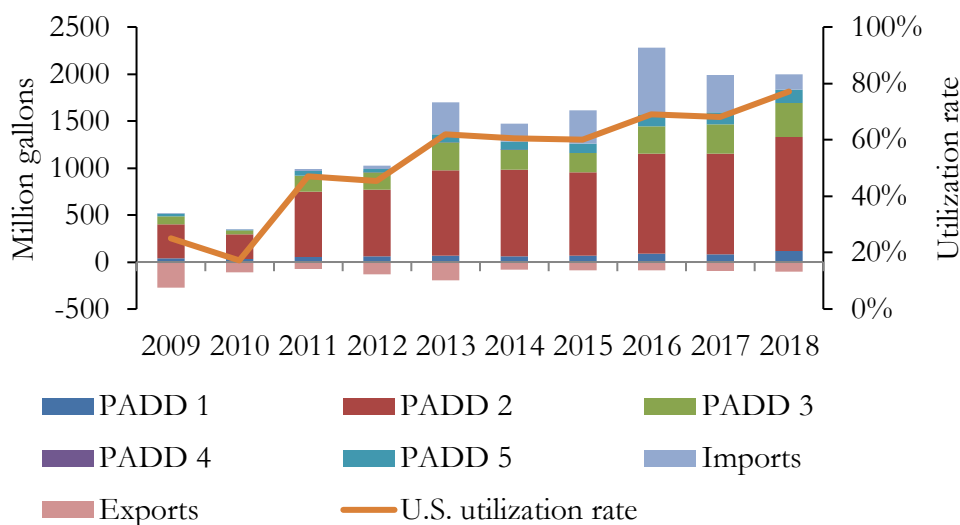


Figure 1-3. Sources of U.S. biodiesel supply and national utilization rate, 2009-2018.⁷

Feedstock availability has increased to match the growth in biodiesel production that has occurred over the last decade, although the U.S. feedstock mix has shifted as new feedstocks have been utilized by producers. The amount of feedstock consumed in biodiesel production increased from 1.6 million megagrams (Mg) in 2009 to 6.4 million Mg in 2018 (see Figure 1-4).⁷ The share of soybean oil in the overall mix was unchanged during that time at approximately 54% as domestic production of both soybeans and soybean oil increased. Feedstocks that were not widely produced

in 2009 have become prevalent as well, with both corn oil and UCO increasing their shares of the mix by 7x and 3x, respectively, even as total feedstock consumption nearly quadrupled. U.S. biodiesel producers utilized 12 different lipid feedstocks in 2018, the largest of which were soybean oil (54% of the total), corn oil (15%), UCO (12%), canola oil (9%), white grease (4%), and tallow (3%).

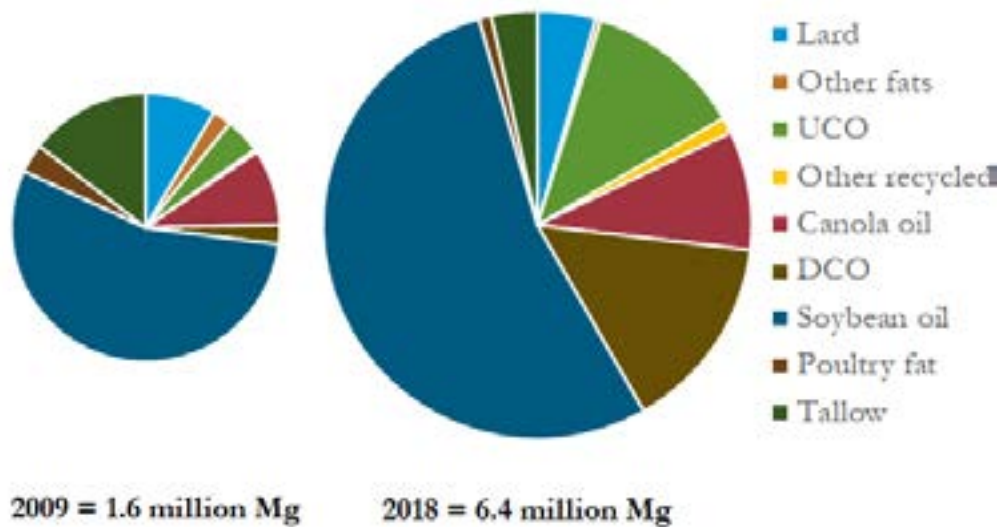


Figure 1-4. Feedstocks utilized in U.S. biodiesel production, 2009 and 2018.⁷

Two types of vegetable oil are obtained from corn: edible corn oil, which is utilized as a cooking oil and is produced during the front-end corn wet-milling process, and distillers' corn oil (DCO, also known as corn distillers' oil or CDO),* which is removed from what becomes distillers grains and soluble (DGS) via the back-end ethanol distillation process. While the U.S. has produced edible corn oil for several decades due to the historical prevalence of the wet-milling process, DCO requires the installation of additional equipment at dry-mill facilities that has only become widespread at ethanol production facilities since 2013. DCO production has increased rapidly since then, however, and now comprises 63% of all U.S. corn oil production.⁹ It is not considered fit for use as a cooking oil due to an aroma that is described as resembling that of a brewery, a high FFA content, and contaminants, however, and DCO has historically traded at an average discount of 18% compared to edible corn oil.¹⁰ Most of the corn oil that is utilized by the U.S. biodiesel sector is in the form of DCO as a result.

* The U.S. government uses "DCO" while the U.S. Renewable Fuels Association uses "CDO."

Biodiesel producers have benefited as the domestic production volume of corn ethanol has increased from 10,938 million gallons in 2009 to 16,061 million gallons in 2018. The large majority of that increase has occurred at dry mill ethanol facilities that have the option of producing DCO rather than the edible cooking oil that is produced at wet mill facilities.¹¹ DCO's growing supply and persistent cost advantage, combined with a moderate free fatty acid content (10-20%) and ability to produce biodiesel with a low cloud point (27 °F), has contributed to corn oil's growing share of the U.S. biodiesel feedstock mix.¹²

DCO's primary limitation as of 2019 is that U.S. corn ethanol production now exceeds that biofuel's 15 million gallon ceiling under the RFS, making it uncertain whether the future production growth rate will come close to that of recent years.* DCO only contributes an average of \$0.06/gallon to corn ethanol margins¹³ which is insufficient on its own to incentivize corn ethanol production. That said, the biodiesel industry's DCO consumption in 2018 of 0.95 million Mg was equal to only 67% of the amount of the feedstock that could have been produced that year (1.4 million Mg) had all U.S. dry mill ethanol facilities produced the feedstock.^{†,14} While the increase in DCO consumption by U.S. biodiesel producers from 0.04 million Mg to 0.95 million Mg over the last decade is not likely to be repeated barring a major future increase to ethanol production in the U.S., current corn ethanol production could feasibly support a 50% increase to DCO use by BBD producers from 2018 levels.

UCO[‡] is another lipid feedstock that became widely utilized by biodiesel producers in the U.S. and other countries over the last decade. It differs from the other major biodiesel feedstocks in three important ways. First, unlike soybean oil and corn oil, it is a waste product that had limited or even negative value (i.e., disposal costs) prior to its adoption as a biodiesel feedstock. Second, UCO is further differentiated from agricultural oils in that it is heavily produced in urban rather than rural

* Future DCO supply volumes will be determined in large part by the rate of 15 vol% ethanol blend ("E15") adoption in the U.S. following the EPA's 2019 decision to allow E15 to be sold year-round in the country. While E15 has been available at convenience stores since 2012, until 2019 it could not be sold during the warmer months of the year. Some analysts believe that consumers will rapidly adopt E15 (despite having not done so after 2012) now that it is available year-round, in which case U.S. corn production and, by extension, DCO production, could feasibly increase by up to 50% from current volumes.

† Based on 5,736 million bushels of corn consumed by U.S. dry mill ethanol facilities and a DCO yield of 0.27 kg per bushel of corn processed.

‡ The literature often conflates both UCO and animal processing residues with "yellow grease." This report adopts the U.S. Energy Information Administration's definition of yellow grease, which is "used cooking oil from restaurants." Animal processing residues are separately categorized as "tallow" (beef fat), "white grease" (pork fat), or "poultry" (chicken fat).

areas since the former have the highest volumes and concentrations of restaurants and other food production facilities. Finally, unlike other waste products such as animal processing residues that are frequently produced in very large, concentrated processing facilities, UCO must be moved to concentrated collection points for processing from a larger number of restaurants that are distributed across a city or even multiple cities.

UCO's supply characteristics make its potential domestic, not to mention global, supply volume difficult to ascertain compared to other biodiesel feedstocks. In 1998 the National Renewable Energy Laboratory (NREL) calculated that 4.1 kg of UCO are produced annually per person in the U.S.¹⁵ This equates to U.S. UCO availability of 1.3 million Mg based on the country's 2018 population of 327.2 million. By comparison, the U.S. produced 1 million Mg in that year, of which U.S. biodiesel facilities consumed 0.75 million Mg of UCO, or 75% and 58% of the actual and potential domestic supply volumes, respectively.^{7,16} A more conservative estimate from the International Council on Clean Transportation (ICCT) estimated that the U.S. supply of UCO would hold steady at 0.7 million Mg from 2015 through at least 2022,¹⁷ although recent UCO supply data has already cast doubt on this forecast.¹⁶

Projections of overall U.S. BBD feedstock volumes have repeatedly fallen well short of actual feedstock availability. A 2006 academic study that was widely referenced by the subsequent literature on indirect land-use change calculated the "absolute biodiesel potential" in the U.S. based on feedstock availability to be 848 million gallons of production.¹⁸ A heavily-cited study from the same year in the *Proceedings of the National Academy of Sciences* concluded that replacing 6% of U.S. diesel fuel consumption with BBD would require the utilization of all of the country's soybean production, an outcome that the authors wrote was "unlikely" because "[soybeans] are major contributors to human food supplies."^{19*}

The creation of the RFS caused the estimates of potential BBD feedstock supply to increase on the assumption that it would also cause feedstock costs to move substantially higher, and that those feedstock costs would be the primary constraint on long-term consumption growth. A 2008 analysis by the U.S. Department of Energy (DOE) in response to the implementation of the RFS projected that total U.S. BBD supply, including imports, would not exceed 1,900 MMGY by 2020 due to

* Total U.S. BBD supply in 2018 was 2,360 million gallons, equal to 4% of that year's total diesel fuel demand (or 6% of on-highway diesel fuel demand). Of this supply, 2,184 million gallons was produced in the U.S.

feedstock constraints that even high petroleum prices would not be able to overcome.²⁰ In that same year an analysis by researchers at Iowa State University’s Center for Agricultural and Rural Development (CARD) described a “dismal outlook for the U.S. biodiesel industry” due to “feedstock prices always being bid to the industry’s break-even point” and concluded that “farmers and landowners should expect to see the lion’s share of benefits from [the RFS].”²¹ A 2009 report from the United Nations Conference on Trade and Development predicted a doubling of lipid feedstock prices between 2007 and 2017 due to “expanded production and use of biodiesel.”²²

In 2010 and 2011 it appeared that these forecasts were being borne out as the prices of major biodiesel feedstocks in the U.S. all increased by 50% or more (see Figure 1-5). U.S. BBD production nearly tripled from 2010 to 2011⁷, but commercial-scale production of next-generation feedstocks such as jatropha and microalgae defied earlier expectations and failed to provide new feedstock volumes.^{22,23} This led to projections that continued increases to the BBD mandate under the RFS would harm U.S. energy security as blenders increasingly turned to imports to meet their mandated volumes. One widely read analysis estimated that BBD imports would need to increase by 261 million gallons between 2014 and 2018 in order to meet just the BBD category of the RFS, or 931 million gallons in order to comply with the broader Advanced Biofuels mandate under the RFS.²⁴ That report concluded that “[No] feedstock is available to be used for biodiesel production without a substantial increase in price.”

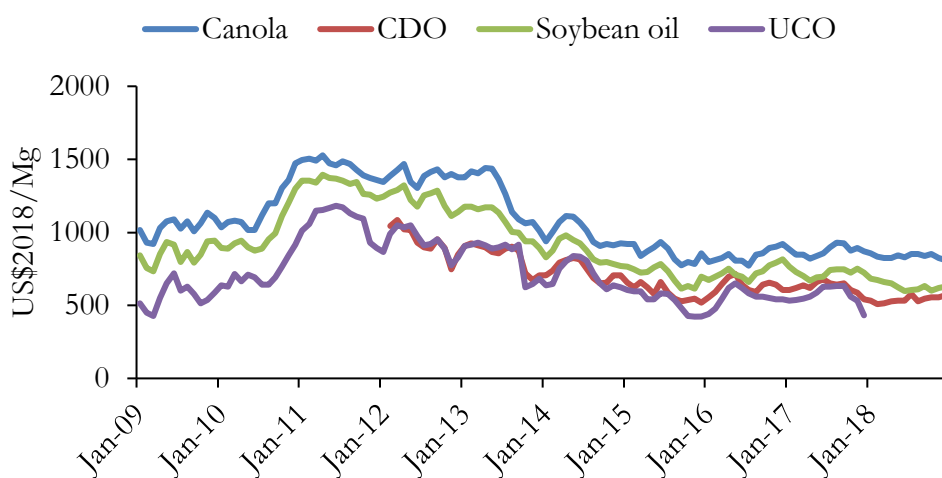


Figure 1-5. Real prices of major North American biodiesel feedstocks, 2009-2018.²⁵

Contrary to these predictions, 2011 ultimately proved to be when North American BBD feedstock prices peaked (see Figure 1-5 and Figure 1-6). The prices of canola, soybean oil, and UCO were all lower in real terms in 2018 than in 2009; while DCO prices were not reported until 2012, that commodity was near its all-time low price in 2018. Waste lipid price indices in 2018 were at or near their 2009 levels. The largest price drops occurred in 2012 and 2013, and feedstock prices have remained near their current lows for the last five years. As early as September 2012 the EPA observed that the feedstock availability predictions that it had made in March 2010 for future years had substantially underestimated actual availability due to higher-than-expected supplies of UCO, animal processing residues, and DCO.²⁶

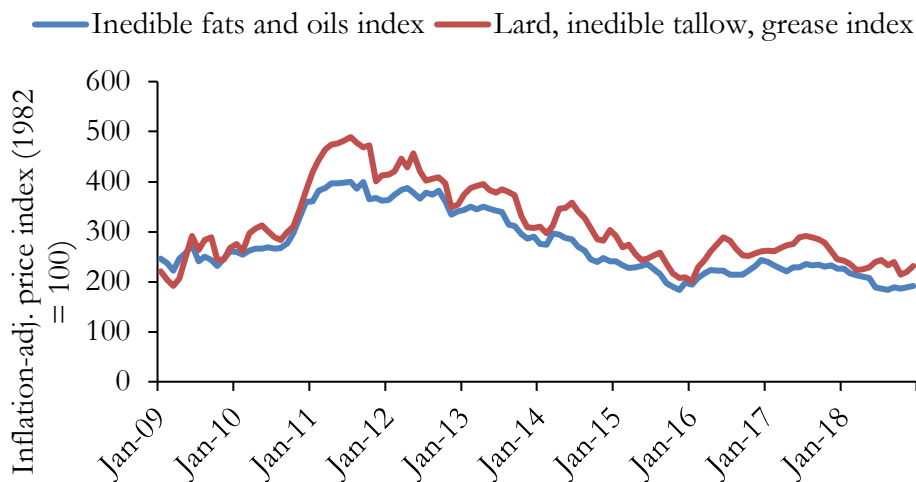


Figure 1-6. Price indices for residue and waste BBD feedstocks, 2009-2018.^{10,27}

Feedstock availability only continued to increase after 2012 even as domestic BBD production increased. U.S. exports of UCO actually increased from 0.13 million Mg in 2009 to 0.16 million Mg in 2018 despite its increased use in BBD production over the period.²⁸ Europe was the destination for 83% of these exports, presumably for use as BBD feedstock there, followed by Asia (primarily Singapore, where Neste Oil operates a major renewable diesel facility). Europe's imports of U.S. UCO increased from 0.02 million Mg in 2009 to 0.13 million Mg in 2018.²⁸ 57% of U.S. UCO exports in 2018 originated from the PADD 1 region, in which New York City was the largest port of origin.

UCO is not the only BBD feedstock that the U.S. currently exports. 0.17 million Mg of tallow was exported in 2018, of which just over 50% went to Singapore (where a Neste Oil facility uses tallow

from North America as a renewable diesel feedstock).²⁹ Almost all U.S. tallow exports leave the country via ports in Texas. Singapore is also one of the largest destinations for U.S. exports of pig and poultry fats, which totaled 0.17 million Mg in 2018 (of which Singapore accounted for 40%) and left via ports in Texas. Finally, U.S. soybean exports declined very slightly from 1.1 million Mg in 2009 to 1.0 million Mg in 2018, 72% of which left the country through New Orleans.³⁰ The fact that U.S. export volumes of these major BBD feedstocks have held relatively steady over the last decade despite the concurrent growth in BBD production volumes does not support the contention that feedstock volumes are a constraint on the BBD sector.

In many ways the debate over BBD feedstock supply and prices resembles that from the previous decade over peak petroleum production. Prior to 2009 there was a widespread expectation in the energy markets and among policymakers that global petroleum production was at or near a peak that would be followed by a rapid decline,³¹ and this sentiment culminated in a daily WTI crude price of \$145.31/bbl on July 3, 2008.³² One of the few entities to disagree with this outlook was Cambridge Energy Research Analysts (CERA), which argued that peak production was decades away and would be followed by a very gradual decline when it did occur. CERA's position was based on the premise that high petroleum prices in response to supply concerns would prompt the development of new technologies that would increase the volume of recoverable reserves.³³ This, of course, is exactly what happened, and the daily WTI crude price fell to \$26/bbl less than eight years after setting its July 2008 record even though demand for petroleum in both the U.S.³⁴ and global³⁵ markets increased over the same period.

A similar supply situation explains why lipid feedstock prices have fallen over the last eight years, although multiple factors are responsible. First, predictions that U.S. corn acreage would displace U.S. soybean acreage in order to meet the RFS's 15,000 million gallon corn ethanol volumetric limit³⁶ have not come to pass, and the country's soybean acreage instead increased by 19% between 2011 and 2018.³⁷ U.S. soybean yields per acre increased by 23% over the same period,³⁸ further contributing to feedstock supply. Overall U.S. soybean production increased by 46% between 2011 and 2018³⁹ because of these two factors. At the same time, the rapid rise in DCO and UCO consumption by BBD producers in response to 2011's lipid prices further contributed to overall lipid feedstock supply volumes. Finally, China's imposition in 2018 of tariffs on imported U.S. soybeans at a time when a substantial fraction of China's livestock had been destroyed due to African Swine Fever may serve to permanently reduce U.S. soybean export volumes, according to

the U.S Soybean Export Council.⁴⁰ As with the shift in petroleum supply between 2008 and 2016, the effect of these developments was to cause a large decline in BBD feedstock prices despite, or perhaps because of, higher BBD demand.

The fact that the trend in favor of higher feedstock supply and lower feedstock prices has prevailed for almost a decade does not mean that it is guaranteed to support large future expansions to BBD production volumes. For this reason, research continues to be underway into the development of pre-commercial lipid feedstocks, including both cultivated feedstocks such as microalgae and waste lipids such as brown fats, oils, and greases (FOG). Microalgae has been studied as a potential large-volume BBD feedstock since the DOE's Aquatic Species Program was conducted in the 1980s and 1990s.⁴¹ The conclusion of that program was that microalgae had the potential to produce enough BBD feedstock to displace a large fraction of U.S. petrodiesel consumption due to its high oil productivity, but only if costly technical hurdles to microalgae cultivation were overcome. Subsequent research in the early 21st century identified specific routes for reducing microalgae's costs,⁴² including the development of photobioreactors, but interest in the feedstock waned after petroleum prices collapsed in late 2008. One of the main research efforts to survive the current era of inexpensive fossil fuels has been led by a joint venture between Exxon Mobil and Synthetic Genomics. This JV made a major cultivation breakthrough in 2017 that could result in commercial-scale production of algae-derived BBD by 2025.⁴³

Brown FOG is a feedstock category that covers grease trap waste. Unlike UCO, which is recovered in the same form in which it is used in kitchens, brown FOG is found in the wastewater that is produced by kitchen cleaning systems such as sinks and dishwashers. Growing concern in municipalities about clogged sewage systems from uncaptured brown FOG and environmental harm resulting from captured brown FOG, much of which is disposed via either land application or landfilling, has prompted research into its use as a BBD feedstock. NREL estimated in 1998 that per capita brown FOG production in urban areas was 50% higher than UCO production.¹⁵ The lipid content is low with a range of 2-5 vol%, though, and estimates of potential BBD production volumes from brown FOG range from 120 MMGY⁴⁴ to 500 MMGY.⁴⁵ Brown FOG poses unique challenges to its use, including the need to remove the 95% of its volume that comprises water and contaminants, a high sulfur content that is removed via distillation, and a high FFA content.⁴⁵ While all of these processing issues have been overcome in laboratory settings,⁴⁶ they increase BBD production costs relative to the use of other feedstocks.

A final note should be made regarding the issue of import substitution and U.S. feedstock availability. A 2016 blog post by a senior scientist at the Union of Concerned Scientists argued that U.S. biodiesel producers were only been able to source increasing amounts of domestic lipid feedstocks such as soybean oil in response to rising production volumes due to higher imports of other vegetable oils into the country.⁴⁷ In other words, any reduction to U.S. vegetable oil import volumes would result in a domestic feedstock supply shortfall as the food sector increased its demand of soybean oil to compensate. It is possible that import substitution has contributed to some of the last decade's increased BBD feedstock availability, but any effect should not be overstated. U.S. imports of major vegetable oils increased by 0.96 million Mg between the 2011/12 and 2017/18 market years whereas feedstock consumption by the biodiesel sector alone increased by 2.6 million Mg (or approximately 2.8 million Mg if estimated renewable diesel feedstock consumption is also included) over the same period (see Figure 1-7).⁴⁸

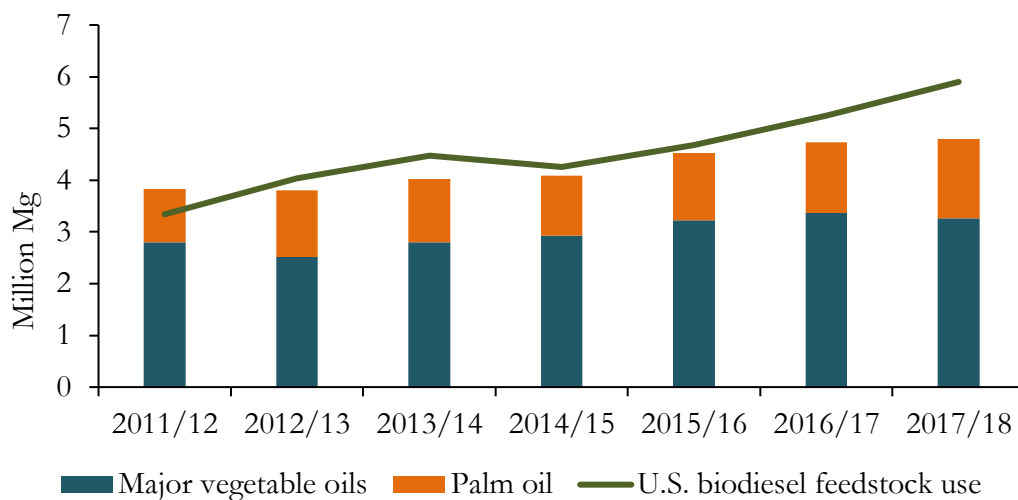


Figure 1-7. U.S. imports of major vegetable oils for all uses relative to U.S. biodiesel feedstock consumption by marketing year.⁴⁸

Moreover, as an earlier Union of Concerned Scientists blog post noted,⁴⁹ this period coincided with the banning of partially hydrogenated oils, which were primarily derived from domestic soybean oil, in the U.S. and subsequent replacement by imported palm oil.* U.S. palm oil imports contributed to more than 50% of the increase to imports of major vegetable oils that occurred between 2011/12 and 2017/18.⁴⁸ Import displacement could have contributed to no more than 16% of the BBD

* As noted above, soybean oil must be partially hydrogenated to take a solid form at room temperature, whereas palm oil takes a solid form at room temperature naturally.

sector's increase to feedstock consumption over that period as a result given that less than 1% of all U.S. BBD production since 2009 has been derived from palm oil, and even that number assumes that palm oil is the only imported vegetable oil to have replaced partially hydrogenated vegetable oils of domestic origin.⁷

The U.S. lipid feedstock market has proven to be very flexible in response to the last decade's 323% increase to U.S. BBD production. Soybean oil's share of the total feedstock mix has remained relatively unchanged but feedstocks that were not widely utilized in 2009, particularly DCO and UCO, are now responsible for important fractions of the total mix. U.S. soybean production has also increased due to higher acreages and yields. Feedstock prices have declined from their comparatively high levels in 2011 and are now at or below their 2009 prices in real terms in response to feedstock supply growth outpacing that of BBD production. Uncommercialized lipids such as microalgae oil and brown FOG are being explored for use as BBD feedstocks, although both have unique challenges that have limited their adoption to date. Feedstock demand is expected to grow rapidly over the next four years as additional renewable diesel capacity comes online, making the feedstock market's continued flexibility important to the BBD sector's future success.

U.S. biodiesel movements

U.S. biodiesel movements by rail, water, and pipeline largely originate in the middle of the country and are moved to the Eastern and Western seaboard, although substantial volumes also move between the PADD 2 and PADD 3 regions (see Figure 1-8). These movements reflect the geographic distribution of production in the country relative to potential demand: the PADD 2 and PADD 3 regions have large amounts of production capacity due to their respective supplies of feedstock but comparatively small populations. The PADD 1 and especially PADD 5 populations, by contrast, are important sources of demand but lack production capacity.

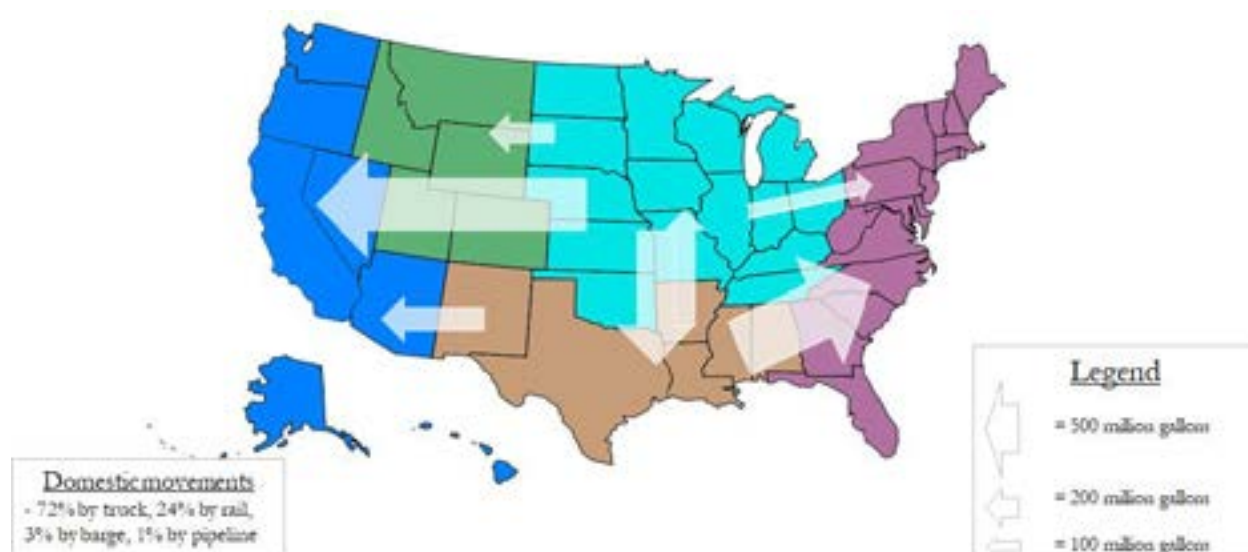


Figure 1-8. Inter-PADD biodiesel movements by rail, water, and pipeline, 2009-2018.^{7,50}

Approximately 20% of U.S. biodiesel production is moved by rail between PADD regions (see Figure 1-9).⁵¹ The PADD 3 region moves the highest share of its total production by rail; 29% of its production volume in 2017 was moved by rail to other PADD regions. This was followed by the PADD 3 and PADD 5 regions, which moved 7% and 3%, respectively, of their production volumes by rail. The PADD 1 and PADD 4 regions did not do so in that year, although the former has moved small shares of its production volumes by rail in the past. By comparison, the ethanol sector moved more than 60% of its production volumes by rail over the same period.⁵¹ Like the biodiesel sector, ethanol is primarily shipped from the PADD 2 region to other PADD regions. Unlike the biodiesel sector, though, ethanol producers benefit from larger production volumes that allow them to utilize more cost-effective modes of rail transportation such as “unit trains” that only carry ethanol cargo.⁵²

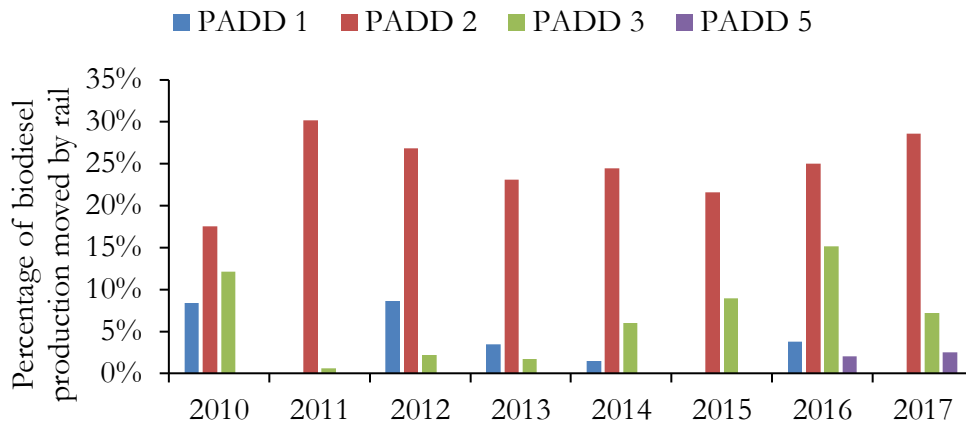


Figure 1-9. Share of annual biodiesel production moved by rail in each PADD region, 2010-2017.⁵⁰

It is possible that the share of BBD production that is moved by rail will increase as production increases in the coming years, especially given the comparatively large facility scales that are being planned. Such an increase has not happened yet, however: the share of U.S. production moved by rail declined slightly between 2011 and 2017 even as U.S. biodiesel production volumes increased by 61%. The supply of the railcars that move liquid fuels such as biodiesel and ethanol has been constrained in recent years as well, posing a unique infrastructure hurdle to the biodiesel sector.

An important consequence of this constraint is that more than 70% of U.S. biodiesel production is moved via truck. The results of an industry survey that was conducted by the National Biodiesel Board in 2016 indicated that movements by truck experience an upper limit of 300 miles,⁵² and discussions with industry stakeholders during the drafting of this report indicated that 150 miles is more common. Truck transport is very cost-effective (\$0.03-\$0.06/gallon) at short ranges but less so over longer distances (\$0.10-\$0.20/gallon) due to loads that are limited to around 7,000 gallons of biodiesel.⁵² Trucks are also the least fuel-efficient option, contributing to transport costs and greenhouse gas emissions, the latter of which negatively affect the value of biodiesel that is shipped to California to participate in the state's Low Carbon Fuel Standard (LCFS). Water transport is both more cost-effective and fuel-efficient than truck and rail for distances of several hundred miles or more but also limited to existing waterways. Rail transport provides the biodiesel sector with a routing flexibility that is not provided by water transport and lower costs than are provided by truck transport for movements over longer distances.

Movement in existing refined products pipelines is the most cost-effective and fuel-efficient option for BBD. Renewable diesel faces few constraints in this regard other than proximity to existing pipelines. Biodiesel, on the other hand, faces technical hurdles when being used in pipelines that are discussed in greater detail in Section 3. These hurdles have proven to be surmountable in small-scale operations but the methods of overcoming them have yet to gain widespread adoption by refined products pipeline operators. Biodiesel faces the additional challenge of pipeline location: existing refined products pipelines were sited to move products from refining clusters to demand centers, and these do not necessarily correlate with areas of biodiesel production. PADD 2 states such as Iowa and Missouri, for example, host substantial biodiesel production capacity that is located hundreds of miles from the nearest refineries. This is less of an issue for PADD 3 producers, though, who would gain access to most of the PADD 1 region's largest demand centers through the use of refined products pipelines such as the major Colonial Pipeline. The construction of new pipelines incurs very high capital costs and it is highly unlikely that new pipelines would be constructed to move biodiesel over long distances.

1.2. *Renewable diesel*

Unlike biodiesel, renewable diesel is comprised of hydrocarbons and does not contain oxygen. Its performance characteristics are almost identical to those of petrodiesel despite being produced from lipids rather than fossil fuels. Renewable diesel's lack of oxygen content is due to its production pathway's utilization of hydrogen rather than methanol. This hydrogen reacts with oxygen to form water that is easily separated from the resulting hydrocarbon product. For this reason renewable diesel is known by a variety of names including "hydroprocessed vegetable oil" (HVO) and "hydrogenated esters and fatty acids" (HEFA).^{*} Hydroprocessing yields a mixture of alkanes that, from a performance perspective, has a high cetane number (>100) but also high cloud point (≥ 68 °F) relative to petrodiesel.

^{*} There is no perfect term for the lipid-derived diesel fuel that this report refers to as "renewable diesel." HEFA is frequently used to describe lipid-derived gasoline and jet fuel in addition to lipid-derived diesel fuel. HVO is not an accurate label given the large percentage of U.S. renewable diesel production that is derived from animal fats rather than vegetable oils. The term renewable diesel can refer to non-lipid feedstock pathways such as the production of diesel fuel from lignocellulosic biomass via the Fischer-Tropsch process. That said, renewable diesel is also the term that is employed by the DOE and major global producers such as Neste Oil, Diamond Green Diesel, and Renewable Energy Group, and it is employed in this report as a result.

Most renewable diesel production utilizes an additional isomerization step to branch the straight-chain alkanes into branch-chain alkanes. Isomerization results in fully paraffinic fuel that has a lower energy density and therefore energy content (about 4% lower per gallon) than ULSD. Isomerization also reduces the fuel's cetane number, although renewable diesel's high starting cetane number prevents this from being a major drawback. Isomerization is widely employed due to the low cloud point of fully paraffinic fuels (see Section 3).⁵³

The hydroprocessing and isomerization steps are very similar to those employed by modern refineries, often utilizing the same equipment. This has resulted in the use of small volumes of lipids as a co-feedstock with petroleum in refineries. This “co-processing” of lipid and petroleum feedstocks offers a major advantage in that it enables renewable diesel production from existing U.S. refining capacity. This capacity is immense: in 2018 there were 132 refineries operating in the country with a total diesel fuel production capacity of 4.6 million barrels per day (bpd), or 66,544 MMGY (see Table 1-2).⁵⁴ Co-processing lipid feedstocks at just a 5 vol% blend would result in 3,327 million gallons of renewable diesel production per year, or more than all current annual U.S. BBD production.

Table 1-2. U.S. refining capacity by PADD region.⁵⁴

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
Number of operational refineries	8	25	56	16	27
Diesel fuel capacity (million bpd)	0.29	1.11	2.78	0.17	0.51

Co-processing has largely been ignored by U.S. refiners to date due to a combination of technical and policy hurdles. Lipid feedstocks can be blended with a refinery's petroleum feed but doing so causes catalyst fouling and reduced product yields due to the severity of the distillation and fluid catalytic cracking processes, neither of which is required for renewable diesel production.⁵⁵ A superior method is to blend the lipid feedstock with the intermediate distillate cut that emerges from a refinery's distillation column and fluid catalytic cracker prior to the hydrodesulfurization step. This step, which is used to produce ULSD, has the same effect as the hydroprocessing step that is performed at standalone renewable diesel facilities.

U.S. refineries operated by BP, Marathon Petroleum, and Sinclair Oil have successfully co-processed lipid feedstocks, although the Marathon Petroleum co-processing refinery is being converted to a standalone renewable diesel facility. This conversion is an example of the policy hurdles that face those refiners that would utilize the co-processing route. Co-processed fuels are excluded from most BBD government incentive programs, and most global renewable diesel production occurs at separate, stand-alone facilities that utilize only lipid feedstocks. Renewable fuels mandates such as the U.S. RFS and California's LCFS have partially* or entirely excluded co-processing due to concerns about the ability to quantify biogenic and fossil carbon streams when assessing the carbon intensities of the resulting renewable diesel.⁵⁶ A lack of cost-effective and accurate biogenic carbon testing methodologies has been a major hurdle to co-processing commercialization: Carbon-14 dating, for example, is unable to detect biogenic carbon for RIN generation purposes when the renewable content of the co-processed feedstock stream is 0.5 vol% or less.⁵⁷ A report commissioned by the California Air Resources Board raised concerns about the ability to quantify the biogenic carbon content when the renewable content is under 10 vol%.⁵⁸ While the biogenic carbon quantification challenge is not necessarily fatal to co-processing, with the National Renewable Energy Laboratory (NREL) suggesting the adoption of a mass balance approach in its place, this uncertainty has hindered co-processing's commercialization at a time when BBD is not competitively priced against ULSD on an unsubsidized basis (see Section 4).

The vast majority of renewable diesel production occurs at standalone facilities that only utilize renewable biomass feedstock. Lipid feedstocks are pretreated prior to hydroprocessing to remove metals and other contaminants capable of poisoning the hydroprocessing catalyst. Lipid hydroprocessing occurs at higher temperatures and pressures than does lipid transesterification. Multiple reactions occur when hydrogen is introduced to the feedstock. The feedstock's triglyceride content is saturated, with the amount of saturation ultimately depending on the natural saturation level of the feedstock.[†] This saturation is necessary for the renewable diesel's ratio of hydrogen to carbon to be the same as that of petrodiesel. Second, the triglyceride's glycerol backbone is hydrogenated to form propane and separated from its fatty acid chains. Like glycerol, this propane is an important co-product, albeit one with very different uses. Third, oxygen is removed from the

* The RFS allows BBD from the co-processing of renewable biomass and petroleum to generate D5 Advanced Biofuel RINs but not the more valuable D4 BBD RINs.

† This is one reason why renewable diesel production facilities prefer to use saturated fats such as animal processing residues as feedstock.

feedstock, leaving only the hydrogen and carbon necessary to form a hydrocarbon fuel. Fourth, the resulting hydrocarbon chains are isomerized to form branched chains with superior cold weather performance. At this point a distillation column, much like that employed by petroleum refiners, separates the renewable diesel from propane and additional hydrocarbon co-products such as naphtha. Renewable jet fuel can also be yielded as a co-product, although this requires an additional hydrocracking process step that increases costs and reduces process efficiencies.

Renewable diesel producers face a different set of feedstock considerations than biodiesel producers do. The use of hydrogen instead of alcohol as an input means that soap formation is not an issue with renewable diesel production since FFAs are instead converted to saturated hydrocarbons. Saturated lipid feedstocks that contribute to reduced low-temperature operability when converted to biodiesel via transesterification do not encounter the same performance constraints when converted to isomerized renewable diesel.⁵⁹ Saturated feedstocks such as palm oil and animal fats, which also have high FFA levels, are widely employed by renewable diesel producers in the U.S. and elsewhere, with refined unsaturated lipids being utilized for biodiesel instead. In the U.S. this is reflected by the rapid growth in vegetable oil consumption but lack of animal feedstock consumption such as tallow and inedible chicken fat by biodiesel producers (see Figure 1-4).

Renewable diesel supply – U.S. capacity

Renewable diesel production capacity is substantially less developed in the U.S. than biodiesel production capacity. Most PADD regions do not host any production capacity and supply is limited as a result. Unlike biodiesel production capacity, however, the first commercial-scale renewable diesel capacity (the 75 MMGY Dynamic Fuels facility, now owned by Renewable Energy Group under the name “REG Geismar”) was not built in the U.S. until 2010.⁶⁰ U.S. renewable diesel capacity subsequently increased to 397 MMGY in 2018 (see Figure 1-10).^{61,62} That figure is expected to grow rapidly to almost 2,500 MMGY in 2022 due to ten recently-announced expansion and greenfield investments totaling 2,082 million gallons of additional capacity.⁶³ U.S. renewable diesel capacity will likely surpass U.S. biodiesel capacity by 2022 if all of these projects are completed as planned.

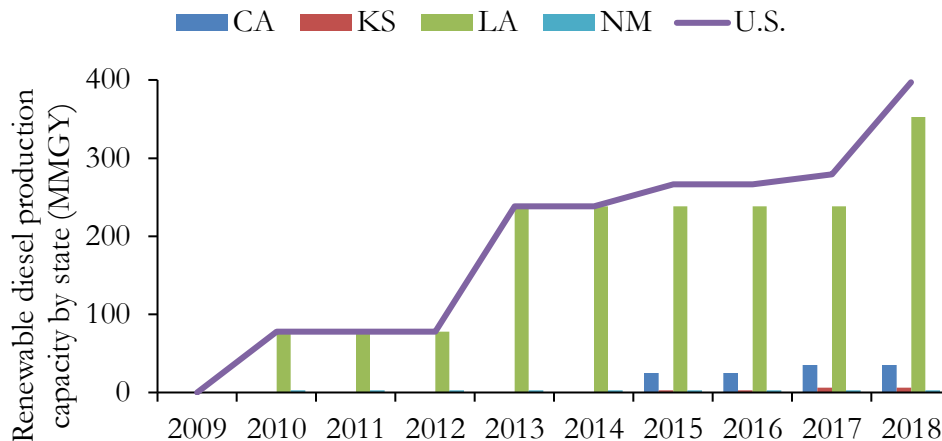


Figure 1-10. U.S. renewable diesel production capacity by state, 2009-2018. Source: Author calculations based on company data.^{61,62}

U.S. renewable diesel capacity is characterized by many facilities that are as much as an order of magnitude larger than U.S. biodiesel facilities. In December 2018 the U.S. hosted five operational renewable diesel facilities: the 3 MMGY Cetane Energy facility in New Mexico; the 3 MMGY East Kansas Agri-Energy (EKAE) facility in Kansas; the 35 MMGY* World Energy Paramount facility (formerly AltAir Fuels and owned at various times by refiners Alon USA Energy and Delek US Holdings); the 75 MMGY REG Geismar facility in Louisiana; and the 275 MMGY Diamond Green Diesel facility, also in Louisiana. Green Energy Products operated an additional 3 MMGY of capacity until 2016, when its parent company WB Services filed for bankruptcy.⁶¹

Louisiana is host to 90% of current U.S. renewable diesel capacity, although this percentage is expected to decline sharply as 1,898 MMGY of new capacity comes online by 2022 (only 510 MMGY of which is planned to be in Louisiana). While Louisiana is a major producer of neither oilseeds nor biodiesel, renewable diesel's unique characteristics explain the presence of so much capacity in the Gulf Coast. Industrial natural gas in the state, from which most hydrogen is derived, has been substantially cheaper (19% in 2018) than the U.S. average for most of the last decade due to the growing volumes of domestic inland production over that period.⁶⁴ Louisiana's abundant petroleum refining capacity also ensures the presence of both the necessary hydrogen infrastructure and technical expertise necessary for large-scale hydroprocessing. Finally, although Louisiana is not a

* The facility's full biofuels capacity is 40 MMGY, of which 35 MMGY is renewable diesel and 5 MMGY is renewable jet fuel.

major source of animal processing residues, neighboring states such as Texas, Arkansas, and Mississippi are,⁶⁵ providing Louisiana's renewable diesel producers with access to animal fat feedstocks. Louisiana's access to pipeline, ocean-going vessel, river barge, rail, and truck transportation modes also enables larger production and off-take volumes than would otherwise be possible.

Louisiana's capacity is expected to increase by 144% between 2019 and 2022 as a new facility and a major expansion at an existing facility come online. Emerald Biofuels is building a commercial-scale facility in Louisiana named Emerald One.⁶⁶ This 110 MMGY renewable diesel facility is expected to become operational in 2019 and will utilize "a wide range of non-edible oil feedstocks."⁶⁶ This is to be followed by a major expansion of the Diamond Green Diesel facility that is also located in Louisiana. The Diamond Green Diesel facility, which is supported through a joint venture between refiner/biofuels producer Valero and food processor Darling Ingredients, already underwent one successful expansion from 160 MMGY to 275 MMGY in 2018. The two partners have agreed to expand Diamond Green Diesel's capacity further to 675 MMGY and construction is scheduled to be completed by the end of 2021.⁶⁷

The PADD 4 region is also expected to begin producing renewable diesel in 2019 as an 84 MMGY facility is scheduled to commence operations in Nevada. The facility, which is part of a joint venture between refiner Phillips 66 and biofuel producer Ryze Renewables, is the first of two that are planned for the state. (A twin facility is scheduled to begin production in 2020.)⁶⁸ Uniquely for a refiner, Phillips 66 is to supply inedible lipid feedstocks to both facilities; it will also move all the resulting renewable diesel to the PADD 5 region for sale.

The PADD 2 region's first large renewable diesel facility is also expected to become operational in 2020. To date the region's capacity has consisted of small facilities co-located with existing biodiesel or corn ethanol capacity that have used readily available feedstocks (e.g., DCO) in the local area. SG Preston is building a 240 MMGY renewable diesel and jet fuel facility in Ohio as the first of five planned facilities totaling 1,200 MMGY.^{69,70} While the SG Preston facility was initially expected to become operational in 2019, it was delayed when the owners decided to double the facility's capacity from its original 120 MMGY size.

A smaller, 34 MMGY renewable diesel and jet fuel facility that will utilize DCO as feedstock is being planned in Iowa. Construction on that facility, which will be owned by Readifuels-Iowa, is scheduled to begin by the end of 2019 to permit operations to begin in early 2021.⁷¹

The full conversion of a North Dakota petroleum refinery into a renewable diesel facility is scheduled to be completed by the end of 2020, with operations commencing in early 2021.⁷² The refiner Andeavor, which was acquired by Marathon Petroleum Corp. in 2018, began co-processing lipid feedstocks at its Dickinson, ND refinery in that same year. At the same time work began to convert the refinery into a 184 MMGY renewable diesel production facility. Following conversion, the facility will utilize feedstocks such as soybean oil and DCO to produce renewable diesel that will be shipped via rail to California.

Finally, several large greenfield facilities and expansions are planned for the PADD 5 region in 2021 and 2022. Upon completion these projects will give the region almost 1,000 MMGY of renewable diesel capacity, or 43% of total U.S. capacity. Biofuels producer World Energy followed up its purchase of the California Paramount facility by announcing its expansion to 306 MMGY, approximately 153 MMGY of which will be in the form of renewable diesel.⁷³ The expanded capacity is scheduled to become operational in 2021. A 567 MMGY renewable diesel facility in Oregon that is being built by NEXT Renewable Fuels is also expected to begin operations in 2021.⁷⁴ The company has entered into a long-term offtake agreement with Shell Trading Co. for the facility's renewable diesel, which is to be produced from both waste and oilseed feedstocks.

Renewable Energy Group, which currently owns and operates one of the world's larger biodiesel production facilities in Washington, the 100 MMGY REG Gray's Harbor facility, has formed a joint venture with Phillips 66 to construct a 250 MMGY renewable diesel facility in that state as well. The new facility will be co-located with the refiner's existing petroleum refinery in Ferndale, WA.⁷⁵ In addition to hydrogen, this proximity will give the new renewable diesel facility access to deep water shipping, rail, and truck transportation modes. While still in the planning and engineering stages, the facility is expected to become operational in 2022 if the joint venture moves forward with construction.

The U.S. renewable diesel supply environment will look very different by the end of 2022 if the planned capacity additions come online as scheduled. The PADD 5 region, which has not been a

major source of U.S. BBD supply to date, is scheduled to be responsible for a plurality of the country's renewable diesel production as early as 2021 (see Table 1-3).

Table 1-3. Planned U.S. renewable diesel capacity additions, 2019-2022.

	Planned new renewable diesel capacity by location (MMGY)					
	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5	U.S.
Existing	0	6	353	3	35	397
2019	0	0	110	84	0	194
2020	0	240	0	84	0	324
2021	0	341	0	0	696	1,037
2022	0	0	400	0	250	650
Cumulative new	0	587	510	168	946	2,602
Existing + new	0	593	863	171	981	2,999

Sources: Author's calculations.

U.S. renewable diesel production volumes have been closely correlated with production capacity volumes and have only declined year-over-year one time, in 2012 (see Figure 1-11). Domestic production has increased from 0 in 2009 to 328.6 MMGY in 2018. In contrast to U.S. biodiesel production, which has never reached a 70% utilization rate at the national level, U.S. renewable diesel production has not fallen below that same utilization rate since 2013 despite a substantial fraction of U.S. capacity being taken offline on multiple occasions due to accidents.⁷⁶ In 2016 and 2017 U.S. renewable diesel facilities ran near or at full capacity, and in December 2018 production reached a record 50 million gallons.

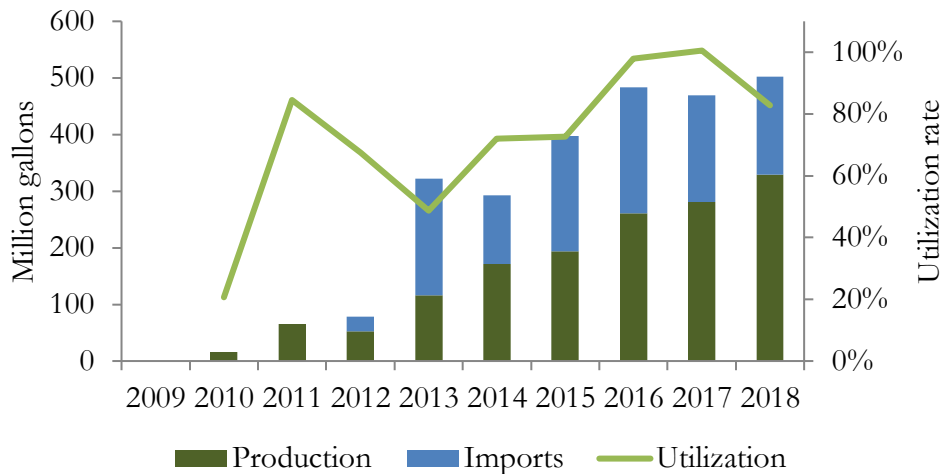


Figure 1-11. U.S. renewable diesel supply, 2009-2018. Includes co-products heating oil and naphtha.^{77,78}

U.S. renewable diesel production has been supplemented by substantial annual volumes of imports that, in 2013 and 2015, exceeded domestic production. Imports peaked in 2016 but have not experienced the large subsequent decline from that level that biodiesel imports have recorded due to the fact that Argentina and Indonesia are not producers of renewable diesel, so U.S. renewable diesel imports have not been impacted by the trade restrictions that have been imposed on those two exporters. Almost all of U.S. renewable diesel imports have arrived from Singapore, which hosts a 300 MMGY Neste Oil production facility (see Figure 1-12). Finland, where Neste Oil has an additional 156 MMGY of capacity, was the source of the balance (excluding two small, isolated shipments from Aruba in 2012 and 2013).^{*} Singapore has been the only source of U.S. renewable diesel imports since September 2014, and Neste Oil has been responsible for 99.7% of the total volume of imported U.S. renewable diesel since 2009.[†]

^{*} It is not clear why renewable diesel was imported from Aruba. EIA data shows that the shipment was made by Neste Oil, although the country did not host any renewable diesel production capacity so the renewable diesel must have originated in another country before arriving in Aruba.

[†] An important discrepancy exists between two of the most important databases of U.S. renewable diesel imports. The U.S. EIA maintains a comprehensive database of biofuel imports by company, country, biofuel type, port of entry, and monthly volumes that this report utilizes. According to the EIA, the U.S. imported 1,142.8 million gallons of renewable diesel between 2012 and 2018 (see endnote 77). The U.S. EPA maintains a separate monthly database of biofuel imports by biofuel type and monthly volume as part of its RFS accounting (see footnote on page 68). The EPA database shows that 2,018 million gallons of renewable diesel were brought into the U.S. over the same period. The likely explanation for the difference is that the EPA database includes all volumes produced by a “foreign generator” under the RFS – Neste Oil, in this case – rather than just those that have physically entered the U.S. The RFS allows renewable diesel from palm oil to qualify for D6 but not D4 Renewable Identification Numbers (RIN). If only renewable diesel from foreign

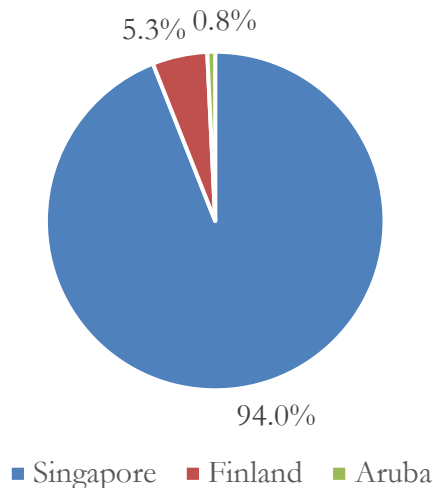


Figure 1-12. Sources of U.S. renewable diesel imports, 2009-2018.⁷⁷

Renewable diesel supply – U.S. feedstocks

The EIA does not publish data on the specific volumes of different feedstocks used to produce renewable diesel. While it is not possible to identify the specific feedstock mixes that are employed by domestic producers as a result, the small number of domestic production facilities allows for the different feedstocks that are utilized to be identified. The largest renewable diesel production facilities, Diamond Green Diesel and REG Geismar, have both had their pathways certified under California's LCFS. Diamond Green Diesel has certified the use of the following feedstocks: soybean oil, UCO, tallow, and corn oil.⁷⁹ The involvement of food processor Darling Ingredients in the Diamond Green Diesel joint venture means that waste feedstocks such as animal processing residues and UCO serve as important feedstocks for the facility,⁸⁰ but its access to multiple transportation modes provides it with feedstock flexibility in response to feedstock supply and pricing.

Likewise, REG Geismar was originally built as a joint venture between advanced biofuels company Syntroleum and food processor Tyson Foods as a means of utilizing the latter's waste animal processing residues.⁸¹ While the facility was purchased by Renewable Energy Group in 2014, it is

generators and importers that meets the D4 RIN category is included, then the EPA's volume declines to within 8 million gallons of the EIA's volume. In other words, it is likely that palm oil-derived renewable diesel from foreign generators is included in the EPA's database even though it never actually entered the U.S. The author wishes to credit Christopher Anderson and his colleagues at Renewable Energy Group for providing this explanation.

certified under the LCFS as a producer of renewable diesel from tallow, as well as from UCO, DCO, and soybean oil.⁸² Most of the country's existing renewable diesel capacity was designed to utilize animal processing residues and, given the feedstock's attractiveness as a renewable diesel feedstock and lack of growth over the last decade as a biodiesel feedstock, it can be assumed that animal processing residues remain an important source of U.S. renewable diesel production. As with the biodiesel sector, though, an individual facility's feedstock sources are a function of both its geographic location and its access to the transportation infrastructure.

The renewable diesel supply profile of each PADD region is presented in Appendix I.

1.3. BBD supply incentives

BBD supply incentives have been implemented at the national, state, and local levels in the U.S. The only common factor among these incentives is that they have been designed for the purpose of increasing the volume of BBD that is supplied to consumers within a specific jurisdiction. The types of incentives that have been employed to date are incredibly varied, ranging from explicit annual supply (usually via blending) mandates to tax credits for BBD infrastructure investments to fuel tax exemptions to low-interest loans and loan guarantee programs. This section identifies and summarizes the incentives that affect BBD supply in each U.S. PADD region and further categorizes each according to the level of government (national, state, and in limited instances local) at which they are enacted and by incentive type. Finally, this section also notes any sustainability criteria that apply to each incentive (besides qualifying as BBD fuels).

The U.S. Renewable Fuel Standard

A variety of government policies have been adopted at the national, regional, state, and local levels in the U.S. in order to incentivize increased BBD supply. The largest of these, and the primary government driver of BBD supply at the national level, is the U.S. RFS. The RFS mandates the blending of rising volumes of BBD (biodiesel and renewable diesel both qualify) with diesel fuel by “obligated blenders” (i.e., petroleum refiners) prior to consumption by drivers. These obligated blenders must blend an annual volume of BBD that is determined by their individual market share relative to the total mandated blending volume in that year. Large and potentially limitless penalties are imposed for non-compliance. Compliance is demonstrated via D4 RINs, which are tradable

commodities that are created when every gallon of qualifying BBD is produced under the RFS.* RINs cannot be separated from the associated gallons until the underlying biofuel is either blended or sold for retail. At this point the now-separate RIN can be submitted to the EPA, if held by an obligated blender, to demonstrate partial compliance with its share of the blending mandate. Alternatively, the RIN can be sold to another entity, similar to how cap-and-trade schemes allow carbon credits to be sold between multiple entities.

Most of the annual volumes established under the RFS through 2022 were set by Congress when it drafted the legislation, the Energy Independence and Security Act of 2007, that created the mandate. An exception was the BBD category; Congress established a minimum BBD blending volume of 1,000 million gallons but tasked the U.S. EPA with setting the actual volume through an annual rulemaking. The actual BBD volume was last set at the minimum level in 2012 and the EPA has increased it for every subsequent year except 2019, when it was held steady at 2,100 million gallons.⁸³ The rulemaking process has been contentious, though, and much debate has focused on lipid feedstock availability and the ability of U.S. producers to supply the additional BBD needed for the mandate to be achieved when the EPA requires higher annual BBD blending volumes.^{24,84} To date BBD producers have been able to meet or exceed all of the EPA's increases to the BBD mandate, but the flexible nature of the mandated BBD volumes within the RFS ensures that future rulemakings will continue to be contentious.

The mandated BBD volume has increased from 500 million gallons in 2009 to 2,100 million gallons in 2019 (see Figure 1-13); early rulemaking will see this volume further increase to 2,430 million gallons in 2022.^{83,85} BBD is not limited to only the BBD category of the RFS, though. Each of the four major categories (Total Renewable Fuel, Advanced Biofuel, Biomass-based Diesel, and Cellulosic Biofuel) have specific definitions. The Total Renewable Fuel category (D6 RINs) is the broadest of the four, covering any biofuel with a CI that is at least 20% lower than that of gasoline (or diesel fuel, in the case of BBD).[†] The Advanced Biofuel category (D5 RINs) covers biofuels other than those from corn starch with a CI that is at least 50% lower than that of the corresponding petroleum-derived fuel. The BBD category (D4 RINs) covers biodiesel and

* Other biofuel categories generate other RIN numbers. A second important RIN number for the purposes of this report is D5, which applies to the Advanced Biofuels category within which the BBD category is nested.

† Biofuels from corn starch, such as corn ethanol, are capped at a 15,000 MMGY blending volume under the RFS; additional gallons can be blended legally, but any volume above that cap does not qualify for RINs.

renewable diesel with carbon intensities that are also at least 50% lower than that of diesel fuel. The nested nature of the categories allows for biofuels qualifying for one category to also qualify for all the less stringent categories (although it can only earn RINs from a single category): BBD can generate D4 RINs or, alternatively, it can generate D5 or D6 RINs instead. The reverse is not true: corn ethanol can only generate D6 RINs.

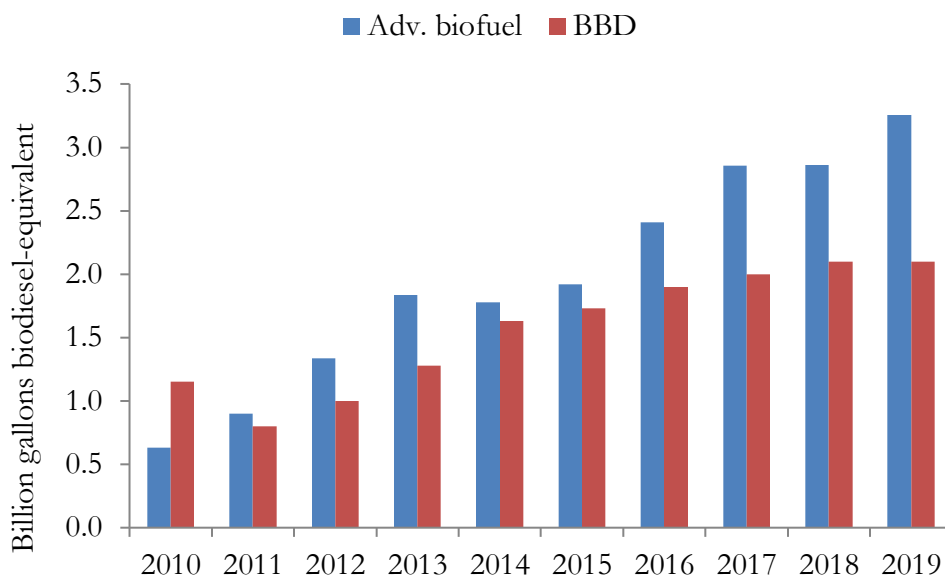


Figure 1-13. Advanced biofuel and BBD mandated blending volumes under the U.S. RFS.^{85*}

The nested nature of the RFS has incentivized BBD supply beyond the immediate volumes contained within the individual D4 category of the mandate. At least 448 million gallons of BBD, including renewable heating oil,⁸⁵ have contributed to the D5 and D6 categories over the last decade.^{78†} Most of those contributions occurred between 2013 and 2016 at a time of declining U.S. imports of Brazilian cane ethanol, which has historically been a major source of D5 RINs, as that country dealt with a multi-year drought that hurt its sugarcane output.⁸⁶ BBD producers have had a financial incentive to increase production and supply to the D5 category due to the fact that D5 RIN prices traded at an average discount of only \$0.03 to D4 prices between July 2013 and the end of 2018 (see Figure 1-14). Even D6 RIN prices have even come close to converging with D4 prices on occasion in past years.

* The 2010 BBD volume reflects the combination of the statutory 2009 and 2010 volumes.

† This is a conservative estimate that excludes D6 RINs generated by “Foreign Generators” under the mandate.

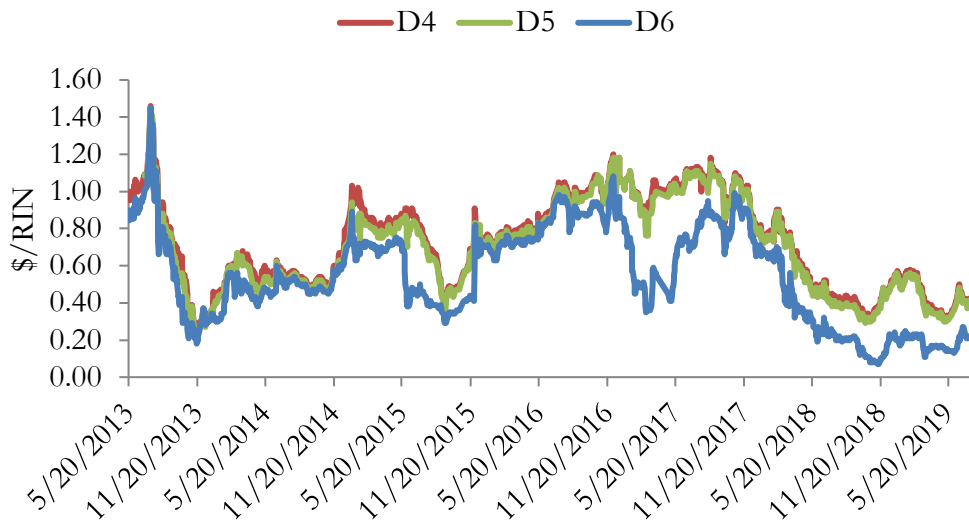


Figure 1-14. D4, D5, and D6 RIN prices under the RFS, 2013-2018.⁸⁷

The lack of a price spread between D4 RINs and the less-stringent D5 and D6 RINs has had the effect of encouraging the supply of BBD relative to non-BBD biofuels since BBD does not face the blending constraints of ethanol fuels, which are normally the main sources of supply under the non-BBD categories. In 2013 U.S. ethanol consumption reached the so-called “blend wall” of 10 vol%, causing D6 RIN prices to rapidly converge with D4 and D5 prices as blenders turned to BBD blending to generate the necessary volume of RINs under the D6 category.^{88,89*} This development caused the annual volume of BBD that was supplied under the RFS to be as much as 5% higher than that supplied under the D4 category volume alone in 2016 (see Table 1-4). The overall effect contributed to a sharp increase of the BBD supply in 2016, in part due to a 10% increase to the D4 mandate and in part due to BBD’s increased contribution under the D6 mandate.[†]

* The use of fuel ethanol in unmodified vehicles has historically been limited to a 10 vol% blend with gasoline known as “E10.” Declining U.S. gasoline consumption in 2012 and 2013 caused the amount of biofuel supply required by the RFS to exceed 10 vol% of gasoline demand, at which point obligated blenders had to turn to less conventional and often more expensive means of generating their required volumes of D5 and D6 RINs such as higher blend rates (E15 and E85, neither of which have been widely supplied to date) and BBD blending. BBD subsequently became the source of the marginal biofuel gallon, as illustrated by the RIN price convergence, used to meet the differences between the E10 blend wall volume and the D6 mandate as well as between the D5 and D4 mandates.

† A contributing factor to 2016’s large increase to BBD supply was the EPA’s release of the BBD volumetric mandates for 2014-2017 in late 2015, two years behind schedule in the case of the 2014 mandate and three years after the release of the EPA’s previous “annual” rulemaking. In the interim BBD producers had been left with no guidance regarding blending volumes other than the statutory minimum of 1 billion gallons and this uncertainty contributed to the declines in U.S. production volumes and utilization rates that occurred in 2014 and 2015. The EPA ultimately set the volumetric mandates for both years at their actual respective volumes.

Table 1-4. Annual volumes of BBD supplied to each RIN category under the RFS. All units in millions of gallons. Note: excludes BBD volumes under the D6 category from Foreign Generators.⁷⁸

RIN category	2010	2011	2012	2013	2014	2015	2016	2017	2018
D4	215.4	1,122.7	1,146.9	1,794.3	1,763.4	1,823.1	2,615.2	2,503.6	2,514.3
D5	15.2	20.6	12.3	41.3	8.7	5.5	5.6	6.4	25.4
D6	12.5	4.2	0.7	36.8	53.2	74.5	112.9	0.0	0.3
Total	243.1	1,147.5	1,159.9	1,872.4	1,825.3	1,903.1	2,733.7	2,510.0	2,540.0

U.S. BBD supply peaked in 2016 and then declined by 9% in 2017 (see Figure 1-3 and Table 1-4) despite continued annual increases to the D4 mandate. Three factors contributed to this decline. The large decline to petroleum prices that began in late 2014 caused U.S. gasoline consumption to increase by almost 5% between 2014 and 2017,⁹⁰ raising the ethanol blending volume permitted by the E10 blend wall. Second, the end of the Brazilian drought resulted in a doubling of ethanol imports under the D5 category of the RFS in 2017 to 73.9 million gallons,⁷⁸ increasing the competition for supply as the marginal gallon. At the same time the U.S. imposition of countervailing duties to Argentinian and Indonesian biodiesel caused the combined imported volume from those two countries to fall from 555.8 million gallons in 2016 to 290.6 million gallons in 2017 and zero gallons in 2018.⁹¹

Finally, and perhaps most impactfully, the incoming Trump administration took steps in late 2016 to reduce the mandate's requirements of obligated blenders. Announcements of proposed reforms to the RFS in early 2017 caused D6 RIN prices to decline rapidly⁹² and later that year the EPA greatly expanded the number of Small Refinery Exemptions (SRE) that it awarded to obligated blenders.⁹³ The SREs exempt recipient obligated blenders from some or all of their individual blending requirements under the RFS. While SREs had been awarded in smaller numbers before, the 2017 expansion caused the exempted RIN volume to increase by more than 500% between 2015 and 2017.⁹³ Not only did the prices of D4, D5, and D6 RIN prices all collapse in response to this reduction in RIN demand (see Figure 1-14), but BBD's status as the marginal D6 gallon at the time meant that it experienced, according to one independent calculation, a 739 million gallon reduction to mandated supply in 2017 because of the SRE expansion.⁹⁴ The National Biodiesel Board more conservatively estimated a reduction to mandated BBD supply of 239 million gallons for that same year on the assumption that only D5 and D4 RIN demand was affected.⁹⁵ In either case, this reduction in turn explains why the disappearance of biodiesel imports from Argentina and Indonesia

in 2017 and 2018 was not offset by increased domestic production, imports from other countries, or even, in the case of PADD 1 supply, increased shipments from other PADD regions.

The EPA has set the required BBD blending volumes for 2019 and 2020 at 2,100 million gallons and 2,430 million gallons, respectively. It anticipates actual BBD supply in those years to be 2,800 million gallons and up to 2,930 million gallons, respectively, after BBD that is blended to generate D5 RINs is also accounted for.⁹⁶ The EPA proposed in July 2019 to maintain the BBD blending volume for 2021 at 2,430 million gallons, unchanged from 2020, on the grounds that it is “appropriate to maintain the ability for other advanced biofuels to compete for market share” by establishing “the BBD volume at a level lower than the advanced biofuel volume.”⁹⁷ The actual impact of the RFS on BBD supply will not be known until the Advanced Biofuel category’s mandated blending volume for 2021 is established in 2020. It is also unclear at the time of writing what impact, if any, the allocation of future SRE waivers will have on the effective BBD blending requirements.

This new rationale introduced by the EPA in its 2021 proposed rulemaking potentially caps the mandated BBD volume at 2,430 million gallons after 2021 since the EPA has also proposed to limit the advanced biofuel volume by the maximum amount allowed in 2020 on the grounds that “insufficient reasonably attainable volumes of non-cellulosic biofuels” exist to do otherwise.* In other words, the EPA’s proposed rulemaking argues that the BBD volume must be limited so as to allow other advanced biofuel pathways to compete for market share, but the advanced biofuel volume must be limited due to a lack of non-BBD and non-cellulosic biofuel volumes in the market. The proposed rulemaking can change before the final rulemaking is released (usually by the end of the year) so this rationale has not yet been enacted, but it would have an important impact on mandated BBD supply in the early 2020s if adopted.

The Federal BBD Tax Credits

* The statute set the original cellulosic biofuel mandate under the RFS for 2020 at 10,500 million gallons of ethanol-equivalent. The EPA has proposed to reduce that volume by 9,960 million gallons due to a lack of cellulosic biofuel production capacity. The cellulosic biofuel mandate is nested alongside the BBD mandate within the advanced biofuel category, so the 9,960 million gallon reduction applies to the advanced biofuel category as well.

A pair of federal tax credits dating to 2004 have also served to incentivize U.S. BBD supply. The first of these credits is the Biodiesel or Renewable Diesel Income Tax Credit. This non-refundable tax credit of \$1 (i.e., it was set against a qualifying taxpayer's income tax liability) is awarded to “producers, blenders, or retailers” of biodiesel and renewable diesel for every gallon sold or used by the taxpayer.⁹⁸ The second tax credit, the Biodiesel or Renewable Diesel Mixture Tax Credit, is a \$1 refundable tax credit (i.e., it is set against a qualifying taxpayer's excise tax liability, with any excess taking the form of a direct payment from the IRS) for every gallon of BBD that is blended with diesel fuel for consumption as transportation fuel.⁹⁸ Practically the value of this second credit is often divided between BBD producers and their customers on a contractual basis. The blenders' credit has been the most important of the two tax credits to BBD producers since its value has only been limited by blending volumes rather than income tax liability.* It is commonly referred to as the “biomass-based blenders' credit”, or BTC, by market participants.

The primary purpose of the BBD tax credits is to increase the volume of BBD that is supplied to the transportation fuel sector, either as a pure renewable fuel or as a qualified mixture with diesel fuel. This has even extended to BBD imports: as noted by the USDA's Foreign Agricultural Service, Canadian BBD producers have historically exported the majority of their production volumes to the U.S. so as to participate in the tax credits (as well as the RFS), and Canada imports a similar volume of BBD (often from the U.S.) in order to satisfy its own blending targets.^{99†}

The tax credits' implementation has been haphazard, however, as Congress has allowed them to regularly lapse before enabling retroactive reinstatements, sometimes also with extensions, many months later. The previous iterations of both tax credits expired at the end of 2016, for example, only to be retroactively reinstated (but not extended) by Congress in February 2018 for the period through December 31, 2017, at which point they retroactively expired. The tax credits lapsed until December 2019, at which time they were retroactively reinstated by Congress for 2018 through 2019 and extended until the end of 2022.¹⁰⁰

* The value of a non-refundable income tax credit is limited when the taxpayer has a limited income tax liability due to poor production margins, for example.

† Biodiesel has not historically needed to have a final point of sale in the U.S. in order to receive the tax credits so long as it was either produced or consumed domestically. This has meant that both Canadian biodiesel that was exported to and consumed in the U.S. and U.S. biodiesel that was exported to Canada have qualified, assuming that they met the other requirements. This dynamic gave rise to the trade situation described above.

The tax credits have largely had their intended effect because of a widespread perception among BBD producers that future retroactive reinstatements were probable. For example, BBD producer Renewable Energy Group reported its 2018 earnings on both an actual basis and on the basis of a (as yet) hypothetical retroactive reinstatement of the tax credits for the same year.¹⁰¹ The increase in both U.S. BBD production volumes and capacity utilization rates that occurred in 2018, while insufficient to offset the negative impact on supply of that year's reduced import volumes, suggests that domestic producers continued to assume that the tax credits would be retroactively reinstated after the most recent expiration in December 2017.

California's Low Carbon Fuel Standard

The reduction to mandated BBD supply under the expansion of the SRE waivers has not been any larger than it has because of the largest state-level supply mandate, California's LCFS. The LCFS has run roughly parallel to the RFS as both programs have been implemented since the beginning of the current decade (the LCFS took full effect in 2011). The two programs share multiple similarities in their approach to mandating the supply of alternative fuels such as BBD. Like the RFS, the LCFS as implemented by the staff at the California Air Resources Board (CARB) effectively mandates the inclusion by fuel suppliers of growing volumes of fuels that are defined by their low carbon intensities (CI) relative to petroleum-derived gasoline and diesel fuel within the state's transportation fuel supply. (In 2016 Oregon implemented its own "Clean Fuels Program" that also utilizes a pathway-specific CI system, although California's LCFS has been the primary such program to date.)¹⁰² It does so by requiring gradual reductions to the CIs of fuels supplied to the state market with the goal of reducing the GHG emissions released by California's transportation system. All fuels with a CI that is higher than the declining threshold incur a deficit that is offset by either blending sufficient volumes of low-carbon fuel or purchasing credits that represent those fuels. Also like the RFS, the LCFS utilizes a banking and trading system for the credits among regulated parties, giving the credits a market value* that incentivizes the supply of the necessary low-carbon fuels into the overall transportation fuel network.

*An inflation-adjusted cap of \$200/Mg in 2016 dollars is imposed to address possible credit shortages as part of the Credit Clearance Market. This cap reflects concerns by refiners (also expressed during the debate over the RFS) that low-carbon fuel producers might effectively "strike" by refusing to supply their fuels in order to drive the credit price higher, and that demand for low-carbon fuels under the LCFS might at some point outstrip available supply. Refiners are also

These similarities aside, the LCFS utilizes a very different structure than the RFS in order to achieve its targeted reductions to GHG emissions. First, as the difference in the two programs' names indicates, the LCFS defines the fuels that it covers in terms of CI rather than renewability. Fossil fuels with CIs that are lower than petroleum-derived fuels can participate in the program, and multiple fossil pathways such as non-renewable electricity (for electric vehicles) and natural gas have done so. Second, rather than define each fuel pathway according to a single CI as the RFS does, the LCFS employs life cycle assessment (LCA) to calculate production facility-specific CIs for the low-carbon fuels that participate within the program. These individual carbon intensities are important because the number of LCFS credits that a low-carbon fuel pathway generates is based on its individualized CI. This CI is calculated as a function of pathway, feedstock, location (including emissions released by the movement of the fuel to California), and even indirect land-use change.

The overall CI of California's transportation fuels market is required under the LCFS to steadily decline on an annual basis (see Figure 1-15) via the blending of sufficient volumes of low-carbon fuels with the petroleum-derived gasoline and diesel fuel that make up most of the state's transportation fuel supply. Whereas the RFS mandates the blending of specific volumes of fuels that achieve a minimum predetermined CI reduction threshold (e.g., 50% for BBD), the LCFS allows the market to determine the low-carbon fuel mix that is used to achieve the overall annual CI reduction. The LCFS is pathway-agnostic compared to the RFS in that the program's role is to certify the low-carbon pathways that participate within it rather than to explicitly prescribe those pathways that are allowed to participate. The LCFS further differs from the RFS in that the threshold against which the CIs of low-carbon fuels are measured within it steadily declines over time, meaning that an alternative fuel with a CI that was initially below the threshold might not be in a future year.

able to generate incremental credits on their own by reducing the CIs of their own fuels via the adoption of energy efficiency and renewable electricity upgrades at their refineries or via carbon capture and sequestration investments.

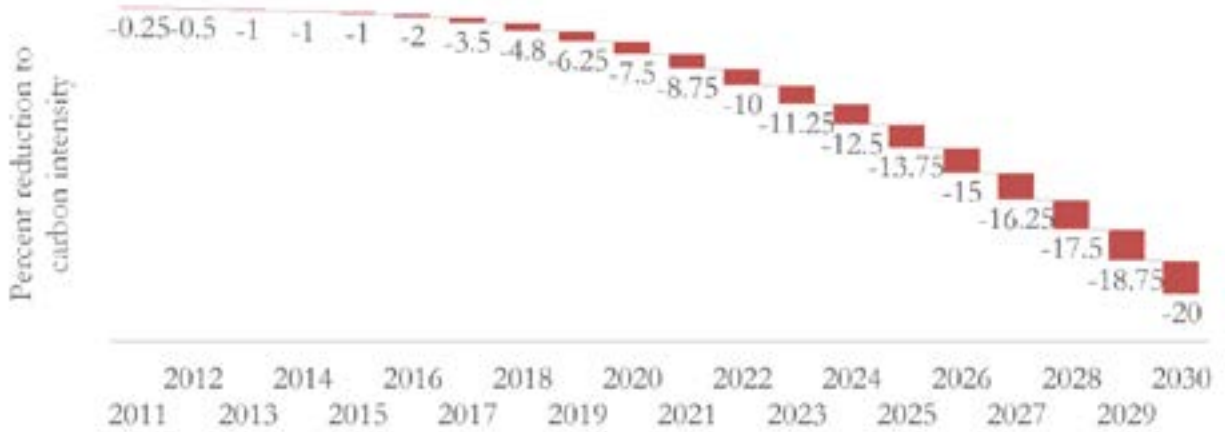


Figure 1-15. Required annual reductions to CI relative to 2010 baseline under the LCFS, 2011-2030.¹⁰³

The LCFS's carbon credit system ensures that sufficient volumes of low-carbon fuels are supplied to California's transportation fuel market to achieve the annual CI reductions. Each credit represents 1 Mg of carbon dioxide equivalent (CO₂e) emissions that have been reduced via the blending of low-carbon fuel relative to the CI threshold in a given year. The credits are tradable commodities with a market value that provides a de facto subsidy to producers of low-carbon fuels, thereby incentivizing the provision of the volumes necessary to achieve the annual thresholds. The declining nature of both the annual thresholds and the annual benchmarks against which the CI reductions of low-carbon fuels are measured are intended to encourage low-carbon fuel producers to achieve continuous reductions to their products while also ensuring steady demand growth.*

Biodiesel and renewable diesel have been major contributors to the LCFS due to their low CIs relative to other alternative fuels and large production volumes. BBD pathways certified under the mandate achieve CI reductions relative to petrodiesel of between 39% and 92%, with the largest reductions being reported for those pathways that utilize waste lipid feedstocks.¹⁰⁴ BBD generated a plurality of the CI reduction credits under the LCFS from 2011-2018 at 40.6%, followed by fuel

* The intended reductions to the annual CI thresholds have been more difficult to implement than was originally anticipated for a variety of technical and legal reasons. The increased production of high-viscosity and unconventional crudes in North America at the beginning of the decade caused an increase to the CI of gasoline and diesel fuel on the continent. In 2014 California adopted a new version of the GREET life cycle assessment model that utilized a modified methodology for the accounting of petroleum refining GHG emissions, further changing the CIs of gasoline and diesel fuel under the LCFS. Finally, the early LCFS was the subject of lawsuits that caused its CI reduction targets to be paused between 2013 and 2015 and the targeted reductions for subsequent years have been smaller than originally intended: the initial target of a 10% CI reduction by 2020 is now not to be reached until 2022, for example.¹⁰³ From the perspective of the BBD sector these developments have caused the CI benchmark against which alternative diesel fuels are measured to undergo annual increases as well as decreases, although it is now expected to steadily decline from 2016 onward.¹¹¹

ethanol at 40.4% (see Figure 1-16). This occurred despite the fact that BBD contributed only 19% of the overall low-carbon fuel volumes on an energy-equivalent basis over the same period.¹⁰⁵ BBD's combined share of total credit generation has steadily increased since 2011 and it first surpassed ethanol as the largest source of credits in 2016. Growth in renewable diesel has been especially fast despite the fuel having been a very marginal generator of credits and contributor of volumes in the LCFS's early years. The supply of BBD to date has made it a rare success story among the pathways that were originally envisioned in 2009 by the CARB staff. Whereas the expected non-starch ethanol volumes have fallen far short of expectations due to a lack of U.S. cellulosic ethanol production capacity,¹⁰⁶ and the number of zero-emission vehicles now available in California are near the bottom of the predicted range of 560,000 – 2,000,000,¹⁰⁷ BBD's expected blend rate of 15 vol% by 2020 was reached in 2018. BBD's share of total credit generation is also almost twice as large as the CARB staff had predicted it would be in 2020 due to lower-than-expected CIs for biodiesel in particular.¹⁰⁵

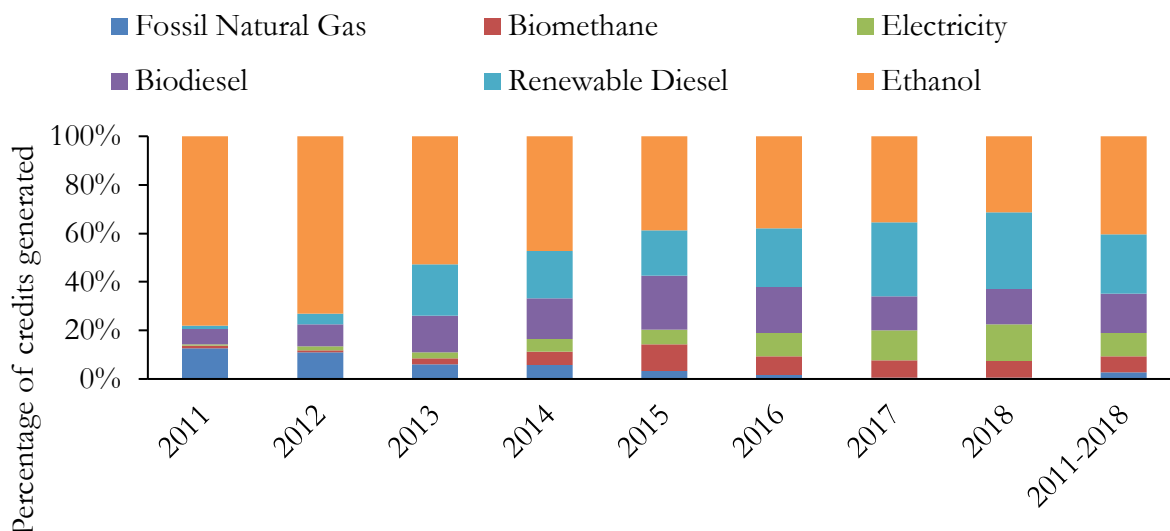


Figure 1-16. Percentage of total credits generated by different alternative fuels on an energy-equivalent basis under the LCFS.¹⁰⁵

BBD's ability to generate an outsized number of credits relative to its volume is due to the large CI reductions achieved by the biodiesel and renewable diesel that has participated within the LCFS. Only electricity has generated more credits per "gallon" of gasoline-equivalent (see Figure 1-17) since 2011. The average annual CI reductions achieved by BBD fuels relative to the diesel compliance standard between 2011 and 2018 have ranged from 55% to 86% for biodiesel and 49% to 75% for renewable diesel; both upper limits are higher if compared against the actual CI of diesel

fuel since the diesel compliance standard declines annually.¹⁰⁸ BBD's large contribution to the LCFS is explained by the optimal position that it occupies under the LCFS relative to the program's other major sources of credits. The relatively high CIs of the fossil natural gas and, to a lesser extent, ethanol pathways have required correspondingly large volumes of both fuels to generate a single LCFS credit: in 2018 this was 326 gasoline gallons-equivalent (GGE) for ethanol and 951 GGE for fossil natural gas.¹⁰⁸ It will become progressively harder for both pathways to generate credits as the compliance schedule becomes increasingly stringent and, barring future reductions to their CIs, starch ethanol will cease generating any credits within 10 years (fossil natural gas is already in the process of being phased out entirely as a qualifying pathway).^{106,111,109} Biodiesel and renewable diesel only required 125 GGE and 123 GGE, respectively, to generate one credit in 2018. Neither was as efficient as electricity, which generated one credit per 57 GGE in that same year. Unlike electricity, though, which requires investments in specialized infrastructure and vehicles in addition to low-carbon production capacity in order to displace petroleum, California's BBD supply to date has remained well below the 20 vol% and 100 vol% blend constraints for biodiesel and renewable diesel,¹¹⁰ respectively, that are imposed by the existing transportation fuels infrastructure.* 630.2 million GGE of BBD was supplied in 2018 under the LCFS compared to only 96.1 million GGE of electricity due to this difference in downstream infrastructure constraints.¹⁰⁵

* California's refineries produced 3,781 million gallons of CARB diesel in 2018. The state's supplied volumes of biodiesel and renewable diesel in that same year equaled 4.9 vol% and 10.1 vol%, respectively, of this CARB diesel production. Biodiesel is approved for use in unmodified engines under major automaker warranties in blends of up to 20 vol% while renewable diesel can be used in blends of up to 100 vol%.

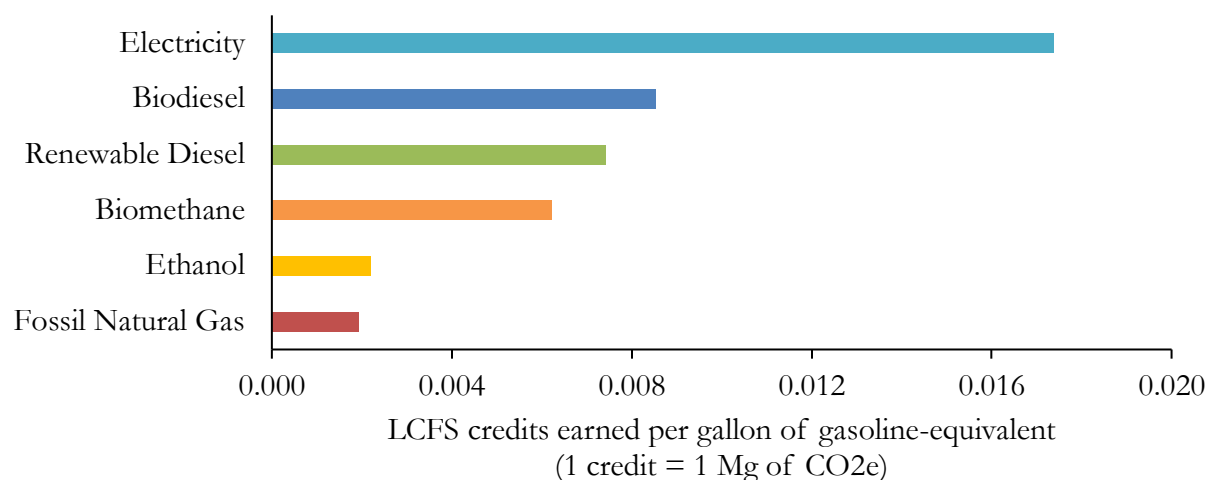


Figure 1-17. Average number of credits generated by different alternative fuels under the LCFS per gallon of gasoline-equivalent, 2011-2018.¹⁰⁵

BBD's CI reductions have in turn provided a strong incentive to producers to supply BBD to California's market in order to participate in the LCFS. This incentive has increased in recent years as the credit price has risen from \$25/Mg in January 2015 to \$183/Mg in December 2018 (see Figure 1-18). 2018's average credit price of \$155/Mg resulted in credits worth an average of approximately \$1.30/gallon and \$1.34/gallon being generated by biodiesel and renewable diesel, respectively, in that year.^{105,108,111} The large increase in PADD 5 BBD supply that occurred between 2015 and 2018 was closely connected to the increase in credit prices. The volume of BBD supplied under the LCFS increased from 291.6 million gallons in 2015 to 568.1 million gallons in 2018, an increase of 95%.¹⁰⁵ By contrast, U.S. BBD supply rose by 25% over the same period. California alone was responsible for 58% of the increase to U.S. BBD supply that occurred over that period. 2,185 million gallons of BBD were supplied to the state between 2011 and 2018, an amount that equaled 82% of the PADD 5 region's total BBD supply over the same period.

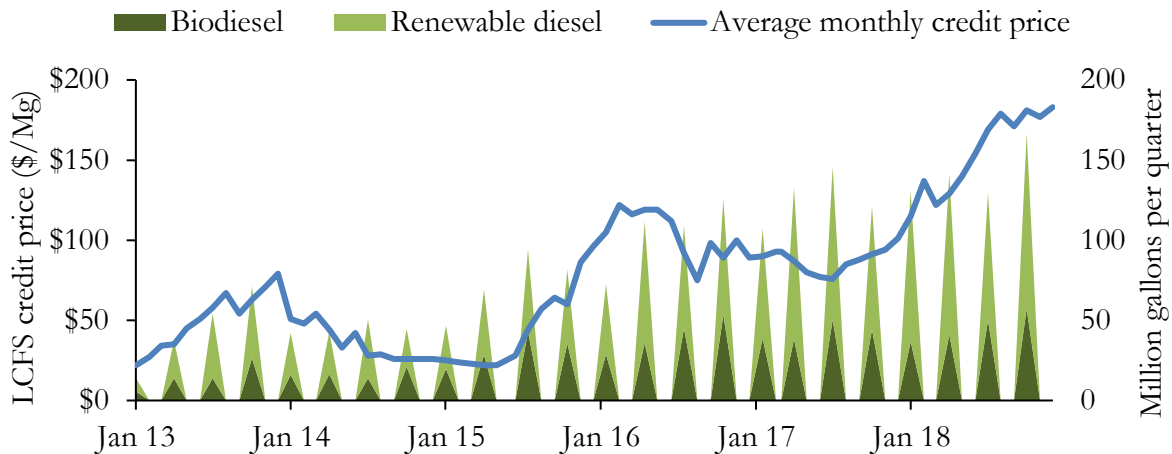


Figure 1-18. Average monthly LCFS credit price and quarterly BBD supply volumes, 2013-2018.^{105,112}

Waste and residual feedstocks such as UCO, animal processing residues, and DCO yield BBD gallons with lower CIs than are obtained via agricultural crop feedstocks such as canola and soybean oils.* The financial incentive that the LCFS provides for lower-CI BBD has prompted those producers that participate in the program to increasingly utilize non-agricultural crop feedstocks in order to generate the maximum number of credits. The volume of BBD from waste and residual feedstocks was 74% greater than that from agricultural crops in 2011. The share of the former increased until by 2018 it was 1,628% greater than the latter (see Figure 1-19).¹¹³ 89% of the BBD, including 82% of the biodiesel, that has been supplied to California under the LCFS since 2011 has been derived from waste and residual feedstocks. This stands in sharp contrast to the U.S. BBD supply with its continued substantial utilization of agricultural crop feedstocks.

* Agricultural crop feedstocks incur carbon-intensive inputs including land preparation, fertilizer application, harvesting, and in some cases land-use change (both direct and indirect). While waste and residue feedstocks can still incur these inputs at various stages of their life cycle (e.g., UCO is commonly derived from agricultural oilseed crops), they are attributed under standard LCA methodologies to the activity that spurred their initial creation and resulted in their ultimate conversion to waste or residue (cooking, to again use the UCO example).

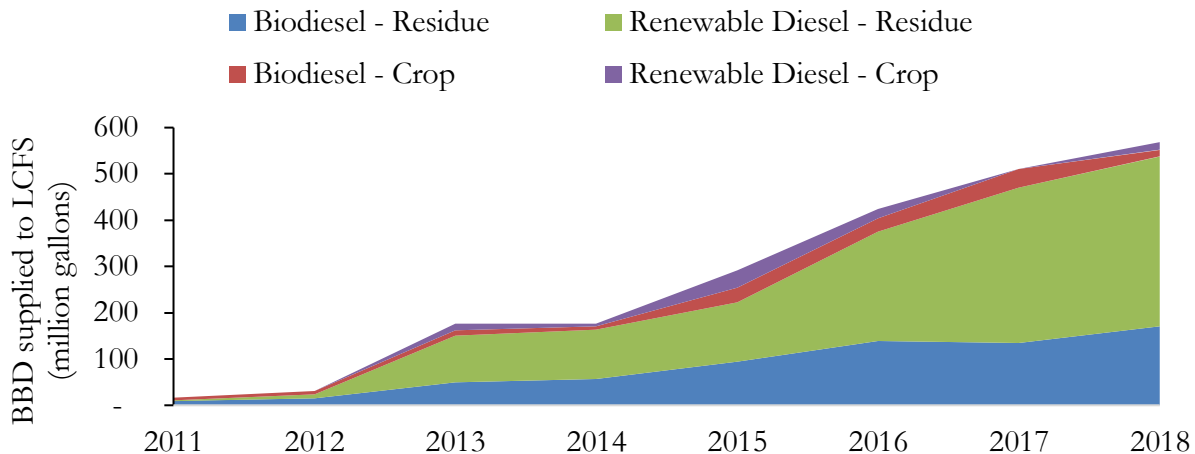


Figure 1-19. Forms of BBD feedstocks utilized under the LCFS, 2011-2018.¹¹⁴

The types of feedstocks that have been used to produce BBD for the LCFS since 2011 do reflect the variety of feedstocks used at the national level, if not in the same proportions. DCO, tallow, and UCO all experienced very rapid growth between 2011 and 2018 in terms of the number of credits that they were used to generate via BBD supply (see Figure 1-20).¹¹⁴ Canola oil, some of it Canadian in origin, has been the primary agricultural crop feedstock employed to produce BBD under the LCFS. Soybean oil, on the other hand, has been only a marginal contributor despite being the source of 50% of biodiesel production at the national level. A review of the BBD pathways that have been certified under the program suggests that location plays an important role in this predominance of canola oil over soybean oil despite their comparable CIs. Of the six certified pathways utilizing canola oil, three source the feedstock from western regions of the North American continent.¹⁰⁴ By contrast, all 19 of the certified pathways utilizing soybean oil source the feedstock from eastern Canada, the Midwest U.S., or South Central U.S. Longer transportation distances hurt BBD margins under the LCFS in two ways: they increase costs, especially when moved by land, and reduce the number of credits generated by increasing the BBD's CI, also especially when moved by land. The LCFS's focus on CIs therefore emphasizes both certain feedstock types and geographic sources of feedstock production over others.

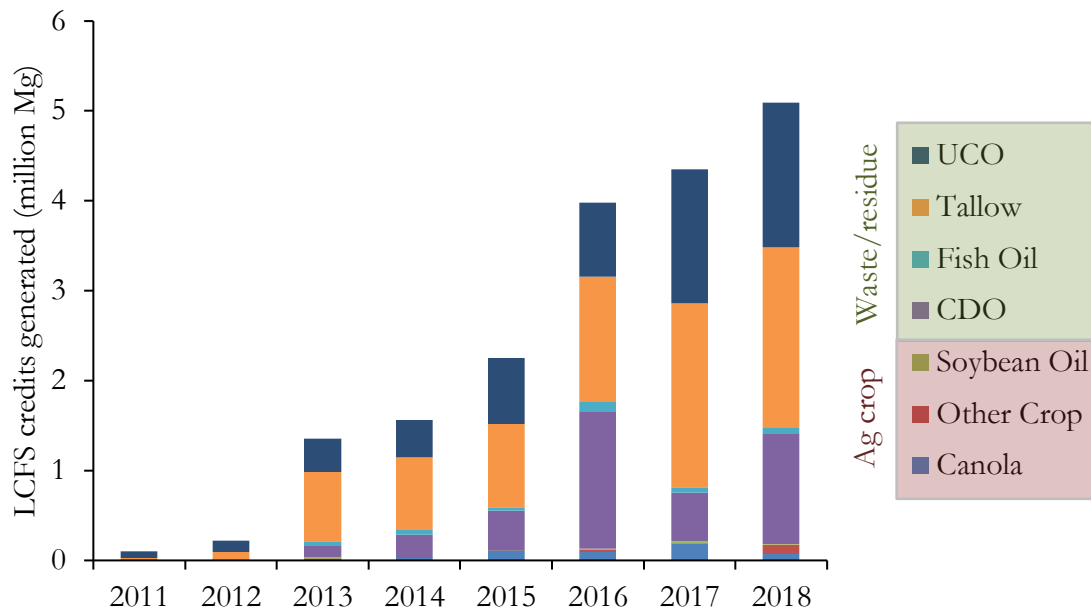


Figure 1-20. LCFS credits generated by BBD per feedstock.¹¹⁴

An additional difference between the BBD that has been supplied under the LCFS and the RFS is that renewable diesel has comprised the majority of the former. Biodiesel was the primary source of BBD supplied under the LCFS during its first two years (see Figure 1-21). Renewable diesel surpassed the biodiesel volume in Q4 2012 as PADD 3 production capacity came online, though, and has been the largest source of BBD supplied to the program ever since. Renewable diesel has comprised 17% of the U.S. BBD supply over the last decade but 63% of the BBD supplied under the LCFS over the same period.¹⁰⁵ Just over half of the total U.S. renewable diesel supply over the last decade has been supplied under the LCFS. The 1,114 million gallons of new renewable diesel production capacity that is scheduled to come online in the PADD 4 and PADD 5 regions by 2022 (see Table 1-3) is being driven by California's (and now also Oregon's) LCFS, with Phillips 66 explicitly referencing the program in the announcement of its joint venture with Ryze Renewables.⁶⁸ The new capacity will be important if California is to successfully improve its CI reduction from 2018's recorded 4.3% result to 10% in 2022, especially as the starch ethanol that has been the largest contributor by volume to date gradually loses its status as a low-carbon fuel.¹⁰³

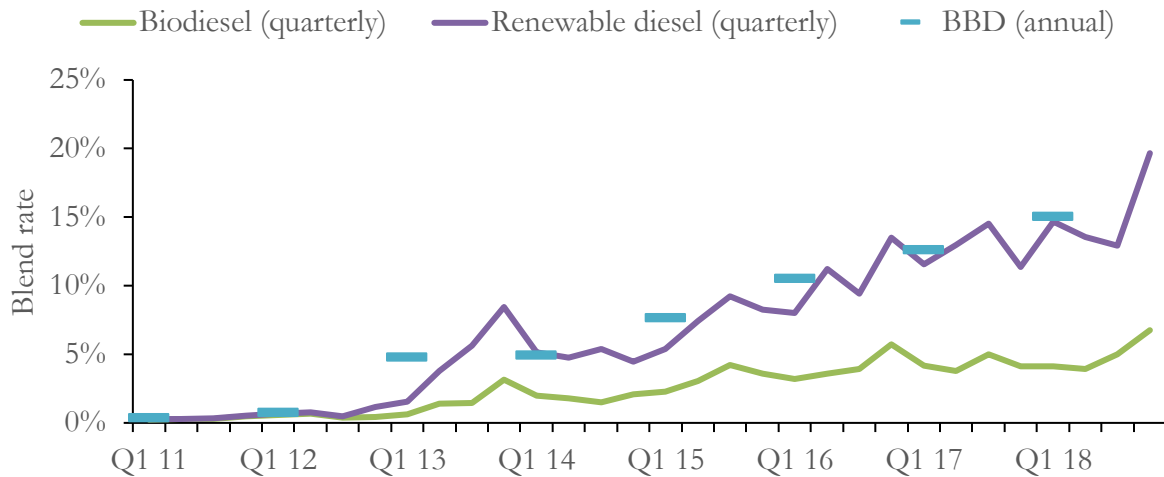


Figure 1-21. Biodiesel and renewable diesel cumulative blend rates with CARB diesel under the LCFS, 2011-2018.^{110,110}

Two distinct factors explain renewable diesel's outsized contribution to BBD supply under the LCFS. First, renewable diesel is normally more expensive to produce than biodiesel¹¹⁵ due to its hydrogen requirement and greater number of processing steps. U.S. renewable diesel production is heavily sourced from waste and residual feedstocks such as DCO, tallow, and UCO that achieve low CIs under the LCFS relative to agricultural crops.* These feedstocks allow renewable diesel to obtain a premium under the LCFS credits that offsets the additional cost of transporting the fuel from the PADD 3 region to California, which is not necessarily the case for PADD 2 biodiesel from agricultural crops with its higher CI.¹⁰⁶

Second, California has imposed two unique constraints on biodiesel within the state that it has not imposed on renewable diesel. First, it requires biodiesel blends above 5 vol% (in the summer) and 10 vol% (in the winter) to contain an approved nitrogen oxide (NO_x)-reduction additive under the Alternative Diesel Fuels (ADF) regulation. This requirement is the result of litigation that was brought in 2012 and again in 2015 by U.S. ethanol producer POET against the CARB over the potential for biodiesel blends in that range to generate increased NO_x emissions relative to California's LCFS ("CARB diesel") when used in older vehicles.¹¹⁶ The litigation resulted in an extended period of uncertainty over whether biodiesel blends above 5-10 vol% would be legally permissible under the LCFS.¹¹⁷ Not coincidentally, the volume of biodiesel supplied to California has

* This is not to say that renewable diesel has a lower CI than biodiesel when produced from the same feedstocks. Isomerization is an intensive process that reduces the yield of renewable diesel from feedstock, increasing a fully-isomerized fuel's CI relative to biodiesel as a consequence.

remained just below 5 vol% of the CARB diesel supply on an annual basis (although the biodiesel supply did increase by 8% in 2018 following the arrival of multiple NO_x-reduction additives and blends to the market).¹¹⁰ The additive requirement imposed by the ADF will remain in place for on-road diesel until at least 2023, at which time the predominance of new diesel engines equipped with advanced emissions controls is expected to result in its partial sunseting.¹¹⁸

Second, the California Water Board until recently imposed restrictive testing and monitoring requirements on biodiesel blends above 5 vol% that were stored in underground storage tanks (UST). This restriction in turn limited biodiesel's supply potential within the state due to the widespread use of USTs by California's public fuel retailers and unwillingness to trigger the additional regulations that were tied to the retail of blends above 5 vol%. A recent state regulatory action will allow biodiesel blends of up to 20 vol% to be stored in most Californian USTs in the near future, removing this historical constraint.¹¹⁹

Renewable diesel has not faced the same constraints under the LCFS as a hydrocarbon- rather than FAME-based fuel, and its supply growth rate rapidly diverged from that of biodiesel after POET filed the second NO_x lawsuit in Q4 2015 (see Figure 1-21). Indeed, the period of uncertainty over 5 vol%+ biodiesel blends may have increased demand for renewable diesel still further by prompting BBD producer Renewable Energy Group to develop and sell a blend of the two BBD fuels that achieves lower NO_x emissions than CARB diesel under the product name REG Ultra Clean Diesel.¹¹⁷ The widespread availability of mechanisms for reducing NO_x emissions from biodiesel to required levels could allow the supply growth rates for the two BBD fuels to converge again. However, the 1,114 million gallons of new renewable diesel production capacity that is expected to come online in the PADD 4 and PADD 5 regions by 2022 suggests that renewable diesel will retain its status as the primary BBD fuel supplied under the LCFS moving forward.

One consequence of the heavy use of renewable diesel under the LCFS despite California's relative lack of renewable diesel production capacity is that 84% of the BBD that was supplied to the program between 2011 and 2018 was produced outside of the state.¹⁰⁵ Californian producers were the primary source of BBD in 2011 and 2012, both years in which biodiesel was the largest form of all BBD that was supplied to the state. This changed in 2013 as large volumes of renewable diesel were moved from PADD 3 production facilities to California, though. The volumes of BBD that have been moved into the state have increased by at least 13% and as much as 70% in every year

since 2014, whereas the volume of BBD from California has remained flat since 2016. The 10-fold expansion of World Energy's Paramount renewable diesel production facility will increase the volume and potentially also the share of the LCFS's BBD supply that comes from within the state, but the new volumes that have been announced through 2022 will be insufficient to reverse the dynamic.

88% of the BBD that was produced within California under the LCFS between 2011 and 2018 was derived from waste and residue feedstocks compared to 89% of the BBD that was brought into the state. Both biodiesel and renewable diesel have been primarily derived from non-crop feedstocks, although a small amount of renewable diesel from agricultural crops was moved into the state in 2016. The main difference between the BBD fuels produced within California and outside of the state has been their form: 68% of California's BBD has been biodiesel whereas only 30% of the BBD moved into the state has been. This is the result of California having substantially more biodiesel than renewable diesel production capacity.

CARB expects BBD to continue to make an outsized contribution to the LCFS between 2019 and 2030. BBD is forecast to generate between 37% and 41% of the total credits generated by all pathways under the LCFS during those years, depending on electric vehicle adoption rates and transportation fuel demand trends.¹²⁰ BBD supply is predicted to generate a small majority of all LCFS credits between 2019 and 2022 before gradually losing share to methane and electricity, although renewable diesel and biodiesel are projected to remain a major, and possibly the largest, combined source of credits under all of CARB's 2030 scenarios. In volumetric terms CARB expects BBD supply under the LCFS to increase by between 100% and 300% through 2030 from 568.6 million gallons in 2018.¹²⁰ U.S. BBD supply would need to increase by 1,500 million gallons by 2030, or 64%, just to meet California's requirement alone under CARB's higher supply forecast. This BBD supply range is predicated in part on CARB's expectation that credit prices will average at least \$110/Mg and as much as \$165/Mg in 2030 (again depending on non-BBD factors).

State BBD Blend Mandates

Explicit BBD blending mandates are one of the most common policies used by state policymakers to incentivize BBD supply. These mandates take a broad range of forms, however, depending on

BBD availability, in-state production capacity, winter weather conditions, and other pre-conditions that state legislators have imposed. Individual state blend mandates are summarized in Appendix I.

State Supply Incentives

States also incentivize BBD supply through their ability to levy taxes on both fuel sales, in the form of excise taxes, and earnings, in the form of income taxes. Income tax credits, diesel fuel excise tax exemptions, and property tax exemptions have found widespread use at the state-level in the U.S., including by those governments that have not adopted state-level blend mandates. A smaller number of states manage loan guarantee and low-interest direct loan programs. These incentives take a variety of forms but the most common are excise tax exemptions, followed by income tax credits. Appendix I briefly reviews the supply incentives that are available in each U.S. PADD region. It should be noted that, in addition to the incentives reviewed there, many state and local jurisdictions have provided one-time incentives, usually in the form of direct loans or property tax abatements, to the BBD sector to encourage individual companies to invest in a specific location.

Loan guarantees

Loan guarantees are a financial support mechanism by which governments subsidize the interest costs of qualifying investments. The government takes on the default risk for part or all the debt incurred in support of the investment (e.g., the capital cost of a BBD production facility), resulting in a reduced interest rate on the guaranteed debt. While loan guarantees do not represent an explicit cash transfer from the government to the recipient project, the purpose of government loan guarantee programs is to support investment in alternative fuel infrastructure. The federal government provides loan guarantees through its Biorefinery Assistance Program (also known as “Section 9003”) for investments in the construction and/or retrofitting of advanced biorefineries. Ryze Renewables has utilized three federally guaranteed loans to help finance its pending renewable diesel production facilities.¹²¹ In 2011 the Diamond Green Diesel renewable diesel production facility was conditionally awarded a federal loan guarantee that it did not ultimately utilize.¹²²

A limited number of states also offer their own, smaller loan guarantee or direct low-interest loan programs that BBD projects can qualify for. Minnesota offers cost-share grants, loans, or other financial assistance for the installation of biofuel blending infrastructure in rural areas under its

Agricultural Growth, Research, and Innovation Program.¹²³ The Bank of North Dakota provides loan guarantees of up to \$8 million for the construction of BBD production facilities that utilize agriculturally-derived feedstocks.¹²⁴ North Dakota's Biofuels Partnership in Assisting Community Expansion Loan Program provides up to \$500,000 of interest buydown for BBD production facilities, including construction, expansion, and upgrade investments. Oregon's State Energy Loan Program (suspended as of April 2018) offers low-interest loans for alternative fuel investments including feedstock production, BBD production, and fueling infrastructure.¹²⁵ Virginia allows the state's Board of Education to provide loans to school boards for the installation of alternative fueling stations.¹²⁶

1.4. *Conclusions*

U.S. BBD production and supply volumes experienced rapid and sustained growth between 2009 and 2018. This growth was achieved despite a lack of sizeable U.S. biodiesel capacity increases over the same period and was made possible by the large biodiesel overcapacity that existed prior to 2009 as well as the arrival of renewable diesel capacity beginning in 2011. While renewable diesel capacity is currently substantially smaller than biodiesel capacity at the national level, the former will exceed the latter by 2022 if announced capacity additions become operational on schedule. Imports of both fuels also increased very quickly between 2013 and 2016, further contributing to U.S. supply growth, although import volumes for both fuels did peak in the latter year due to the combination of trade restrictions and policy changes.

U.S. BBD capacity and production volumes are not distributed uniformly throughout the U.S. The PADD 2 region, which encompasses the country's largest oilseed-producing states, hosts both the majority of the country's BBD production capacity (all in the form of biodiesel) and production volumes. This is followed by the PADD 3 region which, despite having less than half of the PADD 2 region's biodiesel production capacity, hosts most of the country's renewable diesel capacity and production volumes. The PADD 5 region has a small but growing amount of BBD production capacity relative to its population, but its supply has increased rapidly in recent years as PADD 2 and PADD 3 producers have shipped BBD west, and foreign producers have exported BBD to California's ports, in order to participate in that state's LCFS.

The PADD 1 region is the country's primary outlier in terms of both supply and production as its BBD capacity has declined over the last decade. This trend has left it with the country's lowest production capacity and volumes (excepting the PADD 4 region) as well as its lowest production capacity per capita (including the PADD 4 region). The PADD 1 region's lack of BBD production is especially notable given the presence of several major urban centers within its borders that could potentially serve as important sources of both UCO supply and BBD demand.

BBD supply volumes have increased in all five PADD regions since 2009. The disparity in production capacities and volumes between the different regions has resulted in a growing inter-PADD trade as producers in the PADD 2 and PADD 3 regions have shipped growing volumes for consumption in the PADD 1 and especially PADD 5 regions. Most of these inter-PADD movements are conducted via the existing rail system, although some shipments are made via water by producers with access to the Mississippi River and Gulf Coast.

Several important conclusions regarding the state of U.S. BBD can be drawn based on the data that is summarized in this section. First, U.S. BBD producers have had little difficulty meeting their feedstock requirements even as total domestic production has increased from 515.8 million gallons in 2009 to 2,183.6 million gallons in 2018. While soybean oil was responsible for approximately the same percentage of U.S. biodiesel production in 2018 as it was in 2009, DCO and UCO became important feedstock sources over the same period. The feedstock supply increased by so much that U.S. exports of important feedstocks such as soybean oil, UCO, and animal processing residues have remained flat or even increased since 2009. Likewise, U.S. BBD feedstock prices have declined in real terms by as much as 25% over the same period despite the large increase in feedstock demand by U.S. BBD producers. Feedstock supply did not prove to be the constraint from 2009 to 2018 that many forecasts had predicted it would be.

Second, U.S. biodiesel production is only now beginning to approach the volumetric limits imposed by existing production capacity. Excessive investment in capacity prior to 2009 meant that U.S. biodiesel production did not exceed a 50% utilization rate until 2013, and by 2018 it had only reached 77%. U.S. biodiesel capacity has increased by less than 17% since 2009 even as annual production volumes have increased by 260%. Enough operational and registered biodiesel capacity exists to produce an additional 400 MMGY at a 95% utilization rate, or an additional 1,565 MMGY at the same utilization rate if non-operational and/or unregistered capacity is also accounted for.

Third, U.S. renewable diesel production capacity has increased by slightly more than biodiesel production capacity in absolute terms over the last decade despite having been a pre-commercial technology in the U.S. in 2009. Unlike U.S. biodiesel capacity, renewable diesel capacity has operated near or at maximal utilization rates since 2016. U.S. renewable diesel capacity is currently undergoing another major expansion and, assuming all of the announced capacity additions become operational on schedule, overall U.S. BBD capacity will almost double between the end of 2018 and end of 2022. This development can be expected to raise new concerns about the ability of U.S. BBD producers to procure sufficient feedstock volumes to operate at high utilization rates. The arrival of this new production capacity will also increase the importance of the commercialization of new feedstock sources, such as the microalgae production route that is being developed by the JV between Exxon Mobil and Synthetic Genomics.

Fourth, the U.S. BBD supply is much more reliant on truck transport for movements from production facilities to end-users than either petrodiesel (which is mostly moved via refined products pipeline) or fuel ethanol (which is mostly moved via rail). This use of truck transport limits BBD's ability to be cost-effectively moved between PADD regions, especially from the PADD 2 region in which U.S. biodiesel production capacity is concentrated to the PADD 1 and PADD 5 population centers. The ASTM's 2015 decision to increase the maximum amount of FAME allowed in jet fuel from 5 to 50 ppm (see Section 3) has prompted the development of protocols for moving biodiesel via refined products pipelines, and small but uncertain volumes are now being moved via interstate pipelines as of May 2019. The ability of biodiesel in particular to undergo future supply growth will be contingent in part on the sector's ability to move the fuel over longer distances to undersupplied markets such as the PADD 1 region, and this will in turn depend on the sector's ability to increasingly utilize more cost-effective transport modes such as rail, water, and pipeline.

Fifth, U.S. BBD supply in the form of both domestic production and imports is very sensitive to the numerous incentives (as well as disincentives) that have been enacted at the federal, state, and local levels of government, especially given the relatively low diesel fuel prices that have prevailed since late 2014. The RFS spurred strong growth in biodiesel supply between 2010 and 2016 while California's LCFS has had a similar effect on renewable diesel supply since 2012. Changes under the Trump administration to the EPA's allocation of SREs under the RFS has likely hindered BBD supply growth, on the other hand, and in the case of biodiesel even reversed it when combined with

the effect of countervailing duties that have been imposed on biodiesel imports from Argentina and Indonesia.

Sixth, imports of BBD have grown alongside domestic BBD production over the last decade. 34% of U.S. biodiesel supply in 2016 was from imports and, while that ratio fell to less than 10% by 2018, almost one of every five biodiesel gallons of the last decade's U.S. biodiesel supply has been produced abroad. Almost 50% of U.S. renewable diesel supply in 2016 was from imports and 43% of the last decade's U.S. renewable diesel supply has originated with foreign producers. Unlike the European Union, which has heavily utilized biodiesel derived from palm oil, relatively little palm oil is used to produce the BBD that is supplied within the U.S. due to restrictions on the feedstock under the RFS and LCFS.

Seventh, the LCFS has been very effective in incentivizing the supply of BBD produced from waste and residue feedstocks to California, as reflected by the low percentage of BBD produced from agricultural crops in the state relative to the overall U.S. The state program has achieved this by linking the specific value of the incentive that BBD is supplied to the state directly to its CI. This differs substantially from the RFS, which only requires BBD to achieve a specific carbon intensity reduction threshold in order to qualify for the federal program's incentive. It is not immediately clear, however, whether the LCFS has successfully increased the overall production of BBD from non-agricultural crop feedstocks, or if it has instead just successfully incentivized the movement of BBD with low CIs to California from other states and countries.

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SECTION 2.

Overview of U.S. Biomass-Based Diesel Distribution, Blending, and Demand



Section 2. Overview of U.S. biomass-based diesel distribution, blending, and demand

U.S. BBD demand is closely linked to BBD supply due to the retail price competitiveness of BBD blends with pure petrodiesel (see Section 4). Most of the country's BBD supply participates in blending mandates, further strengthening the connection between supply and demand volumes. That is not to say that BBD demand is homogenous throughout the U.S., however. Differences in production capacity, transport infrastructure, and petrodiesel consumption volumes and sources of sector-specific demand all contribute to large differences in BBD consumption volumes and market shares between the five PADD regions. Furthermore, demand incentives (as distinct from supply incentives) and consumption mandates vary from state to state, further contributing to inter-PADD differences. Section 2.1 covers the ways in which BBD is distributed to end-users following transportation from the BBD producer. Section 2.2 provides an overview of BBD blending rates and consumption volumes at the national level. It also discusses seasonal factors affecting both blending and consumption and the impact of policies such as the RFS and blenders' tax credit. Section 2.3 identifies BBD blending rates and consumption volumes in each PADD region and discusses the impacts of regional factors such as weather, infrastructure, and the LCFS. Section 2.4 reviews regional policy factors that directly incentivize BBD demand, including government fleet mandates.

2.1. *BBD distribution*

A lack of BBD movement through refined products pipelines means that BBD fuels, like ethanol, are commonly blended with refined fuels for consumption by terminals, tanker trucks, and even retail stations rather than at refineries. BBD is transported to end-users via multiple distribution channels that vary by region. According to the results of a survey conducted by the NBB in 2016,¹ approximately 41% of U.S. BBD is sold to “fuel jobbers” that are then responsible for moving the biofuel, either as pure BBD or a blend with petrodiesel, to retail stations. 30% is sold directly to retailers, especially those that are in close proximity to the BBD production facilities. The rest is either sold by BBD producers directly to terminals (15%) or to third-party resellers such as brokers or marketers (14%).

In the case of smaller BBD production facilities, especially those that are located near urban areas, BBD is often transported directly to retail stations by truck. Jobbers are independent operators that fill their tanker trucks with petrodiesel and biodiesel sourced from different locations to achieve a desired blend ratio (known as “splash” blending). The truck might be mostly filled with petrodiesel from a refined products terminal and then topped up with biodiesel from a BBD producer, for example. The volumes of each fuel that are added determine the blend rate of the resulting blended fuel. The two fuels then blend into a relatively homogenous mixture (although results vary) via natural agitation as the truck drives to make its deliveries to the retail stations on its route. Jobbers range in size from small, single-truck operations to large entities with multiple trucks and centralized fuel storage facilities. They were the predominant means of moving BBD to customers when BBD production capacity was limited due to a lack of blending and distribution infrastructure. While fuel jobbers have seen their market share erode as bulk terminal operators and refiners have increased their blending volumes (see Section 2.3), they continue to play an important distribution role today in many PADD regions.

Retail stations sometimes conduct their own biodiesel blending operations, and large retail chains such as Casey’s General Stores and Murphy USA have generated substantial income in the past via the sale of Renewable Identification Numbers (RIN) that their blending operations generate under the U.S. Renewable Fuel Standard (RFS). These retailers either operate their own fuel terminals or have extra storage tanks at retail locations for taking deliveries of pure biodiesel that is then blended with petrodiesel to a desired ratio onsite. Retailers’ blending operations can be quite large: a recent report lists the Love’s retail chain as operating a blending and distribution network that consists of 500 tanker trucks, 32 terminals with onsite storage capacity, and 300 rail cars.¹ Some retailers have developed sufficiently-large blending and distribution operations that enable them to purchase BBD directly from BBD producers, eliminating the need for terminal operators and jobbers (and maximizing their generation of RINs in the process). Similarly, some BBD producers now operate their own terminalling operations. Renewable Energy Group, for example, offers BBD in both pure and blended forms at 31 terminals that it operates in 11 different states.² (It also operates another 18 refined products terminals from which its BBD could be offered in the future.)

Fuel terminals are more likely to be utilized by BBD that has been produced at one of the larger BBD facilities with access to multimodal transportation systems. Sufficient BBD supply is an important prerequisite for terminal use given the costs of modifying existing terminals to be capable

of handling pure biodiesel.³ Terminals can operate as either fuel resellers, purchasing BBD from a producer and then selling it after blending to a distributor or retailer, or service providers, performing blending for a distributor or retailer but never taking legal possession of the BBD. Terminals provide two major advantages over fuel jobbers as a distribution channel, the most important of which is a well-established infrastructure that is co-located with the country's major areas of fuel demand. Terminals have long served as an important transshipment connection between the pipelines, railcars, and ships that refineries send their refined products through to the distribution network that supplies these products to a varied group of customers. The fact that terminals already exist in large numbers to supply the U.S. economy with refined fuels gives them the capability to include BBD among their offerings. Some modifications can be necessary, depending on the terminal's geographic location and BBD blend rate (see Section 3), but these modifications are much less expensive than new standalone construction. Existing terminals are also located near current demand centers, ensuring that any BBD sold from them quickly enters existing distribution networks. Of 453 U.S. cities that hosted refined products terminals in 2016, 81% had access to terminals providing biodiesel or biodiesel blends and 57% had access to terminals providing both biodiesel and petrodiesel.¹ The PADD 4 region was the only PADD region that hosted fewer than 10 biodiesel terminals in 2016 while Wyoming and Montana were the only states that lacked biodiesel terminals in that year.

A second major advantage of terminals is their employment of blending mechanisms that provide superior control and improved homogenization* relative to splash blending. Terminals operate one of two different types of blending infrastructure. Manifold blending systems perform the blending process at the front of the terminal by directly blending BBD with petrodiesel coming off of a pipeline as the former enters the terminal. Manifold blending's simplicity limits its capital costs (\$1/gallon of monthly biodiesel blending capacity was reported for California in 2013)³ but also constrains the terminal operator's (or BBD blend purchaser's) ability to offer multiple blends (for example, 0 vol% versus 5 vol% versus 20 vol%). Manifold blending systems are more attractive in states such as Minnesota that mandate minimum BBD blend rates in all petrodiesel consumption but less attractive in states such as Iowa that consume biodiesel at a variety of blend rates.

* Homogenization is important as the supply of higher biodiesel blends such as 20 vol% becomes more widespread. Incomplete blending can cause some gallons in a load of blended biodiesel with an average 20 vol% blend rate to be above (and others below) that average, potentially causing problems in engines that are only warranted for use with blends of up to 20 vol%.

Rack blending uses an in-line fuel blending system to move a specified BBD blend directly from the terminal to the truck, thereby eliminating the need for the truck to be filled by separate fuel streams at two different loading points. The BBD is commonly pulled from an onsite storage tank that may need to be heated and/or insulated, depending on where the terminal is located and if biodiesel is the form of BBD. This use of separate streams allows for desired blend rates to be selected by the terminal operator or the blended biodiesel purchaser and is an advantage in markets that supply fleets with BBD consumption mandates.³ The increased flexibility incurs higher capital costs due to the need for separate BBD and petrodiesel storage systems onsite, however, and it is not necessary in all BBD markets.

A third blending option has been underutilized to date due to technical constraints, although these have been mitigated in recent years (see Section 3). Terminals, jobbers, and retailers all conduct blending operations because BBD, especially biodiesel, is not normally blended onsite at refineries. The blending of biodiesel at refineries offers advantages such as access to a more extensive distribution system and reduced fuel movement costs (see Section 1). BBD that is blended at a refinery then utilizes the existing refined products pipeline infrastructure, providing increased market scope while limiting the need for downstream infrastructure modifications for the handling of pure biodiesel. Onsite refinery blending resembles rack blending in that the refiner, rather than the customer, determines which blend rate is utilized. Additionally, onsite refinery blending is not necessarily a feasible option in states, particularly many of those in the PADD 2 region such as Iowa, that have large BBD production volumes but no refineries.

Regardless of how BBD is blended with petrodiesel, the resulting blend is taken to retail stations by truck. Fuel jobbers and terminals both enable BBD producers to quickly move their product offsite as it is produced, eliminating the need for expensive storage capacity. Some BBD producers, particularly those with large production facilities that are located near major transportation infrastructure and/or customers, have opted to invest in this storage capacity so as to retain control of the distribution channel and its margins. The specific distribution channel that is used to get BBD from the producer to the end-user is ultimately dependent on factors such as the type of BBD transportation infrastructure that exists near the BBD producer, the size of the BBD producer, and the existence of blending infrastructure nearby. The variability of these factors has caused substantially different blending patterns to arise across the U.S. PADD regions (see Section 2.3).

2.2. U.S. demand

Few states collect data on BBD consumption within their borders.* The EIA therefore calculates BBD consumption volumes as the sum of outbound domestic shipments, exports, and increases to stocks subtracted from the sum of BBD production, domestic receipts, and imports.⁴ These individual datasets are available at the national and PADD levels, permitting consumption to be calculated at the same levels. The EIA also separately publishes sales volumes for pure and blended biodiesel at the national (but not PADD) level,⁵ and the combined volumes are strongly correlated (but not identical) to the EIA's national consumption calculations (see Figure 2-1).†

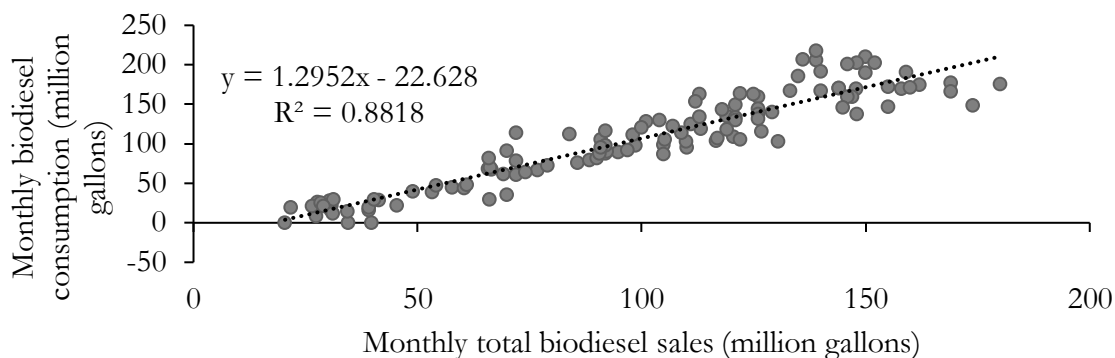


Figure 2-1. Linear correlation between monthly U.S. biodiesel sales and consumption volumes, 2009-2018. R^2 value denotes correlation strength (1.0 = perfect correlation).^{4,5}

U.S. monthly biodiesel sales volumes have historically trended on a seasonal basis, bottoming in January and peaking during the summer months.⁵ This pattern reflects two factors, the first being that sales of ultra-low sulfur petrodiesel (ULSD) are lowest during the winter, when the weather hinders transportation and other sectors such as construction that utilize heavy-duty vehicles (HDV), and highest in the late summer.⁶ Likewise, the prices of both petrodiesel and biodiesel have historically been at their lowest in the winter and highest during the summer, ensuring that the supply volumes of both fuels increase along with temperatures.⁷ It is typical for both petroleum

* A notable exception is California, which collects comprehensive BBD consumption data as part of its LCFS monitoring and enforcement mechanisms. Iowa also collects data on biodiesel blend sales from fuel retailers.

† Differences between the sales and consumption numbers are attributable to the use of different methodologies to calculate each result. The sales volumes are calculated via responses to the Form EIA-22M Monthly Biodiesel Production Survey by registered biodiesel producers. The consumption numbers are based on responses to additional surveys by refiners, exporters, and importers. The sales volumes therefore more accurately reflect sales of domestic biodiesel while the consumption volumes reflect demand for biodiesel from all sources.

refineries and biodiesel production facilities to schedule planned downtime for the beginning of the year as a result.

The second factor is biodiesel's poor cold-weather performance relative to ULSD (see Section 3), which limits its use in northern climates during the winter months. This is illustrated by the greater seasonal swings for biodiesel sales from winter to summer compared to those of ULSD: whereas monthly ULSD sales volumes increase by 10-15% on average from trough to peak in a year, those of biodiesel increase by an average of up to 60% average in years in which the biomass-based diesel blenders' tax credit (BTC) does not expire and more than 100% in years in which it does.^{5,6} The uncertain nature of the BTC, which Congress has allowed to expire in six of the last 10 years, has had a major impact on monthly biodiesel sales variation. Past expirations of the tax credit have occurred on December 31 and BBD blenders have increased late-year blending and subsequently sales in those years in which an expiration was scheduled to occur (see Figure 2-2). In 2013 and 2014, for example, the biodiesel sales volume for December was 122% higher than that of the previous January, as well as more than 10% higher than that of the next highest month, as the biodiesel sector attempted to blend as many gallons as possible with petrodiesel in order to maximize the number of tax credits earned prior to the expiration date.⁵

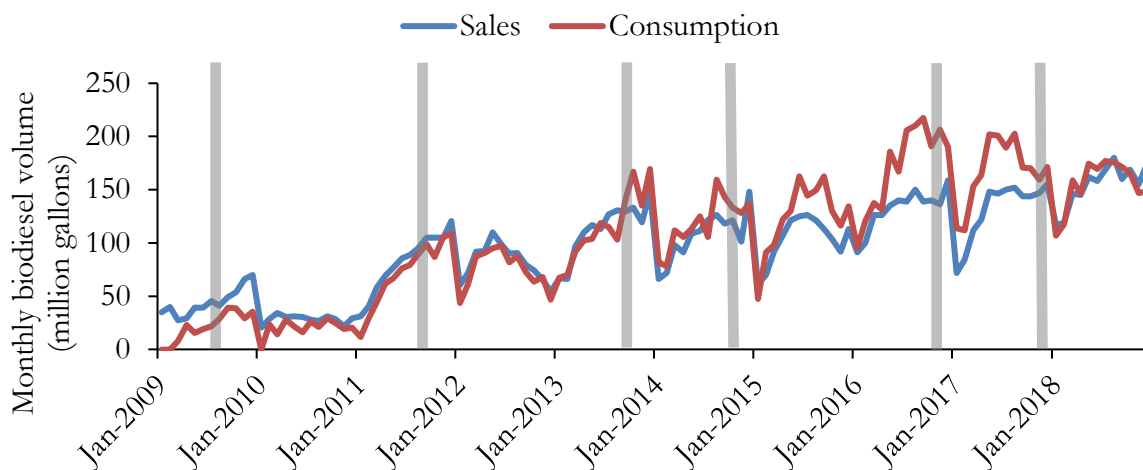


Figure 2-2. Monthly U.S. biodiesel sales and consumption volumes, 2009-2018. Shaded periods represent years in which Congress allowed the biodiesel tax credit to expire.^{4,5,8}

The effect of seasonality on the consumption of biodiesel from foreign producers has also been very strong; net import volumes, as reflected by the difference between the consumption and sales volumes in Figure 2-2, are very low in the early months of the year and usually at their highest levels

during the summer months. The effect of BTC expiration years, on the other hand, is not quite as pronounced, and the largest monthly volumes of the year have only been recorded in December twice over the last decade: 2011 and 2013. That said, the December consumption volume did increase from the prior month's volume in two of the least three expiration years (2014 and 2017), showing that the BTC has continued to affect consumption volumes even if the impact of its expiration on net import volumes has weakened in recent years.

BBD benefits from the fact that diesel fuel demand is substantially less elastic than other sources of energy such as gasoline and even electricity over both short- and long-term periods.⁹ This inelasticity of diesel fuel demand reflects the difficulties inherent in displacing and reducing its consumption. Whereas multiple substitutes exist for fuels such as gasoline (improved fuel economy, ethanol, electricity) and heating oil (improved energy efficiency, natural gas, electricity), BBD is the primary alternative to diesel fuel consumption, as demonstrated by its major contribution to pathway-neutral alternative fuels mandates such as California's LCFS (see Section 1). The literature on BBD demand elasticity, while limited, identifies two ways in which the inelasticity of diesel fuel demand directly affects BBD demand.¹⁰ First, BBD demand is elastic in the absence of a mandate and quickly increases when diesel is the more expensive fueling option due to a lack of other substitutes; U.S. BBD consumption increased by almost 900% as the wholesale price of No. 2 diesel fuel increased by 70% between 2004 and 2006, for example.^{4,11} Second, BBD demand is inelastic under government policies requiring reduced petrodiesel consumption, including those such as the LCFS that utilize a pathway-neutral mechanism, in that such mandates increase BBD demand even when BBD is more expensive than petrodiesel on an unsubsidized basis due to the same lack of other alternatives.

Most U.S. petrodiesel consumption is incurred by the on-road transportation sector, followed by the farming and rail sectors (see Figure 2-3). The country's total distillate fuel oil consumption, which includes both diesel fuel and heating oil, increased by 8% between 2009 and 2017 to 60,281 million gallons. Data on BBD sales by sector is not available due to differences between the two survey forms that the EIA uses to calculate petrodiesel and biodiesel sales volumes.* It is possible to deduce the volumes of biodiesel that are consumed by the different sectors, however, due to restrictions

* Distillate fuel oil sales volumes are reported by fuel oil dealers on Form EIA-821 Annual Fuel Oil and Kerosene Sales Report, which collects data on the end-use of the fuel sold. Biodiesel sales volumes are reported on Form EIA-22M Monthly Biodiesel Production Survey which, because it is completed by fuel producers rather than dealers, does not collect end-use data.

imposed by both the equipment employed by individual sectors and the federal and state policies under which most U.S. biodiesel is consumed. It is more difficult to estimate how much renewable diesel is used by each sector, if only because the fuel does not face the same equipment restrictions as biodiesel and can therefore be used in a greater number of applications.

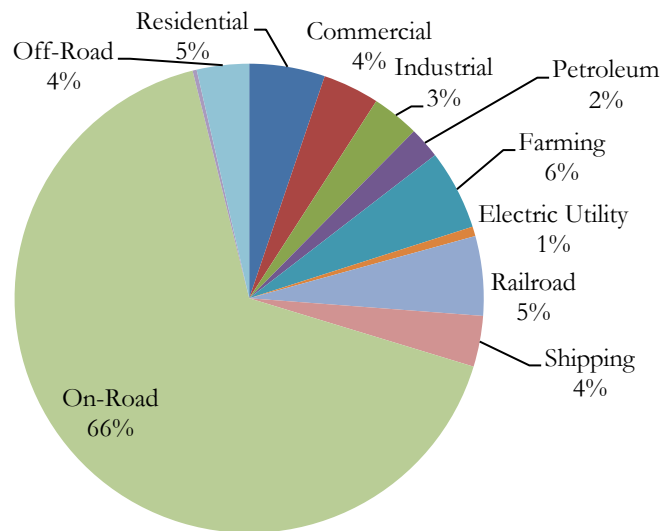


Figure 2-3. U.S. distillate fuel oil (excluding kerosene) consumption by sector in 2017. Percentages are rounded to nearest whole digit.^{12,13}

Almost all the biodiesel that is produced in or imported to the U.S. contributes to the RFS, as evidenced by the fact that the biodiesel consumption volumes that are published by the EPA regularly exceed the EIA's own published biodiesel consumption volumes.^{4,14*} The RFS in turn requires that the U.S. transportation fuel supply contains the mandated volumes of biofuels in each year of the program. The transportation fuel supply in turn includes only gasoline and diesel fuel, the latter of which covers motor vehicle (on-road), non-road (off-road), locomotive, and marine (MVNRLM) diesel fuels;¹⁵ while biodiesel that is blended with heating oil or marine bunker fuel (distinct from marine diesel fuel) can generate RINs under the mandate, for example, those two distillate fuels are not required to contain BBD. Likewise, diesel fuels used in stationary engines are not required to contain biodiesel in most circumstances. This excludes much of the residential,

* The volumes published by the EPA are based on RIN generation data rather than fuel producer and importer surveys. This RIN generation data, while comprehensive, includes RINs that have been generated by biodiesel gallons that are ultimately exported, RINs that have been generated by foreign generators on gallons that are not actually exported to the U.S., and RINs that have been erroneously generated. Unfortunately the database does not make clear how these RIN generation issues individually affect the EPA's published biodiesel volumes, resulting in EPA data that shows 1,187 million more gallons of biodiesel consumption since 2010 than is reported by the EIA for the same period.

commercial, industrial, petroleum, electric utility, and shipping sectors from having to blend BBD under the RFS (although the blending of biodiesel with heating oil is required at small blend rates by the governments of a handful of Northeastern U.S. states, as discussed in Section 1.3).

The on-road sector is almost certainly the largest source of BBD demand in the U.S. due to its large share of the total diesel fuel market and the compatibility of BBD with on-road diesel engines in use in the U.S. All known original equipment manufacturers (OEM) currently allow the use of blends of up to 5 vol% of biodiesel that meets the ASTM D6751 specification.¹⁶ 78% of new diesel engines have been further cleared under OEM warranties for use with biodiesel blends of up to 20 vol%, including 90% of the medium- and heavy-duty OEMs that are responsible for 92% of on-road diesel fuel consumption.^{17,18} The number of OEM warranties that cover blends of up to 20 vol% is steadily increasing over time as well since those that do not are generally for engines manufactured before 2009, and these are being retired from use due to age and stricter subsequent U.S. emissions standards. This widespread coverage by OEM warranties has led the EPA to conclude that “the ability of vehicles to consume biodiesel and renewable diesel is highly unlikely to constrain the use of these fuels” based on an assumed BBD consumption volume of 2,800 million gallons in 2019.^{19,20}

The EPA further estimates that diesel fuel used for transportation purposes contains almost 5 vol% BBD “on average.”²⁰ On-road diesel fuel consumption in 2017 (the most recent available year) was 41,405 million gallons and total diesel fuel consumption within the MVNRLM sectors was 49,759 million gallons.^{12*} A 5 vol% average BBD blend in the on-road, off-road, farm, and rail sectors is equal to 2,488 million gallons of BBD consumption. For comparison, the EIA’s calculated BBD consumption volume for 2017 is 2,479 million gallons.

In reality, it is unlikely that consumption is evenly distributed across the MVNRLM sectors due to differences in the equipment and infrastructure employed. On-road vehicle engines have an average age of eight years (light-duty vehicles are slightly older and heavy-duty vehicles are slightly younger)²¹ and are mostly compatible with biodiesel blends of up to 20 vol% as a result. Higher blends (10-20 vol%) in the U.S. are commonly located along long-haul truck routes, especially along the interstate highway system.¹ The on-road sector’s share of total diesel fuel sales has risen from 61% in 2009 to 69% in 2017,¹² giving BBD dealers and retailers an additional reason to emphasize sales to that

* This section reports MVNRLM diesel fuel consumption volumes to permit comparisons with the mandated BBD blending volumes under the RFS.

sector given the need for biodiesel distribution infrastructure up to the blending point.* Total biodiesel consumption accounted for 4.9 vol% of on-road diesel fuel consumption in 2017 and an estimated 4.3 vol% of 2018's consumption (assuming that on-road diesel fuel consumption increased in proportion to total diesel fuel consumption in the latter year).²² Whether the average biodiesel blend percentage increases by 2021 will largely depend on the status of imports from Argentina and Indonesia. Most of the new BBD capacity that is scheduled to come online by 2021 will produce renewable diesel. Furthermore, the EIA expects diesel fuel consumption to increase by 1.3% between 2018 and 2020, which will cause the average biodiesel blend to decline unless U.S. biodiesel consumption increases by a larger percentage over the same period.²²

Renewable diesel does not face the same equipment limitations as biodiesel given that it is a hydrocarbon fuel. It is therefore feasible that renewable diesel consumption is spread across diesel fuel-consuming sectors in the same proportion as overall diesel fuel consumption. Unfortunately, data is not available on the volumes of renewable diesel that are distributed to fuel suppliers and retailers by the different available means (e.g., pipeline blending, terminal blending, retail blending, or consumption at 100 vol% renewable diesel). While this lack of data further complicates efforts to determine the role that the fuel plays in each sector, the inclusion of the on-road, off-road, locomotive, and marine diesel fuel sectors within the RFS mandate makes it likely that renewable diesel contributes to one or more of them. As with biodiesel, virtually all renewable diesel consumption in the U.S. occurs under the RFS. California's LCFS, under which 80% and 85% of U.S. renewable diesel fuel consumption in 2017 and 2018 occurred, respectively, is still more narrowly drawn than the RFS in that it primarily covers motor vehicles and certain categories of rail and marine diesel fuel engines.²³ Based on the definitions employed by these two programs, then, it can be assumed that U.S. renewable diesel consumption is concentrated in the transportation sector, with on-road engines being responsible for the majority of those volumes.

U.S. BBD consumption on average reached a high of 5 vol% of MVNRLM diesel fuel consumption in 2016 before declining to 4.8 vol% in 2017 (see Figure 2-4, which presents the numbers as average blend rates). Biodiesel's and renewable diesel's highest blend rates on average were 4 vol% and 1 vol%, respectively (biodiesel in 2016 and renewable diesel in 2017). These average blend rates are lower still relative to all U.S. distillate fuel oil consumption, with highs of 4.1 vol%, 3.4 vol%, and

* The movement of large volumes of biodiesel through refined fuels pipelines would potentially shift this dynamic by enabling biodiesel to be distributed through refinery's downstream supply chains, in which case biodiesel blends would be more uniformly divided across diesel fuel-consuming sectors.

0.8 vol% in 2016 for BBD consumption, biodiesel consumption, and renewable diesel consumption, respectively. Viewed from a different perspective, U.S. biodiesel consumption could increase by 7,200 million gallons relative to its 2017 volume, assuming maximum blend rates of 20 vol% in the on-road sector and 5 vol% in all other distillate fuel oil-consuming sectors,* before reaching blending constraints in existing diesel fuel engines. Renewable diesel consumption could increase by 59,830 million gallons relative to its 2017 volume before reaching its own blending constraint, assuming maximum blend rates of 100 vol% in all distillate fuel oil-consuming sectors.

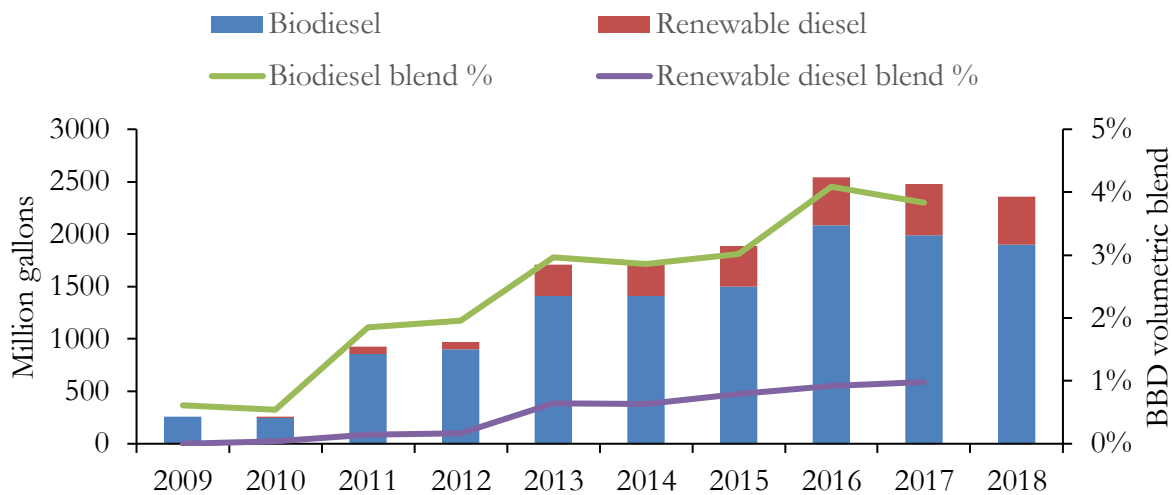


Figure 2-4. U.S. annual BBD consumption volumes (2009-2018) and average blend rates as percentage of MVNRLM diesel fuel consumption (2009-2017).^{5,12}

The blending of BBD with petrodiesel is generally performed by one of three different entities. Historically the smallest volume has been blended directly by refiners with petrodiesel as the latter moves from the refinery to the wholesale terminal (see Figure 2-5). This was very rarely done prior to 2012, and refiner blending accounted for only 1% and 3% of U.S. BBD consumption in 2009 and 2010, respectively.^{24,25} Refiners had little incentive to blend BBD prior to the implementation of the RFS and, even after the volumetric mandate became binding, the small volumes involved meant that many refiners opted to instead purchase the necessary D4 RINs. Refiners' blending volumes increased sharply in 2013 as D4 and D5 RIN prices tripled between early January and late July, however, and the share of BBD consumption blended by refiners increased from 8% in 2012 to

* The definition of distillate fuel oil that is used in this section includes both motor vehicles and stationary engines but excludes the aviation sector.

10% in 2013 and 17% in 2014. Refiner blending has accounted for 12% of BBD consumption over the last five years.

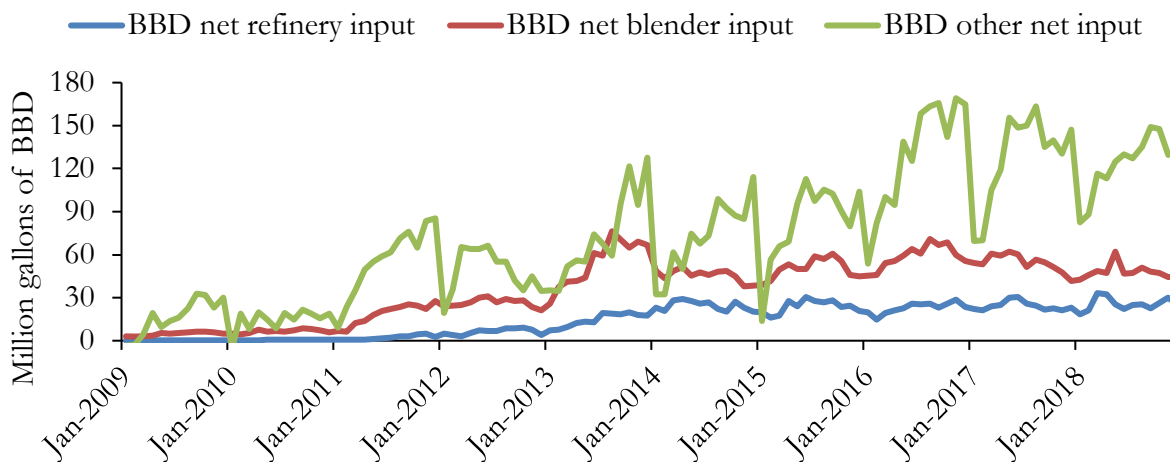


Figure 2-5. U.S. net BBD inputs by blender category, 2009-2018.^{24,25}

The average monthly BBD blend rates by refiners* varies widely by PADD region (see Figure 2-6). The effect of the historical pipeline movement constraint is evident from the fact that U.S. refiners have achieved a maximum average BBD blend rate of only 0.5 vol% (in March 2018) on a monthly, let alone annual, basis.^{25,26} While this blend rate has increased by a factor of 10 since 2011, it remains equally distant from the 5 vol% blend that can still be marketed as pure petrodiesel under the ASTM D975 specification and Federal Trade Commission labeling requirements (see Section 3). It should not be assumed that even these volumes of blended biodiesel were moved by refiners through pipelines with the rest of their refined products; rather, the relatively low blend rate instead reflects those refiners that own truck racks and other types of terminalling infrastructure that are co-located with their refineries.

* The EIA does not report distillate fuel oil volumes for bulk terminal operators and so it is not possible to calculate average monthly BBD blend rates for the EIA's "blenders" category.

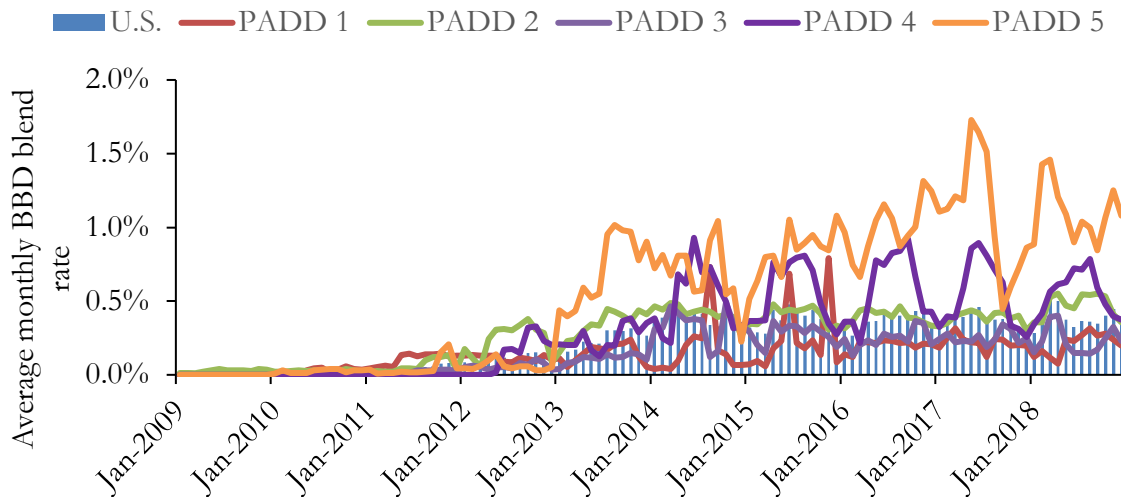


Figure 2-6. Average monthly BBD blend rates by refineries in the U.S. and PADD regions, 2009-2018.^{25,26}

Three interesting conclusions are reached from the refineries' average BBD blend rates. First, some regions, such as the PADD 4 region, have exhibited strong seasonal blending trends in which the summer blend rates are much higher than the winter blend rates. Other regions, such as the PADD 2 and PADD 3 regions, have instead exhibited substantially less seasonal variability. It is possible that this is due to only a small number of refineries being responsible for most of the blending volumes in the PADD 4 region given that blends of <1 vol% are largely immune from the effects of temperature on cloud points (see Section 3). Second, refineries in the PADD 4 and especially PADD 5 regions have had the highest historical blend rates, with the PADD 5 refineries achieving an average monthly high of 1.7 vol% in June 2017. The effect of California's LCFS is evident in the blend rates, with the PADD 4 region's above-average blend rate despite its lack of BBD production (see Section 1) likely being due to the region's proximity to California. Third, the average annual U.S. refinery blend rate increased by 150% from 2012 to 2013, suggesting that refineries responded to that year's rapid RIN price increase by turning increasingly to BBD blending as a means of obtaining RINs (U.S. BBD consumption increased by 77% over the same period).⁴

The second largest source of U.S. BBD blending is by bulk terminal operators. These blenders are defined by the EIA as facilities that lack refining capacity but possess blending equipment.²⁷ Blending by these entities accounted for 22% and 30% of BBD blending volumes in 2009 and 2010, respectively. This share reached 33% by 2012 as the RFS's BBD mandate was implemented. Another contributing factor during this time was a trend by refining companies to spin off their

downstream logistics assets, including fuel wholesale and retail operations with BBD blending capabilities, as semi-independent and publicly-traded master limited partnerships (MLP).^{*} Bulk terminal operators' share of BBD consumption peaked jumped to 39% in 2013 as D4, D5, and D6 RIN prices all rallied strongly. It has since declined but has still accounted for 29% of the total over the last decade.^{24,25}

The EIA's BBD blending data only reports volumes from refiners and blenders (the latter being bulk terminal operators). The difference between these combined volumes and the EIA's BBD consumption volumes for the same time periods reflects BBD's relatively recent arrival to the transportation sector and lack of downstream infrastructure compared to petrodiesel and, to a lesser extent, fuel ethanol. The remaining share of the consumption volume can be attributed to fuel jobbers, as the independent wholesale distributors who blend smaller volumes of BBD with petrodiesel are known. Traditionally fuel jobbers have accomplished this via splash blending. As BBD consumption has grown some fuel jobbers have increased their blending capabilities via the purchase of fixed blending infrastructure, although this only shows up in the EIA's blending data if the infrastructure has at least 50,000 barrels (2.1 million gallons) of storage capacity.²⁸ The 76% of BBD consumption in 2009 that was not blended by refiners and bulk terminal operators can be assumed to have been mostly blended by jobbers (as well as retailers with onsite blending capabilities) instead.^{24,25†} That share fell to 46% in 2013 as high RIN prices prompted increased investment in fixed blending infrastructure.²⁹ It subsequently rebounded to 59% in 2018 due to low RIN prices in the preceding years and the commencement of blending operations by some fuel retailers. The volume of BBD consumption that has not been blended by refiners and bulk terminal operators stands at 55% over the last decade.

As with BBD consumption, monthly BBD blending volumes by refiners and bulk terminal operators are lowest in the winter and highest in the summer (see Figure 2-7). On average over the last decade they have increased by 77% between January and September^{24,25} as blenders have responded to the combination of increased BBD availability from producers and increased demand from consumers for petrodiesel during the summer. Blending volumes have also resembled consumption volumes in terms of the impact that the expiration of the BTC has had on late-year volumes. In those years in

^{*} These spin-offs raised cash for the parent, or "sponsor", refining companies but also left many of them with insufficient biofuel blending capacity to meet their annual blending requirements as obligated blenders under the RFS.

[†] This assumption is based on conversations with various industry participants as well as the literature.^{Error! Bookmark not defined.}

which the tax credit either did not expire or was not about to expire before last-minute action by Congress, average blending volumes in November and December were 24% and 8% higher, respectively, than in January. In those years in which the tax credit either did expire or was almost allowed to expire, on the other hand, the average November and December blending volumes were 89% and 86% higher, respectively, than in January. This trend in favor of increased late year blending in expiration years is not surprising given that the BTC was earned via blending rather than production activities.

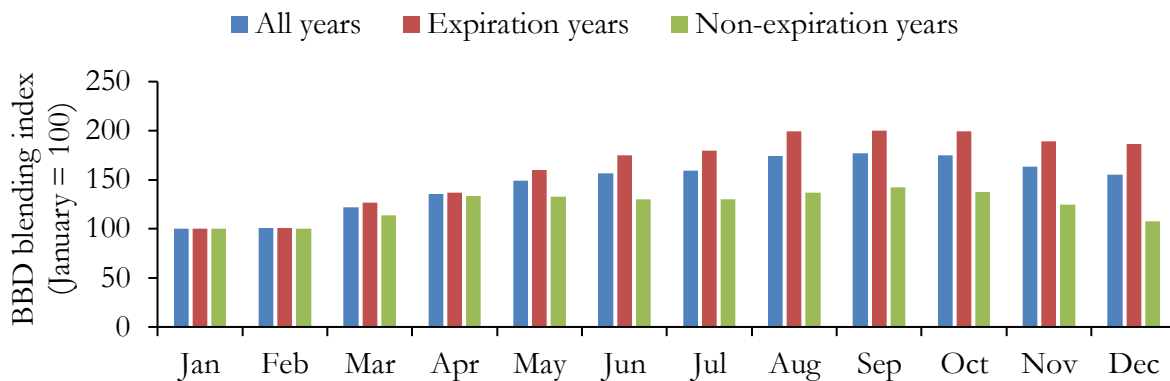


Figure 2-7. Index of monthly U.S. BBD blending volumes by refiners and bulk terminal operators, 2009-2018. Figures shows average index values for all years, those years in which the BTC expired or almost expired, and those years in which the BTC did not expire.^{24,25}

2013 was an especially abnormal year in terms of monthly U.S. blending volumes. The June and August volumes for that year were 123% and 189% higher, respectively, than in the prior January (see Figure 2-8). Equally notable was the fact that the December blending volume was 155% higher than in the prior January. While the tax credit did expire at the end of 2013, the comparative average December volume across expiration years other than 2013 was only 25% higher than the average January volume for the same years. Blending volumes by refiners and bulk terminal operators remained high in 2013 relative to other years even after D4 RIN prices declined from their July 2013 peak.

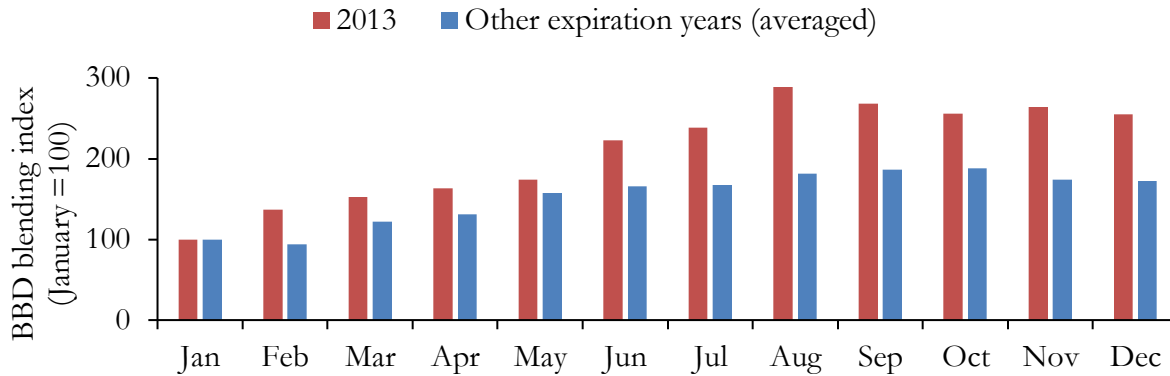


Figure 2-8. Index of monthly U.S. BBD blending volumes by refiners and bulk terminal operators, 2013 compared to average of other years in which the BTC either expired or almost expired.^{24,25}

A similar situation occurred in 2015, which was a year in which the tax credit did not expire. The monthly D4 RIN price increased by 62% from December 2014 to January 2015 and maintained its strength until October 2015.³⁰ Blending volumes by refiners and bulk terminal operators in the late spring and summer months were substantially higher than in the other years in which the tax credit did not expire: the volume in July 2015 was 48% higher than in January 2015, compared to an average increase of 30% across all other years in which the BTC did not expire or come close to expiring (see Figure 2-9).

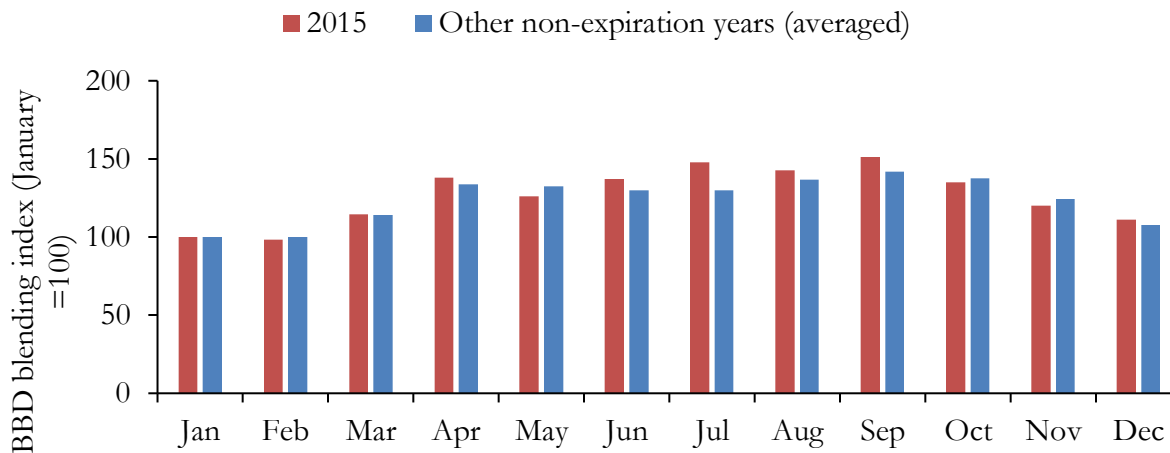


Figure 2-9. Index of monthly U.S. BBD blending volumes by refiners and bulk terminal operators, 2015 compared to average of other years in which the BTC did not expire.^{24,25}

The final example is from 2018, a year in which the D4 RIN price fell by almost 50% over the course of the year.³⁰ Monthly BBD blending by refiners and bulk terminal operators was high

relative to other years in which the BTC did not expire but fell short of those other years during the high-demand summer months (see Figure 2-10). The blending volumes for June and September 2018 were 12% and 16% higher than in January 2018, compared to average increases from January of 36% and 51% for those same months in all other non-expiration years. The imposition of trade restrictions on biodiesel supplied from Argentina and Indonesia also played a role in 2018's comparative lack of seasonal blending growth, although this would have been offset by other sources but for 2018's low RIN prices (themselves a result of the weakening of the RFS mandate via increased small refinery exemption allocations).

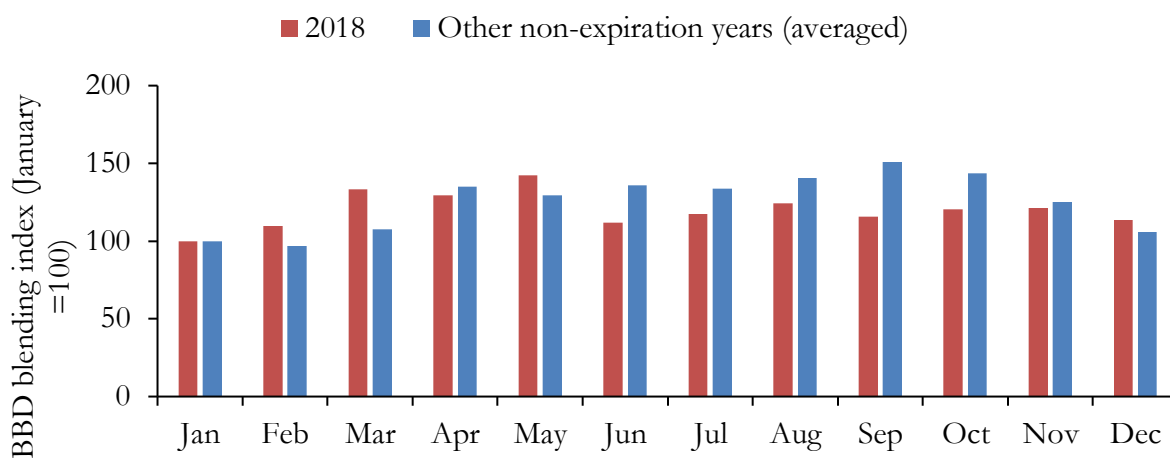


Figure 2-10. Index of monthly U.S. BBD blending volumes by refiners and bulk terminal operators, 2018 compared to average of other years in which the BTC did not expire.^{24,25}

A recent USDA-funded report by Cornell University researchers found that RIN prices affect BBD blending volumes due to the nested nature of the RFS and the presence of the 10 vol% ethanol blend wall.³¹ These two factors have caused BBD to be used to meet the mandated renewable fuel blending volumes in excess of the blend wall, and higher RIN prices have at times been necessary to incentivize sufficient supplies for this purpose. An earlier study examined the impact of three RFS “policy shocks” that occurred in 2013 on renewable fuels. The study determined that these shocks, which prompted the D4 RIN price to decline by more than 70% between August and December 2013, had a disproportionately adverse impact on BBD blending volumes.³²

Testimony to the U.S. Congress by a researcher at Iowa State University reviewed the literature on the interaction between RIN prices and BBD demand.³³ It identified a close relationship between RIN prices and BBD blending due to BBD production costs and high pass-through rates by

refiners, with the latter meaning that RIN prices are positively correlated with the competitiveness of BBD relative to petrodiesel. Low RIN prices reduce the incentive to blend BBD by making petrodiesel less expensive relative to BBD for the same reason. A recent analysis based on a confidential refinery-level dataset also identified high pass-through of RIN prices by refiners to consumers at the national level, supporting earlier findings regarding the strong connection between RIN prices and blending volumes.³⁴

The academic literature on the relationship between RIN prices and BBD blending volumes largely supports the existence of a strong positive correlation between RIN prices and blending volumes. Evidence of this correlation is also to be found in the EIA's monthly blending data as discussed above. The academic literature also supports the existence of a relationship between the BTC and BBD blending volumes, although the specific correlation is more complicated. Irwin et al.³⁵ examined the impact of the BTC's expiration years on BBD prices and identified the presence of price spikes that gradually increased over the course of each expiration year, which the researchers attributed to increased demand for BBD by blenders. Similar price effects were not found in non-expiration years, nor in the periods following the reinstatement of the BTC. This finding is further supported by the data discussed above and in Section 1 showing high late-season BBD production, sales, and blending volumes in expiration years. Irwin et al. further noted, however, that refiners' ability to "bank" RINs generated in expiration years for use in the next year's mandate potentially contributed to the tax credit's price effect.

A complicating factor in the relationship between the BTC's expirations and BBD demand is the influence of a parallel relationship between the BTC and RIN prices. Both the tax credit and RINs have the effect of increasing demand by blenders for BBD.³⁶ The primary difference between the two mechanisms is one of subsidy source rather than effect: the BTC is funded by taxpayers whereas RINs are funded by obligated blenders and, due to high pass-through rates, ultimately consumers. The effect of the BTC in theory, then, is to share the burden that RINs impose on consumers with taxpayers rather than to increase blending volumes. In reality, however, the BTC has had an impact on blending volumes due to imperfect policymaking: blending volumes increased in the frequent BTC expiration years as blenders scrambled to maximize their accrual of credits prior to expiration, and more recently blending volumes declined during the BTC's 2018-2019 absence (prior to its retroactive reinstatement in December 2019) due to the EPA's weakening of the RFS mandates over

the same period (given that the effect of the latter would have been at least partially offset by a reinstated tax credit).

2.3. *Regional demand and blending*

The academic literature has focused on the interplay between BBD blending volumes, the BTC, and RINs at the national level due to data availability. PADD-level variations in blending volumes and blending rates do exist, however, due to a variety of factors including infrastructure constraints, seasonal effects, and state-level supply and demand incentives. Appendix II examines these variations and their causes.

2.4. *BBD demand incentives*

Incentives and regulations at the national and state levels that exist for the purpose of increasing BBD demand are more limited in scope than are those policies that incentivize supply (see Section 1.3). There are no government requirements for the public to utilize BBD, as distinct from requirements that BBD be offered to the public (e.g., blending mandates such as the RFS). Many states mandate that government fleets have a minimum threshold of alternative fuel vehicles, such as those that run on BBD blends, and some of these states specifically mandate that government diesel engine fleets consume petrodiesel that has been blended with varying amounts of BBD. While these mandates are normally implemented for government-owned and -leased fleet vehicles only, surveys of private fleet operators show that biodiesel is the primary alternative fuel used in that sector despite a lack of binding consumption requirements.³⁷

The U.S. Energy Policy Act (EPAAct) of 1992 established basic alternative fuel vehicle requirements that the U.S. Department of Energy (DOE) has implemented as the State and Alternative Fuel Provider Fleet Program for state government and alternative fuel provider fleets of light-duty vehicles (LDV).^{38*} Specifically, covered state governments and alternative fuel providers must ensure

* The EPAAct also tasked the U.S. DOE with determining whether private and local government fleets should be held to a similar set of alternative fuel vehicle requirements as part of a broader target of using alternative fuels to replace 30% of U.S. refined fuels consumption. In 2004 and again in 2008 the DOE determined that a mandate on private and local government fleets was not needed.

that 75% of their annual LDV acquisitions are alternative fuel vehicles.³⁹ Up to 50% of the acquisition requirement can be met via credits generated through the purchase of ≥ 20 vol% biodiesel blends for use in medium- and heavy-duty state vehicles. Multiple states also allow for their agencies to purchase biodiesel using funds generated through the sale of excess EPCRA credits. The EPCRA's state fleet requirements are properly viewed as a minimum requirement, and some affected states have subsequently opted to implement their own, more stringent alternative vehicle and/or alternative fuel requirements. These state requirements, as well as other demand incentives, are reviewed below.

Biodiesel consumption under the EPCRA increased rapidly between the program's implementation in 1999 and 2008. While subsequent growth has been slower or even negative, biodiesel consumption between 2009 and 2017 was 23.6 million gallons for covered alternative fuel provider fleets and 39.3 million gallons for covered state government fleets, or a total of 62.9 million gallons.⁴⁰ This volume comprised only 0.5% of the biodiesel that was consumed in the U.S. over the same period, but its impact on U.S. biodiesel consumption and industry development at the beginning of the century was substantial: in 2003 the program accounted for fully 16% of U.S. biodiesel consumption.^{4,40} The experience that was gained through the subsequent use of ≥ 20 vol% biodiesel blends also contributed to the implementation of subsequent biodiesel consumption requirements beyond the threshold required by the EPCRA, not to mention the supply and blending of biodiesel for consumption by the private sector.

State-level demand incentives are examined in Appendix II.

2.5. *BBD Consumption - Conclusions*

BBD consumption varies widely across the U.S. PADD regions in terms of volumes, average annual blend rates, and actual blend rates. In 2017 the U.S. consumed BBD at an average blend of 4.8 vol% of MVNRLM diesel fuel, or 4 vol% if all distillate fuel oil consumption is considered instead. Roughly 75% of this BBD was in the form of biodiesel. Renewable diesel's share of total BBD blending is small but growing, having been non-existent just a decade ago. The nature of the RFS, which is the country's primary driver of BBD supply in distillate fuel oil, and the widespread approval of blends up to 20 vol% for use in diesel vehicles under most automakers' warranties, in

contrast to 5 vol% for other types of diesel equipment, has made the on-road sector the largest source of BBD consumption in the country. It should be noted that the non-road, marine, and rail sectors are also covered by the RFS, however, and the combined MVNRLM sectors are responsible for more than 82% of U.S. distillate fuel oil demand.

U.S. BBD blending is mostly done by smaller-scale blenders such as fuel jobbers rather than by refiners and bulk terminal operators. The total volume of blended biodiesel that has been provided by these latter two types of entities has remained relatively flat over the last five years even as BBD consumption has continued to grow. U.S. BBD blending is also very seasonal, with total blending volumes and consumption being highest between August and October and lowest between January and February. Weather is not the only important seasonal factor, however. Blending volumes in the later months of the year, especially December, have historically been much higher in those years in which the BTC either expired or was allowed by Congress to almost expire as blenders have worked to generate as many credits as possible before the end of the year. Large RIN price movements have also affected monthly blending volumes, albeit to a lesser extent than the BTC's expiration.

There are three main similarities between BBD blending patterns at the PADD-level. First, blending volumes are lowest in the winter and highest in the summer, although the magnitude of the blending volume change across seasons is greater in the parts of the country that are characterized by colder winter temperatures. Second, years in which the BTC either expired or was almost allowed to expire by Congress were marked by higher blending volumes in the later months of the year, especially in December, although not all PADD regions were affected to the same degree. Finally, with the exception of the PADD 2 region, all PADD regions experienced much higher summer blending volumes in 2013 when RIN prices increased rapidly.

PADD-level blending patterns are also characterized by four important differences. First, average BBD blending volumes ranged widely in 2017 from a low of 0.7 vol% in the PADD 4 region to a high of 8.5 vol% in the PADD 5 region relative to MVNRLM diesel fuel consumption. Second, different types of blenders accounted for the largest share of BBD blending across regions: bulk terminal operators in the PADD 1 and PADD 5 regions, fuel jobbers and other smaller blenders in the PADD 2 and PADD 3 regions, and refiners in the PADD 4 region. Third, the limited state- and city-level data that is available shows how policies at these levels affect blending patterns. Iowa's blenders' tax credit incentivizes the use of 10 vol% and higher BBD blends, with the result that the

overall blending pattern is distinctly heterogenous and much of the state's diesel fuel supply contains no biodiesel. The use of strict blend mandates in Minnesota diesel fuel supply and, at a smaller scale, in New York City's government fleets and buildings, results in a homogenous blending pattern that is uniform throughout the entire covered diesel fuel supply. Last, California's adoption of an escalating pathway-neutral blend mandate has caused BBD blending in that state to escalate very rapidly, to the point that almost all the PADD 5 region's BBD consumption occurs within that state. California's heavy consumption of renewable diesel contributed to this speed by minimizing the infrastructure upgrades needed, as illustrated by the large contribution that bulk terminal operators have made to blending volumes in the state.

The available state-level data on BBD blending and consumption in the U.S., shows that there is no single "correct" policy that governments must employ in order to increase BBD consumption. California, Iowa, and Minnesota had all achieved comparable average annual blending rates by 2017 via very different mechanisms. California requires a specific percentage of low-carbon fuels to be blended into the overall transportation fuel supply, Iowa incentivizes the blending of biodiesel with diesel fuel in a way that provides additional value for blending at higher rates, and Minnesota requires every gallon of diesel fuel that is sold within the state to contain a specific volume of biodiesel. These different approaches do have important implications regarding infrastructure requirements (e.g., the delayed implementation of Minnesota's earlier mandates due to a lack of blending infrastructure in parts of the state), BBD's environmental and human health impacts, and potential BBD consumption volumes that merit further study.

Data limitations present a constraint on efforts to comprehensively analyze BBD blending and consumption patterns within the U.S. The federal government's BBD fuel reporting requirements are less developed than those for fuel ethanol, let alone refined fuels, as illustrated by the use of very different BBD definitions and categories among the different federal department and agencies (see Appendix I). Simple changes to federal surveys of BBD producers and distributors would enable the generation of the type of sector-level consumption data that is collected from refined fuel producers. The U.S. Energy Information Administration (EIA) has taken an important step by proposing to utilize BBD categories in its surveys that correspond to those used by the U.S. Environmental Protection Agency (EPA), but granular blending data remains lacking. The state of Iowa has shown that BBD sales across different blend rates can be calculated even at the county level, but the EIA's current surveys are not set up to do so since they require the reporting of total blending volumes

rather than by different blends. State-level data is even more limited and just a handful of states such as California and Iowa publish consumption volumes, although the former lacks data on blending trends.

Another major constraint is a lack of data on BBD consumption at lower blend levels (<6 vol%). Federal law only requires that fuel dispensers advertise the biodiesel blend being dispensed when it exceeds 5 vol% (labeling requirements are covered in greater detail in Section 3). As this section discusses, however, very few states, let alone PADD regions, reach that threshold on an annual average basis. Some states do impose additional labeling requirements on dispensers of <6 vol% blends (see Section 3), although these are often vague (e.g., “May contain up to 5 % biodiesel”). Many of the EIA’s databases do not even report biodiesel volumes along the distribution chain when blended below the <6 vol% thresholds. Government policies such as the RFS and LCFS that collect comprehensive data on production and blending volumes do not report actual blending percentages since they are supply rather than demand mandates: the specific BBD blend used does not matter so long as the fuel enters the overall transportation fuel supply pool. The only demand mandates for which blending percentages might be required are for government fleets, and these only comprise a small fraction of total diesel fuel demand. Iowa and New York City have both demonstrated that this data can be collected and published, seemingly without too much difficulty, but the practice is not common.

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SECTION 3.

Biomass-Based Diesel Technical and Environmental Performance



Section 3. Biomass-based Diesel Technical and Environmental Performance

Section 3.1. BBD Technical Performance

Biodiesel

Biodiesel's oxygen content reduces its theoretical energy content per gallon by approximately 7% compared to one gallon of ultra-low sulfur diesel (ULSD). One gallon of No. 2 ULSD (defined as petrodiesel diesel with a sulfur content of 15 ppm or less) contains 129,488 Btu¹ while one gallon of biodiesel contains 119,550 Btu.^{2*} This difference has little impact on consumers, however: one gallon of 20 vol% biodiesel blend has 99% of the energy content of one gallon of ULSD,^{2,3} and even this difference disappears in the more common <20 vol% blends. Technical studies of the engine power provided by biodiesel blends have identified both increases and decreases relative to petrodiesel, although these variances have been small and dependent on engine speed, blend rate, and biodiesel feedstock; notably, there is no discernible correlation between power difference and blend rate.⁴ A 2011 review of the literature noted that pure biodiesel has a lower energy content but higher density and superior combustion performance compared to petrodiesel, and that these factors largely offset in laboratory engine tests.⁵

Similar findings regarding the energy contents and engine power of biodiesel blends relative to pure petrodiesel have been reached by surveys of fleets that consume biodiesel blends. A survey of 39 fleets across the U.S. by the California Air Resources Board (CARB) found that 80% reported no engine power difference when using biodiesel blends, 10% reported increased engine power, and 10% reported reduced engine power.³ Similarly, 69% of the surveyed fleets reported no difference in fuel economy when using biodiesel blends, compared with 10% that reported a slightly reduction and 5% that reported a still smaller increase (the remaining fleet respondents did not track fuel economy). The survey's authors concluded that the reported fuel economy differences were most likely attributable to factors other than the biodiesel blend. Academic studies of fleets have reached similar conclusions.^{6,7}

Biodiesel is not a hydrocarbon and its chemical composition causes three important, albeit manageable, technical challenges to its use that petrodiesel either does not encounter or encounters to a lesser degree. First, biodiesel's oxygen content can limit the length of time that it is stored prior

* The specific energy contents of both fuels vary widely across the literature, but biodiesel is commonly found to have an energy content that is within 8-10% of that of petrodiesel.

to combustion. Oxidation occurs when biodiesel decomposes into secondary products that cause its viscosity and acidity (as measured by total acid number, or TAN) to increase, both of which negatively affect diesel engine performance. Some common feedstocks such as canola oil yield biodiesels that are less prone to oxidation than others such as palm oil do (see Table 3-1). Oxidation reactions can be limited through the use of antioxidants that are added to biodiesel.⁸ Oxidation can also be managed by storing biodiesel at unelevated temperatures (<109 °F) and limiting its movement when exposed to the air.⁹ Alternatively, oxidation can be prevented through regular product turnover. The extended use of a 20 vol% biodiesel blend with heating oil by New York City's local government revealed that intentional turnover as part of a routine maintenance plan was able to prevent oxidation even when the fuel was used in infrequent applications such as fueling emergency generators.¹⁰

Table 3-1. Oxidation stability of biodiesels derived from common feedstocks. Higher values indicate superior stability towards oxidation by air.¹¹

Biodiesel	Oxidation stability (h)
Canola	7.6
DCO	2.2
Soybean oil	2.1
Tallow	1.6
UCO	1.0

Biodiesel's chemical composition also makes it more prone than petrodiesel to microbial fouling, which occurs when microbes consume biodiesel and convert it into secondary products. As with oxidation, this unintended process increases the biodiesel blend's acidity and can cause corrosion when the fuel is stored in metal tanks for extended periods. The various bacterial and yeast strains that consume biodiesel also produce biofilms over weeks and months that can cause engine fouling. While microbial fouling is not unique to biodiesel given the presence of some microbial strains that consume hydrocarbons, biodiesel's oxygen content further contributes to the growth of some microbial strains.¹² Many biodiesel terminals are equipped with filters that prevent biofilms and other fouling agents from making it into the biodiesel blend.¹³ From the consumer's perspective microbial fouling, as with oxidation, can be prevented via regular fuel turnover.

Both petrodiesel and biodiesel gel, or freeze, at low temperatures. This phenomenon occurs when wax, which is present in all distillate fuels, solidifies; when enough solidification occurs, the fuel can

clog diesel engines. No. 2 ULSD has a cloud point, which is the temperature at which visible crystals form in the fuel as it begins to freeze, of around 16 °F.¹⁴ No. 1 ULSD, which is more expensive than No. 2 ULSD and primarily used in cold temperatures, has a cloud point of approximately -20 °F.¹⁵ Biodiesel terminals and above-ground storage tanks often are insulated and heated to ensure that clouding does not occur prior to the blending of the pure biodiesel with petrodiesel. Biodiesel's cloud point is a function of the feedstock from which it is derived. As a rule, unsaturated feedstocks (e.g., vegetable oils) yield biodiesels with substantially lower cloud points than saturated feedstocks (e.g., palm oil and animal fats) do (see Table 3-2).¹¹ This trait is because of the high melting points, and therefore also crystallization temperatures in mixtures, of saturated lipids relative to unsaturated lipids.¹⁶ The large share of saturated feedstocks that is utilized by renewable diesel producers is properly viewed in this context, as the cloud point of renewable diesel can be closely controlled to match that of petrodiesel, regardless of feedstock, in a way that is not possible with biodiesel (see below).

Table 3-2. Cloud points of pure biodiesel derived from common feedstocks.¹¹

Feedstock	Cloud point (°F)
Canola	26
DCO	27
Lard	53
Soybean oil	34
Tallow	61
UCO	36

Biodiesel blends have lower cloud points than pure biodiesel due to the effect of the petrodiesel component. 20 vol% biodiesel blends from soybean oil, UCO, and tallow with No 2. ULSD have cloud points of 19 °F, 20 °F, and 23 °F, respectively.¹⁷ The cloud points of 5 vol% blends are within <10 °F of the added petrodiesel and those of blends derived from oilseeds are very close to the petrodiesel's cloud point. This is reflected in restrictions on the use of biodiesel blends above 5 vol% by fleets and mandates in the northern U.S. (e.g., Minnesota's 5 vol%/20 vol% blend mandate) during the colder months of the year (see Section 2).

Practically, few consumers outside of the upper Midwest states can expect to encounter technical difficulties from clouding through the use of 20 vol% biodiesel blends. In 2018 New York City's chief fleet management officer recommended that the city's government fleets adopt 10 vol% biodiesel blends in the winter and gradually expand to 20 vol% blends during that season; this

recommendation was based on multi-year trials with various biodiesel and ULSD blend combinations, including the consumption of two million gallons of a 20 vol% blend without problem in the winter of 2017/18 (New York City’s average low temperature was 33 °F in that January).^{18,19} A two-year, 1.5 million mile study on the use of soybean-derived 20 vol% biodiesel blends in commercial heavy-duty vehicles (HDV) across the upper Midwest found that the use of a commercial additive prevented clouding issues even in conjunction with No. 2 ULSD for the majority of the year; problems were avoided during a brief period of especially cold temperatures through the use of a blend consisting of 40 vol% No. 1 ULSD, 40 vol% No. 2 ULSD, and 20 vol% biodiesel.²⁰

Other tests and surveys have reached similar conclusions regarding the winter use of 20 vol% biodiesel blends. In 2010 the CARB concluded based on a literature review that earlier reported problems with the cold weather performance of biodiesel blends was due to quality issues that were subsequently resolved through compliance with updated ASTM specifications.³ Likewise, the same report found that fleets nationwide view cold weather performance as a management rather than technical problem. While several respondents to that report’s survey noted that they had encountered inferior cold weather performance when using biodiesel blends, these issues arose in states characterized by especially cold winter temperatures, and many of these respondents had resolved their issues through the use of fuel additives and/or temporary blending with No. 1 ULSD. The CARB report concluded that “biodiesel blends can be operated year-round in most of the [surveyed] states by developing a cold weather management plan.”³ A more recent report by the National Renewable Energy Laboratory (NREL) reached a similar conclusion regarding the cold weather performance of biodiesel blends, stating that “with proper blending and handling, B20 has been used successfully all year in the coldest U.S. climes.”²² Cold weather performance decreases as the biodiesel blend rate increases, though, and >20 vol% biodiesel blends face winter usage constraints in the coldest climes that are more restrictive than those in warmer regions.

A technical issue related to cold weather performance is that of filter plugging. Biodiesel can cause fuel filter plugging via four different mechanisms. Filter plugging was a recurring problem before the development of uniform quality standards as excess glycerol in the biodiesel, the result of improper process stream separation and/or filtration at biodiesel production facilities, found its way into diesel fuel engines. The development of BQ-9000 and ASTM D6751 fuel quality standards has eliminated this source of plugging. More recently the solvent nature of biodiesel has caused plugging

issues in older, poorly-maintained engines as engine deposits are broken down, although this can be managed through routine engine maintenance. Filter plugging that occurs now is usually attributable to improper fuel storage and management. As discussed above, lengthy biodiesel storage times can result in the formation of biofilms that clog fuel filters. NREL recommends that pure untreated biodiesel be stored for periods of less than four months in part to prevent filter plugging (as well as to limit oxidation).²² The CARB survey revealed that fleet users of biodiesel generally do not store biodiesel for more than 120 days for the same reasons.³ Finally, the use of biodiesel blends in situations where the cloud point is higher than the ambient temperature can also cause filter plugging as the biodiesel begins to solidify, although this is manageable via the use of anti-gelling additives and blending with No. 1 ULSD.

Biodiesel and biodiesel blends provide consumers with multiple usage and performance advantages compared to petrodiesel, three of the most important being a higher flash point, improved lubricity, and a superior Cetane number. The flash point is the lowest temperature at which a substance will ignite when exposed to an ignition source. Substances with low flash points are categorized as “flammable” whereas those with high flash points are categorized instead as “combustible.” Biodiesel’s flash point is required to be at least 200 °F,²² but in reality it is as high as 338 °F.³ Biodiesel is far less flammable than petrodiesel, which has a flash point of 126-204 °F, and provides an important safety advantage relative to distillate fuel oils as a result.

Diesel fuel is the source of lubrication in diesel engines due to naturally occurring constituent compounds. Lubricity has become a growing concern in the 21st century, however, as low-sulfur regulations have become increasingly strict in the U.S. The removal of sulfur from petrodiesel reduces its lubricity and ULSD’s low consequent lubrication ability has prompted concerns about premature engine wearing. Pure biodiesel has a high lubricity, to the point that the blending of 1 vol% biodiesel with low-lubricity petrodiesel can result in a satisfactory lubricity rating in the resulting blend.²² NREL has concluded that a blend containing “2% biodiesel almost always imparts adequate lubricity” for diesel engines regardless of the pure petrodiesel’s lubricity rating.²²

The cetane number of diesel fuel is a measure of its ignition delay and, by extension, its combustion speed; the cetane number is positively correlated with combustion speed. Pure biodiesel usually, but not uniformly, has a higher cetane number than petrodiesel does. A review of available diesel fuels by NREL identified cetane number ranges of 40-55 and 47-65 for petrodiesel and biodiesel,

respectively.²² The cetane number of biodiesel is also positively correlated with the cloud point, meaning that saturated feedstocks yield biodiesel with higher cetane numbers than can be obtained from unsaturated feedstocks. This fact has caused the superiority of biodiesel's cetane number to sometimes be overstated in the literature given that the majority of U.S. biodiesel is derived from unsaturated feedstocks (see Section 1). In California, which has its own diesel fuel specifications that are separate from the U.S. Environmental Protection Agency (EPA), the cetane number for soybean oil-derived biodiesel is comparable to on-road petrodiesel.³

Three different ASTM specifications dictating minimum acceptable quality and performance indicators exist for biodiesel, depending on the specific biodiesel blend that is created. Pure biodiesel is covered by the ASTM D6751 specification, which requires analysis of the fuel's flash point; methanol, water, and sediment content; viscosity; oxidation stability; sulfur content; corrosion; cetane number; cloud point; TAN; and other important properties.²¹ For example, the specification requires that, among other things, the pure biodiesel have a minimum cetane number of 47, a maximum TAN of 0.5, and a minimum oxidation stability of 3 hours. The specification is process neutral in that it covers all biodiesel that is comprised of mono-alkyl esters of long chain fatty acids (e.g., FAME) and produced from either vegetable oils or animal fats. The purpose of the specification is to ensure that the biodiesel will result in high quality biodiesel blends following the blending process. The D6751 specification covers two different biodiesel grades, No. 1-B and No. 2-B. The primary difference between these is the No. 1-B grade imposes a maximum monoglycerides content for the purpose of improving cold weather performance. Most U.S. biodiesel production qualifies for the No. 1-B grade.²²

The ASTM D7467 specification is for 6-20 vol% biodiesel blends with petrodiesel. This specification accounts for inherent differences between the two fuels by implementing requirements that account for their combined properties. The specification requires a minimum cetane number of 40, which is lower than that of the D6751 specification because petrodiesel's cetane number is lower than that of pure biodiesel. The D7467 TAN and oxidation stability requirements are lower and higher, respectively, than those of pure biodiesel to account for the impact of petrodiesel's contribution to the blend.²²

The final specification is not for biodiesel but rather for petrodiesel. The ASTM D975 specification establishes minimum acceptable quality and performance indicators for covered diesel fuels. The

specification allows for up to 5 vol% of the diesel fuel to be biodiesel but does not require that the biodiesel content be explicitly listed so long as it is below this threshold.²² Importantly, with the exception of the biodiesel content, the D975 specification was not otherwise modified to account for biodiesel's properties, meaning that ≤ 5 vol% biodiesel blends meet all of the performance requirements of petrodiesel.

The inclusion of up to 5 vol% biodiesel in the D975 diesel fuel specification has important implications for biodiesel use. First, it means that biodiesel can be used throughout the refined products infrastructure, most notably at petrodiesel dispensing pumps. The Federal Trade Commission (FTC), which was tasked by Congress in 2007 with the creation of biodiesel labeling requirements for retail station dispensers, decided to not require labels for biodiesel blends of ≤ 5 vol% so long as they meet the D975 specification.²³ Pumps that provide biodiesel blends of between 5 vol% and 20 vol% must carry a label with the header “B-20 Biodiesel Blend” and the statement “contains biomass-based diesel or biodiesel in quantities between 5 percent and 20 percent.”²² Finally, pumps that provide biodiesel blends of $>20\%$ must carry a label that shows the specific biodiesel blend being dispensed. The FTC rule also applies to “biomass-based diesel” and presumably covers renewable diesel as a result.

The FTC's requirement is a minimum standard and six states have imposed their own, stricter labeling requirements. Illinois requires fueling pumps to display ratings “consistent with the percentage by volume of the alternative fuel being dispensed.”²⁴ Mississippi requires pumps dispensing biodiesel blends of up to 5 vol% to be labeled with “may contain up to 5% biodiesel” and blends of 6-20 vol% to be labeled with the percentage of biodiesel; pumps dispensing blends above 20 vol% must include the additional warning to “consult vehicle manufacturer fuel recommendations.”²⁵ North Carolina requires fuel distributors to label product containing more than 5 vol% biodiesel by showing its biodiesel content within a variance of 1.7 vol%.²⁶ North Dakota requires alternative fuel retailers to label dispensers with the price, name, and main components of biodiesel and biodiesel blends being sold.²⁷ Tennessee limits biodiesel blends sold to the public at retail locations to a maximum blend rate of 20 vol%.²⁸ Washington requires pumps dispensing biodiesel blends of 5 vol% or less to carry a label that states “may contain up to five percent biodiesel.” It further requires pumps dispensing >5 vol% blends to state the specific biodiesel blend being provided.²⁹

Wisconsin also imposes labeling requirements, albeit of a different kind than the other states. The state prohibits fuel retailers from labeling a biodiesel blend as such unless it contains at least 2 vol% biodiesel and the actual blend rate is explicitly identified. Presumably this does not require ≤ 5 vol% blends to be labeled as such, though.³⁰

The ASTM D975 specification has not meant that biodiesel blends of up to 5 vol% have been compatible with all infrastructure over the last decade. Prior to 2015 the ASTM specification for jet fuel required that it contain no more than 5 ppm of FAME and other lubricity additives. This constraint affected refined products pipelines even before U.S. biodiesel consumption became widespread, dating to the EPA's implementation, beginning in 2006, of ULSD in place of LSD. While the ULSD requirement reduced sulfur emissions from petrodiesel consumption (No. 2 LSD contains 500 ppm of sulfur while No. 2 ULSD contains 15 ppm), the consequent reduction in lubricity prompted refiners to begin blending No. 2 ULSD with lubricity additives. In 2004 the Colonial Pipeline, which runs from the Gulf Coast to New Jersey, banned products containing lubricity additives on the grounds that ULSD batches would leave residue, or "trailback", of the additives that would be picked up by following jet fuel batches, thereby causing the latter to move out of spec.³¹ Other refined products pipelines quickly adopted similar restrictions and, in an outcome that is analogous to the more recent biodiesel distribution situation, terminals made expensive infrastructure upgrades that enabled them to blend lubricity additives with petrodiesel as the latter exited the pipeline.

The Colonial Pipeline tested 5 vol% biodiesel blends at the same time that the EPA's ULSD requirement was being implemented and determined that a highly uncertain amount of trailback was picked up by subsequent batches of petrodiesel. The lack of precision with the testing mechanisms that were in use at the time, combined with the then-ASTM jet fuel specification allowing no more than 5 ppm of FAME, caused refined products pipelines to restrict the movement of biodiesel blends as well, although some exceptions were made by smaller pipelines that did not move jet fuel batches.³¹

Two important developments in the subsequent decade have increased the compatibility of ≤ 5 vol% biodiesel blends with refined products pipelines, including those that move jet fuel batches, although biodiesel movements through the latter have yet to become widely allowed. First, extensive testing has determined that FAME trailback can be minimized and even eliminated by rearranging the

movement of different refined products through the pipelines so that multiple pure petrodiesel batches follow biodiesel blends. The pure petrodiesel picks up the FAME trailback, effectively “scrubbing” the pipeline of FAME residue so that subsequent jet fuel batches can be moved through without encountering potential contaminants.³² (It is much more difficult to move biodiesel through pipelines that transmix since the biodiesel complicates the subsequent fractionation process.) Second, in 2015 the ASTM implemented a new jet fuel specification that allows up to 50 ppm of FAME, up from the previous 5 ppm limit.³³ This new specification was introduced after extensive testing determined that jet fuel encountered no performance issues with FAME contents of up to 400 ppm, and as early as 2015 the expectation existed that the specification’s FAME limit would be further increased to 100 ppm in the future.³⁴

The Explorer Pipeline,³⁵ Plantation Pipeline,³⁶ and Central Florida Pipeline³⁷ all show on their ULSD product specification sheets that the product can contain up to 5 vol% biodiesel at the destination on some lines, although the latter two do not allow biodiesel blends at the origin (this is not stated for the former). If this recent trend continues and the technical hurdles to moving biodiesel blends through refined products pipelines are overcome, one further potential constraint is the absence of uniform labeling requirements in different states. The Colonial Pipeline’s 2017 decision to move ≤5 vol% biodiesel blends through segments that do not carry jet fuel attracted opposition from two of its customers on the grounds that this blend could make their own blending operations come into conflict with North Carolina’s unique labeling requirements. The customers in question splash blend biodiesel to up to 20 vol% with petrodiesel after the latter leaves the pipeline.²⁶ While North Carolina’s labeling requirements are more stringent than those of the FTC in that they require the label to show the specific blend rate, the customers are able to carefully monitor the volume of biodiesel that is added and, since the petrodiesel exiting the pipeline contained no biodiesel in the past, the exact blend rate was easily calculated. The customers noted in a protest filed with the Federal Energy Regulatory Commission (FERC) that they would be unable to continue to do so without incurring the expense of testing every obtained batch of petrodiesel if the petrodiesel exiting the pipeline contained up to 5 vol% biodiesel but, in compliance with the ASTM D975 specification and FTC labeling requirements, was not labeled with the specific blend.

While the FERC ultimately ruled in favor of the Colonial Pipeline on jurisdictional grounds,²⁶ the debate did reveal an important potential constraint to the utilization of biodiesel blends that are moved via pipeline into states such as North Carolina that require blend rates to be specifically

labeled. That constraint could feasibly disincentivize blending operations result in >5 vol% biodiesel blends in such states. The FTC labeling requirement in conjunction with pipeline-approved biodiesel blends could similarly disincentivize blending to >20 vol% rates across the country for the same reason, although the available evidence suggests that the immediate impact would be minimal due to the scarce availability of such blends in most PADD regions (see Section 2). This constraint is mitigated, but not entirely avoided, by the FTC requirement that blends of up to 20 vol% simply state the blend range rather than the specific blend rate. Blenders that use petrodiesel from pipelines that comply with the D975 specification in such situations would need to limit their maximum blending volume to 15 vol% so as to avoid any risk of exceeding 20 vol% and consequently needing to test the product to determine the specific blend rate for labeling purposes. Doing so would require them to forgo the RINs and any tax credits obtained through that share of their blending operations.

Renewable diesel

Renewable diesel differs from biodiesel in that it is comprised of only hydrogen and carbon, making it a hydrocarbon-based fuel despite being derived from biomass rather than petroleum. Renewable diesel is a fully paraffinic fuel, which causes it to have a lower density and therefore energy content than ULSD (approximately 4% less per gallon), although it does offer some performance advantages relative to petrodiesel. Renewable diesel is categorized as the same type of fuel as petrodiesel when it meets the ASTM D975 specification, but as a diesel fuel in its own right rather than as a ≤ 5 vol% blending component as biodiesel is. Renewable diesel also meets the CARB diesel specification due to its low aromatic content and high cetane number.³⁸ Renewable diesel's chemical composition is so similar to that of petrodiesel that the two fuels can only be distinguished when blended through carbon dating as a means of determining the ratio of fossil carbon versus biological carbon.²²

Renewable diesel that meets the ASTM D975 specification is not restricted by technical considerations to specific blend limits. Reviews of the literature have found renewable diesel to, in contrast to biodiesel, have a slightly lower density than petrodiesel; like biodiesel blends, however, renewable diesel blends have been found to have engine power outputs that are very similar to petrodiesel.^{39,40} From a performance standpoint renewable diesel offers a mix of advantages and disadvantages relative to both biodiesel and petrodiesel. As with petrodiesel, the renewable diesel

producer can tailor the fuel's cloud point to a desired specification range. While straight-chain renewable diesel has a cloud point that is comparable to that of No. 2 ULSD, this can be isomerized to yield branch-chain renewable diesel with a cloud point that is even lower than that of No. 1 ULSD.³⁸ This process does entail a trade-off due to the reduced renewable diesel yields from isomerization, though, and a lower cloud point necessitates a greater amount of conversion of renewable diesel to the less-valuable co-product naphtha.

Straight-chain renewable diesel has a cetane number of 100 or higher that is well above those of petrodiesel and biodiesel. Fully-isomerized renewable diesel's cetane number is lower at 70-99, although this is still substantially higher than those of petrodiesel and biodiesel. Renewable diesel's oxidative stability is comparable to that of petrodiesel. Its lubricity is comparable to that of ULSD, however, meaning that both fuels have a similar need for lubricity additives despite their very different feedstock origins (in contrast to biodiesel).³⁸ Renewable diesel's lack of aromatics compounds relative to petrodiesel can also cause performance issues from elastomer shrink and consequent fuel leakage, although these issues can be managed and the ASTM D975 specification does not require a minimum aromatics content.⁴¹

Renewable diesel is a “drop-in” biofuel that is not blend-constrained by technical limitations; it can be used at any blend rate in any application that petrodiesel meeting the ASTM D975 specification can be used in. This is not to say that renewable diesel is entirely blend-agnostic, however. Labeling requirements that were developed at a time when biodiesel was the sole form of BBD consumption in the U.S. now apply equally to renewable diesel in many jurisdictions. The FTC imposes the same blend labeling requirements on renewable diesel that it imposes on biodiesel: renewable diesel blends that are greater than 5 vol% up to 20 vol% must be labeled as being within this range, and blends exceeding 20 vol% must carry a label stating the specific blend rate.³⁸ Some states have adopted a similar regulatory approach by requiring all biomass-based fuels or alternative fuels to utilize the same blend labeling standards. As with biodiesel, it is feasible that renewable diesel will encounter regulatory constraints created by the current system of blending labels that is required by federal and some state regulations despite its complete fungibility with petrodiesel.

Pipeline operators have been relatively quick to adapt to the increasing availability of renewable diesel supply in the U.S., by contrast. The Explorer Pipeline's product specifications sheet contains a “Ultra Low Sulfur Diesel Fuel Renewable” category that meets the same specifications as its ULSD

category, including with regard to fungibility.³⁵ (The pipeline's biodiesel blend categories, by contrast, are segregated.) The Plantation Pipeline includes fungible product specifications for ULSD containing up to 5 vol% renewable diesel³⁶ and the Colonial Pipeline accepts product that contains > 5 vol% renewable diesel, so long as the blend rate is specifically disclosed and the renewable diesel does not contain any fatty acid esters such as FAME.⁴²

Section 3.2. BBD Environmental Performance

Mandates and other incentives for BBD have been widely adopted in the U.S. and other developed countries due to the fuel category's ability to contribute to multiple environmental goals. Petrodiesel combustion results in emissions of both global forms of air pollution, the most important of which is the greenhouse gas (GHG) carbon dioxide (CO₂), and non-global forms of air pollution such as emissions of carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NO_x), particulate matter (PM), and sulfur oxides (SO_x). CO₂ emissions are the world's most prevalent source of greenhouse gas⁴³ and have been responsible for 73% of the increase in radiative forcing (e.g., the greenhouse gas effect) that occurred globally between 1750 and 2011.^{44*} The effects of the emission pollutants HC, NO_x, PM, and SO_x are more localized in that they affect the regions in which they occur rather than the entire planet. All of these pollutant emissions are considered by economists to be a negative externality, however, in that the costs that are incurred by their impacts (e.g., rising sea levels and changing weather patterns from CO₂; respiratory illnesses and other negative human health consequences from HC, NO_x, and PM; acid rain from SO_x) are not typically borne by the entities that are responsible for the emissions.

A growing number of governments have implemented incentives, regulations, and other types of policies that are aimed at internalizing these externalities from petrodiesel combustion and/or limiting petrodiesel emissions. Many of these policies, including the U.S. Renewable Fuel Standard (RFS) and California's Low Carbon Fuel Standard (LCFS), do so by replacing some petrodiesel consumption with BBD. The rationale behind these policies is that the environmental impacts of BBD combustion are largely (but not uniformly) less negative than those of petrodiesel combustion. The RFS and LCFS both require, for example, that participating BBD fuels either achieve a specific carbon intensity (CI) reduction threshold relative to petrodiesel (in the case of the RFS) or generate

* Petrodiesel combustion has only contributed to a small fraction of this total effect.

credits that are a function of this reduction (the LCFS). Similarly, many policies that incentivize BBD consumption have the intended side-effect of also reducing emissions of non-global pollutants.

BBD is the largest source of carbon credits under the LCFS (see Section 1) due to the low CI of BBD fuels compared to petrodiesel. It is important to note that this is not due to a reduction of tailpipe CO₂ emissions when BBD blends are combusted; inasmuch as the carbon contents of BBD fuels and petrodiesel are comparable, their tailpipe CO₂ emissions will be similar under like combustion conditions. In the case of biodiesel that is derived from feedstocks that are characterized by higher carbon numbers, such as UCO and soybean oil, tailpipe CO₂ emissions can be as much as 30% and 60% higher than petrodiesel's tailpipe emissions.⁴⁵ Rather, the low CI of BBD fuels reflects the fact that they contain biogenic carbon, whereas petrodiesel contains fossil carbon.

The difference between biogenic and fossil carbon is one of accounting rather than of chemistry. Petrodiesel is derived from carbon that has been stably sequestered underground for millions of years prior to extraction in the form of petroleum. (Ironically, much of this fossil carbon had been in lipid-rich biomass such as microalgae prior to sequestration.) BBD, by contrast, is derived from carbon that has been stably sequestered in the form of biomass for a period of mere months. The carbon content of both petrodiesel and BBD is emitted to the atmosphere as CO₂. Whereas petrodiesel's carbon content (or an equivalent amount of atmospheric carbon) will remain in a non-sequestered state after combustion until absorbed by new carbon sinks over the course of thousands and millions of years, that of BBD (or an equivalent amount of atmospheric carbon) will promptly be sequestered again via photosynthesis during the BBD feedstock's next growing season.* Put another way, petrodiesel combustion very quickly releases an amount of carbon into the atmosphere that took millions of years to be sequestered. BBD combustion releases an amount that is roughly equal to what the BBD feedstock sequestered only months earlier and what the next crop of BBD feedstock will withdraw from the atmosphere in the subsequent growing season.

BBD is not a “zero fossil carbon” fuel even when its carbon content is entirely biogenic. This is because the BBD production process utilizes varying amounts of fossil energy. Agricultural feedstocks require fertilizers that are derived from natural gas, for example, and most of the

* This distinction again is one of accounting rather than chemistry, as biomass has no preference between biogenic and fossil carbon when utilizing atmospheric CO₂ during photosynthesis.

feedstock production/collection, BBD production, transportation, and distribution processes consume petroleum-derived refined fuels, including petrodiesel. Furthermore, the production of some BBD feedstocks such as palm oil occurs on land that was originally rainforest before being converted to palm oil production. Rainforest destruction in developing countries often occurs via the slash-and-burn technique in which the woody biomass is cut down and then burned (the resulting ash fertilizes the land in advance of agricultural production). The burning of trees converts carbon that has been sequestered for decades or longer into CO₂ emissions, causing such deforestation to have a similar effect on the climate as fossil fuel combustion since a carbon sink, in this case the rainforest, has been destroyed.

Life cycle assessment (LCA) is a carbon accounting methodology that tracks emissions of CO₂ and other GHGs throughout the full life cycle of a product, rather than just accounting for the carbon contained in the product alone. LCA accounts for both direct emissions from the combustion of the BBD fuel and indirect emissions from its production cycle, including land-use change. The RFS and LCFS both require that the CI calculations of participating BBD fuels be on a LCA basis so as to ensure that low-carbon fuels actually have life cycle CIs that are low relative to that of the petrodiesel they are replacing. Whereas the RFS only requires participating BBD fuels to achieve a 50% CI reduction threshold relative to petrodiesel, under the LCFS a unique CI reduction value is calculated and published for each participating BBD fuel. The LCFS dataset provides a snapshot of the CI reduction profiles of the BBD that is sold into one of the world's largest BBD markets. The resulting dataset is not fully representative of global production since it explicitly excludes palm oil-derived BBD and implicitly discourages BBDs with higher CIs from participating, but it provides a good overview of the range of CIs that are achieved by U.S. BBD producers.

Among the LCFS's certified BBD fuels, the smallest CI reductions for biodiesel and renewable diesel relative to petrodiesel (ULSD) are 38% and 44%, respectively (see Figure 3-1) while the largest CI reductions are 91% and 83%, respectively.⁴⁶ A majority of the biodiesel fuels (although not necessarily by volume) achieve CI reductions of 70% or more; a majority of the renewable diesel fuels, which are fewer in number, achieve CI reductions of 65% or more relative to petrodiesel. In general, BBD fuels that are derived from waste and residual feedstocks have lower CIs than those that are derived from agricultural feedstocks, and the life cycle CI of the BBD feedstock is one of the most important determinants of the BBD fuel's CI reduction relative to petrodiesel. For example, under the LCFS the average reported CI for BBD from DCO is 47% lower than that of

BBD from soybean oil, despite both feedstocks coming from the Midwest and South Central U.S. regions.⁴⁶

The refereed literature reaches similar conclusions regarding the lifecycle CIs of BBD relative to petrodiesel,⁴⁷ with reductions of at least 66% and 51% being calculated for U.S. soybean oil- and canola-derived biodiesel, respectively, even after accounting for land-use change effects (e.g., converting grassland to cropland).⁴⁸ Other research has determined that these reductions have a high probability of occurring after accounting for uncertainty.⁴⁹ The biodiesel production process is less carbon-intensive than the renewable diesel production process due to the latter's isomerization requirement, assuming no difference in feedstock CI.

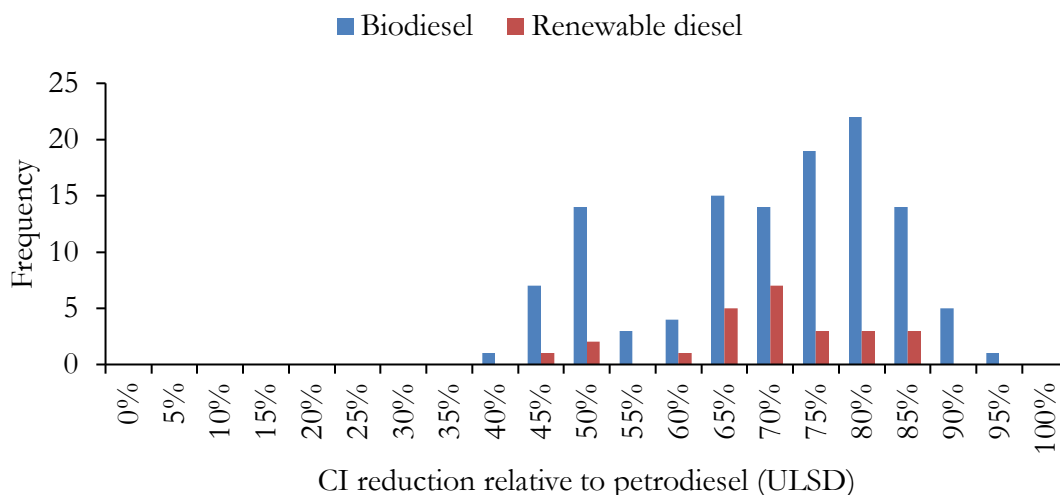


Figure 3-1. CI reductions of biodiesel and renewable diesel relative to petrodiesel under the LCFS.⁴⁶

The higher tailpipe emissions (not to be confused with life cycle emissions) of CO₂ by biodiesel relative to petrodiesel have a positive side-effect in the form of lower CO emissions for biodiesel that is derived from all major feedstocks.⁴⁵ Much as ethanol is intentionally added to gasoline in part to increase the amount of oxygen available in the combustion process for the purpose of emitting CO₂ instead of CO,⁵⁰ biodiesel's status as an oxygenated fuel results in reduced CO formation in exhaust following its combustion relative to petrodiesel and renewable diesel.⁵¹ While the negative human health effects from the inhalation of high concentrations of CO are widely known, even limited ambient exposure has been associated with increased hospital admissions for heart disease and congestive heart failure, as well as increased human morbidity from neurological disease, fetal loss, and abnormal childhood development.⁵² Major U.S. biodiesel feedstocks such as soybean oil,

canola, UCO, and tallow all yield biodiesel that reduces CO emissions relative to petrodiesel by up to 50%.^{45,51,61} Renewable diesel's CO emission reductions relative to petrodiesel are lower than that of biodiesel but still substantial, despite not being an oxygenated fuel, at 15-28%.^{51,53} In both cases the reduction magnitude scales in proportion to the BBD blend, with the largest reductions being reported for pure BBD.

The combustion of fuels that contain sulfur cause the element to oxidize into a group of gases, including sulfur dioxide (SO₂), that are commonly known as SO_x. These gases are emitted into the atmosphere where they cause both negative human health effects, including respiratory distress and illness, and negative environmental health effects from acid rain.⁵⁴ Sulfur is naturally occurring in petroleum, from where it can find its way into refined fuels during the refining process. In recent decades the U.S. government has imposed increasingly stringent limits on the allowable sulfur content of diesel fuel in an effort to reduce SO_x emissions and limit the poisoning of diesel engine system catalysts. In 1993 the limit was reduced from 5,000 ppm to 500 ppm (0.05 wt%) for on-road diesel fuel, known as LSD, and the 500 ppm limit was imposed on non-road diesel fuel in 2007.⁵⁵ In 2006 the on-road limit was further reduced to 15 ppm, which is the fuel that carries the ULSD label; that limit also became binding on non-road diesel fuel in 2010 and locomotive/marine diesel fuels in 2012.⁵⁶ As discussed above, ULSD suffers from reduced lubricity due to the hydrodesulfurization process that is used by refiners to limit petrodiesel's sulfur content; in addition to sulfur, hydrodesulfurization also removes oxygen- and nitrogen-containing compounds that contribute to lubricity.¹⁶

Biodiesel's sulfur content ranges from 0 to 15 ppm²² due to a lack of sulfur in biodiesel feedstocks; one analysis found the upper limit in available pure biodiesel to be as low as 0.01 ppm.³⁹ Renewable diesel also contains very low quantities of sulfur relative to petrodiesel.³⁸ While biodiesel blends only incur a limited reduction to sulfur content relative to petrodiesel due to the ULSD requirement in the U.S. (i.e., biodiesel blending is not expected to replace hydrodesulfurization by refiners as a means of complying with the 15 ppm sulfur limit), very low biodiesel blends (1-2 vol%) effectively offset the negative effect of hydrodesulfurization by contributing lubricity to the blended ULSD without contributing additional sulfur.

One sector in which BBD blending does have a desulfurization potential is with marine fuel oil. The marine fuel oil category consists of a mix of residual fuel oil and high sulfur diesel. Starting on

January 1, 2020 the International Maritime Organization (IMO) will require the sulfur content of marine fuel to be reduced from the 2012 standard of 35,000 ppm to 5,000 ppm. A recent report placed the current average marine fuel sulfur content at 22,000 ppm, meaning that a 77% average reduction will need to occur when the IMO 2020 rule takes effect.⁵⁷ The availability of multiple alternatives to high sulfur marine fuel, including LPG, scrubber installation on ships, and slower travel speeds has resulted in a wide range of forecasts regarding the new rule's impact on the sector.⁵⁷ BBD is also being considered as an alternative and some ocean carrier operators have conducted initial trials of BBD and marine fuel blends.⁵⁸ BBD's very low sulfur content has the advantage rapidly reducing the sulfur content of any blends with marine fuel. In 2017 the ISO 8217 standard for marine fuel was modified to introduce new fuel grades containing up to 7 vol% FAME; this was done to allow for the increased use of on-road diesel fuel in the marine fuel pool.⁵⁹ Cost and availability are two potential constraints to the blending of BBD with marine fuel oil, however, given regulatory competition with the RFS and LCFS.

BBD combustion also emits much smaller amounts of HC, including polycyclic aromatic hydrocarbons (PAH), than petrodiesel does. Exposure to PAH has been linked to multiple types of cancer, heart disease, and gastrointestinal disorders.⁶⁰ Biodiesel and renewable diesel both have very low aromatics contents²² and the combustion of the former reduces PAH emissions relative to petrodiesel by 75-90%.⁶¹ Similar reductions have been reported for renewable diesel as well.⁴⁰ A related emission type is PM, which are particles that are small enough to enter human lungs but large enough to cause respiratory scarring and blockages.⁶² Biodiesel and renewable diesel have been found to achieve 50%⁴⁷ and 37%⁴⁰ reductions to PM emissions relative to petrodiesel. The reduction that is achieved by biodiesel also varies by feedstock, with pure soybean oil-derived biodiesel resulting in the largest emission decreases relative to petrodiesel (50%+) and that from UCO achieving the lowest (17%).⁴⁵

Relatively low biodiesel blend rates can achieve PM emission reductions compared to petrodiesel, and in 2010 the EPA cited testing that showed 14% and 16% reductions to PM and HC emissions, respectively, from the use of 20 vol% biodiesel blends.⁶³ It should be noted that the petrodiesel baseline for these emissions is in flux as diesel particulate filters become increasingly common in new diesel engines and older, more polluting diesel engines are retired.¹⁶ Heavy-duty diesel engines manufactured after 2007 are not expected to experience any reductions to PM when utilizing a 5 vol% biodiesel blend relative to ULSD as a result.⁶⁴ PM mass is not the only consideration, though,

and an extensive 2015 review of the literature found that differences in the chemical characterization of PM emitted by biodiesel and ULSD caused biodiesel emissions to have a lower toxicity.⁶⁵ The review also found that biodiesel blends lead to longer effective lives of diesel engine emissions control devices than ULSD alone. The EPA has highlighted the potential for manufacturer-warranted biodiesel blends in heavy-duty vehicle engines to change as selective catalytic reduction systems and catalyzed diesel particulate filters become more widespread.⁶⁴

Emissions studies of biodiesel and biodiesel blends relative to petrodiesel have mostly focused on light- and heavy-duty diesel engines. Studies of other engine types have found similar, but not identical, results. A review of biodiesel and biodiesel blend tests in diesel locomotive engines identified reductions in emissions of CO and PM relative to petrodiesel from biodiesel blends of 10 vol% and higher, while those of HC and NO_x were considered to be within the normal test variation range.⁶⁶ Testing of biodiesel blends in marine outboard engines has shown reduced CO emissions and mixed results for NO_x emissions.^{67,68,69}

One environmental disadvantage of biodiesel relative to petrodiesel is that of NO_x emissions. NO_x is a pollutant due to its tendency to react with ammonia and moisture to form PM and with volatile organic compounds to form ozone. Pure biodiesel has generally been found to have slightly higher NO_x emissions than petrodiesel when used in older diesel fuel engines: one review of the literature found increases of <5% and <10 vol% for biodiesel derived from saturated and unsaturated feedstocks, respectively.¹⁶ Biodiesel has nearly been excluded in the past from major demand markets such as California⁷⁰ and Texas⁷¹ due to restrictions in those states on NO_x emissions from transportation fuels. Engine tests have determined that NO_x emissions from biodiesel blends of ≤20 vol% are comparable to those of petrodiesel⁷² and, given that most consumption is within this blending threshold, biodiesel consumption has not been permanently limited by anti-NO_x regulations.

Biodiesel's NO_x emissions have also proven to be manageable: anti-NO_x fuel additives are able to reduce NO_x emissions from pure biodiesel by up to 10% relative to CARB diesel while blends of renewable diesel and biodiesel have also been found to reduce emissions relative to CARB diesel.⁷⁰ The latter outcome is possible due to reduced NO_x emissions from renewable diesel combustion relative to petrodiesel combustion, with reductions of up to 14% reported in the literature.^{40,72} Finally, CARB found in a separate literature review it undertook that newer engines with robust

NO_x emissions control features achieve the same NO_x emissions with 20 vol% biodiesel blends as with CARB diesel.⁷³ Taken together, these developments suggest that it is possible to achieve comparable or lower NO_x emissions from biodiesel than from CARB diesel at blends of >20 vol% through some combination of NO_x additive use and/or renewable diesel blending.

Conclusions

BBD blends have a technical performance profile that is largely comparable to that of petrodiesel, albeit with some important differences. Biodiesel is an oxygenated fuel and, as such, has a lower energy content than petrodiesel. This is partially offset by biodiesel's lack of commercial consumption in pure form. The marketplace's commercially available biodiesel blends (≤ 20 vol%) provide similar levels of engine power as petrodiesel, and surveys have found that fleet operators generally do not notice a discernible difference between the two fueling options. Biodiesel's main technical disadvantage relative to petrodiesel is a comparably high cloud point that can result in reduced cold weather performance, although biodiesel derived from unsaturated feedstocks has a lower cloud point than that of biodiesel from saturated feedstocks. This high cloud point is manageable through the use of anti-gelling additives, reduced biodiesel blending or blending with No. 1 ULSD in especially cold temperatures, and/or proper engine maintenance. Biodiesel also has poor oxidative stability, although this can also be managed through the use of anti-oxidation additives and routine product turnover.

The experiences of fleet operators indicate that biodiesel blends of up to 20 vol% can be consumed year-round in all but the coldest U.S. regions. Biodiesel's two main technical advantages relative to petrodiesel are its higher cetane number and superior lubricity, the latter of which has become particularly attractive with the advent of ULSD. Saturated feedstocks produce biodiesel with a higher cetane number than do unsaturated feedstocks, although in both cases the cetane numbers are higher than that of petrodiesel. Biodiesel's properties enable it to qualify as a diesel fuel and, under federal and many states' labeling laws, sold as such when used in blends of 5 vol% or less under the ASTM D975 specification. Biodiesel's primary technical constraint as a 5 vol% blend is its ability to be moved through pipelines rather than its ability to be consumed, although even this constraint is weakening as pipelines begin to allow 5 vol% biodiesel blends in some situations.

Renewable diesel's technical performance is almost identical to that of petrodiesel due to its status as a hydrocarbon fuel. Its engine power even in pure form is comparable to that of petrodiesel while its cetane number is substantially higher. Its cold point can be reduced during the production process to below that of No. 1 ULSD, although doing so also results in higher naphtha yields at the expense of renewable diesel yields. Renewable diesel complies with the ASTM D975 specification and can be used in any application in which ULSD is suited. However, the presence in many states of uniform blend labeling requirements for both biodiesel and renewable diesel can be a constraint on their movement through pipelines despite the latter's lack of a technical constraint.

Biodiesel consumption yields lower emissions of CO₂ than petrodiesel on a life cycle basis under most circumstances. Biodiesel combustion also results in reduced tailpipe emissions of CO, HC, PM, and SO_x relative to petrodiesel, including ULSD, under most performance conditions, and even biodiesel blends such as 20 vol% produce fewer of these pollutants than pure petrodiesel. Biodiesel combustion does result in slightly higher emissions of NO_x relative to ULSD, with biodiesel derived from unsaturated feedstocks resulting in greater NO_x emissions than biodiesel derived from saturated feedstocks. Extensive testing has found that this difference is non-existent in ≤20 vol% biodiesel blends or when biodiesel is blended with anti-NO_x fuel additives or renewable diesel. Renewable diesel combustion results in lower tailpipe emissions of CO, HC, PM, SO_x, and NO_x relative to ULSD, although not always relative to biodiesel as well.

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SECTION 4.

Biomass-Based Diesel Economics



Section 4. Biomass-based Diesel Economics

4.1. Production Economics

Biodiesel

Biodiesel production economics are dictated by multiple important input costs, including capital (facility) costs, feedstock cost, methanol cost, and catalyst costs. The single most important cost is that of the lipid feedstock.¹ Feedstocks with higher free fatty acid (FFA) contents such as residue and waste tend to be less expensive than those with low FFA contents, although this cost advantage is partially offset by their need for additional pretreatment equipment (see Section 1.1). Biodiesel facilities are also very sensitive to economies of scale, and a 400% increase to production capacity reduces unit production costs by approximately 30%.¹ Conversely, though, the additional feedstock requirements of larger facilities can result in cost-prohibitive increases to unit feedstock costs if the facilities rely on truck transport for feedstock procurement,* making access to rail and/or waterborne transport as important from a feedstock costs perspective as it is to biodiesel offtake.

Two different measures of profitability are employed by U.S. biodiesel producers, each encapsulating a different segment of the manufacturing chain. The “crush spread” is a common measure of profitability that is employed by agricultural lipid producers. This spread measures the difference between the cost of oilseeds and the combined value of the lipid output and any other coproducts. For example, if soybeans are priced at \$9/bushel and the crushing process yields \$6 of soybean meal and \$4 of soybean oil per bushel of soybeans, then the crush spread is equal to the difference between the inputs and outputs, or

$$[(\$6 \text{ of soybean meal} + \$4 \text{ of soybean oil}) - \$9 \text{ of soybeans} = \$1/\text{bushel}]$$

This measure is borrowed from petroleum industry’s concept of the “crack spread”, which measures profitability as the difference between the cost of petroleum at a refinery and the value of the combined refined products. A high crush spread incentivizes the production of the soybean oil that is one of the most important U.S. biodiesel feedstocks.

The U.S. biodiesel industry’s definition of crush spread is different than that of the U.S. ethanol industry. The latter employs the term to mean the difference between the cost of corn and the value

* Feedstock transportation costs, especially when moved by truck, represent a diseconomy of scale in that the transportation costs do not scale proportionately with the transportation distance, but instead increase more rapidly.

of ethanol and its coproducts. The profitability of biodiesel production facilities is instead rudimentarily quantified by the “HOBO spread” (or alternatively BOHO),* which is the difference between the price of heating oil and (soy)bean oil. It is calculated by multiplying the price of a pound of soybean oil by 7.6 since this factor is the industry standard for the gallons of FAME obtained per pound of feedstock.

Heating oil is not a lipid but rather a middle distillate similar to the petrodiesel that is produced as part of the petroleum refining process. The resulting close relationship between the prices of heating oil and petrodiesel means that the HOBO spread represents the margin that biodiesel producers obtain when converting soybean oil, the price of which is closely correlated with other agricultural lipid feedstocks, to biodiesel, the price of which is influenced by the price of petrodiesel. The HOBO spread, when combined with the soybean crush spread, approximates the profitability of the complete biodiesel production pathway since the two spreads are linked by the value of soybean oil. A positive HOBO (or negative BOHO) spread represents favorable blending economics while a neutral number indicates that neither biodiesel nor petrodiesel provides a financial advantage. The HOBO spread has been mostly negative since late 2014 (see Figure 4-1) due to a sustained period of historically low heating oil prices. In early 2016 the spread was as low as $-\$1.19/\text{gallon}$, and it only turned positive again in May 2018.

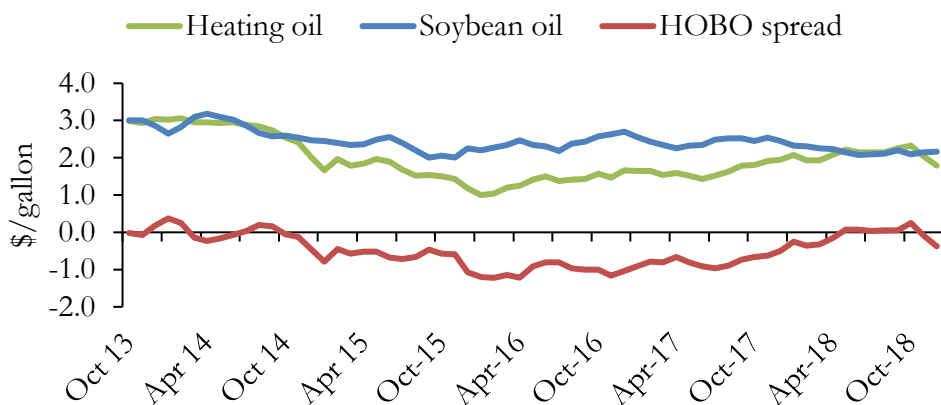


Figure 4-1. Monthly soybean oil price, NYMEX heating oil price, and HOBO spread, October 2013 - December 2018.^{2,3}

* “HOBO spread” is used by BBD producers such as Renewable Energy Group and Darling Ingredients and is the term utilized by this report. Other sources sometimes refer to this as the “BOHO spread”, which is less suitable given that production margins are normally calculated by subtracting the input cost (bean oil, in this case) from the product value (heating oil being the surrogate here) rather than the other way around, so as to calculate a positive number when margins are positive and vice versa.

The HOBOSpread is useful for quickly approximating what average biodiesel production margins are in the U.S. It fails to account for regional price differences, however. This is accomplished by incorporating “basis” into the calculation, which is calculated by subtracting a commodity’s futures price from the local price of the same commodity. Futures prices are commonly based on commodity prices in specific locations (e.g., Chicago, New York Harbor) and region-specific prices can be substantially different. The soybean basis in Iowa, for example, has historically averaged between -\$0.29 and -\$0.59/bushel for futures with July maturities. That basis varies across the state, though: Northwest Iowa has historically had the largest basis while that of East-Central Iowa has been closer to parity.⁴ The soybean basis shows similar variability across the PADD 2 region, with prices being 5-10% lower in Kansas, Minnesota, and the Dakotas than in Iowa and Illinois.⁵ Multiple factors contribute to feedstock basis including the availability of regional transportation infrastructure, transportation costs, and overall demand.

Biodiesel producers also encounter differences in fuel prices across different regions. The average PADD-specific wholesale price of No. 2 heating oil relative to the U.S. average since 2013 has been twice as large in the PADD 1 region as in the PADD 2 region, yet the latter has experienced much larger shifts in both directions.⁶ Similar variation has occurred in the spot market for No. 2 ULSD: average monthly prices in New York Harbor and Los Angeles have been \$0.01 and \$0.03/gallon higher than the national average over the last decade, while those in the Gulf Coast have been \$0.04/gallon lower. As with feedstock basis, this variation reflects differences in regional supply and demand: New York Harbor diesel fuel prices have spiked in the past in response to particularly cold winters that have caused higher heating oil demand, while Gulf Coast diesel fuel prices have been affected by regional oversupply (see Figure 4-2). Biodiesel’s status as a substitute for No. 2 ULSD means that its value as such is also affected by these regional variations.

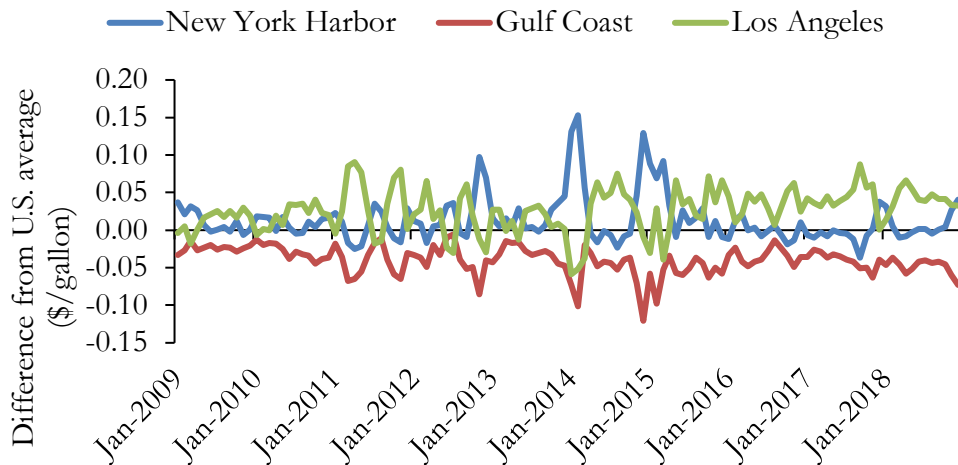


Figure 4-2. No. 2 ULSD regional spot prices relative to average of all three, 2009-2018.⁷

The HOB0 spread is a limited measure of biodiesel production economics in that it only considers one input – soybean oil – and one output – biodiesel. Iowa State University regularly publishes a more comprehensive dataset of biodiesel operating margins in the form of return over operating costs (ROOC) that are calculated as a function of, in addition to the price of soybean oil, the prices of methanol, biodiesel, and other coproducts such as glycerol.⁸ The costs of capital are also accounted for in the form of a \$0.12 operating cost for every gallon of biodiesel production, reflecting the fact that many operational biodiesel facilities are at least partially debt-financed. The University of Illinois Urbana-Champaign has also published a model of a biodiesel production facility located in Iowa that, while still more comprehensive, has calculated very similar outputs since 2013.⁹ A major conclusion of these models is that, other than brief peaks in 2011, 2013, and 2016, biodiesel production margins have been low or negative (see Figure 4-3).

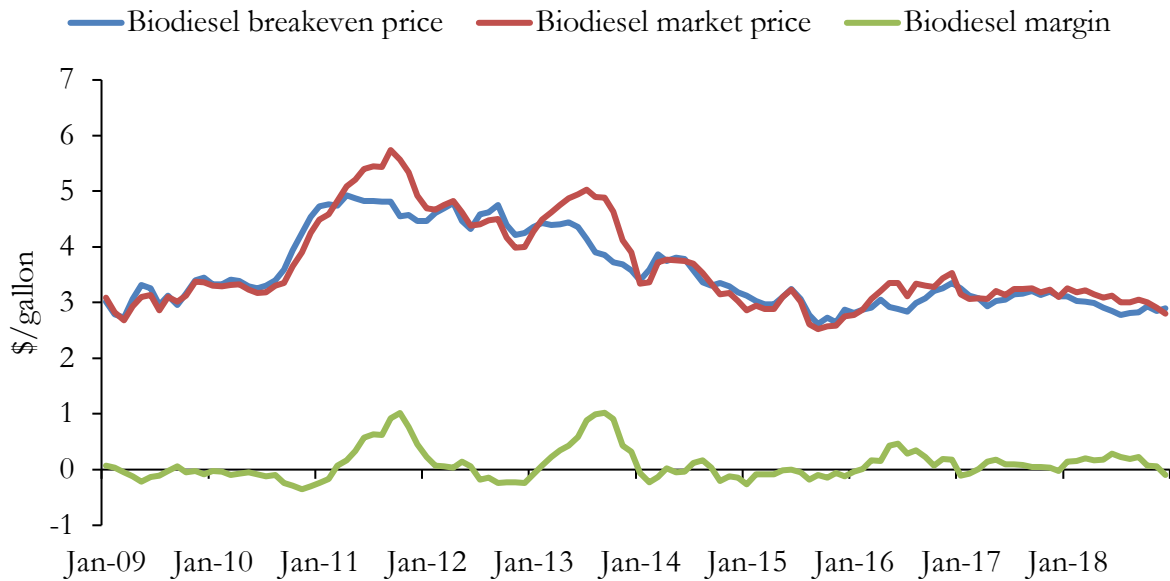


Figure 4-3. Biodiesel price, breakeven price, and production margin, 2009-2018.^{8,10} Breakeven price is calculated here as the minimum biodiesel price necessary to cover production costs, including costs of capital.

The ROOC calculation and HOBOSpread have aligned at times in the past, although the positive correlation between the two is very weak (see Figure 4-4). The ROOC calculation is more limited than the HOBOSpread in that it utilizes local prices, with the values shown in Figure 4-4 being based on Iowa prices. It has two important advantages, though. First, the ROOC calculation's inclusion of methanol and natural gas input costs in addition to coproduct values makes it a more accurate representation of the factors that determine biodiesel production margins than the HOBOSpread. Second, its use of the biodiesel rather than heating oil price enables it to incorporate the effects of the various subsidies and other incentives covered in Section 1 that are often reflected in the market price of biodiesel. The biomass-based diesel blenders' credit (BTC) results in a higher biodiesel price relative to petrodiesel than is otherwise the case, for example, since it increases biodiesel demand by blenders.^{11,12} RIN prices have a similar effect on biodiesel prices for the same reason.^{13,14} Incorporating the biodiesel price into the analysis therefore allows for the effects of these policies on production economics to be indirectly accounted for to a degree that is not fully possible with the HOBOSpread. Not surprisingly, the discrepancy between the ROOC calculation and the HOBOSpread was large during past periods when D4 RIN prices were high (e.g., mid-2013, 2017) and small when RIN prices were low (e.g., 2018). The effect of the expected or actual expiration of the BTC is also seen in the widening of the difference in late 2013 and 2016.¹⁵

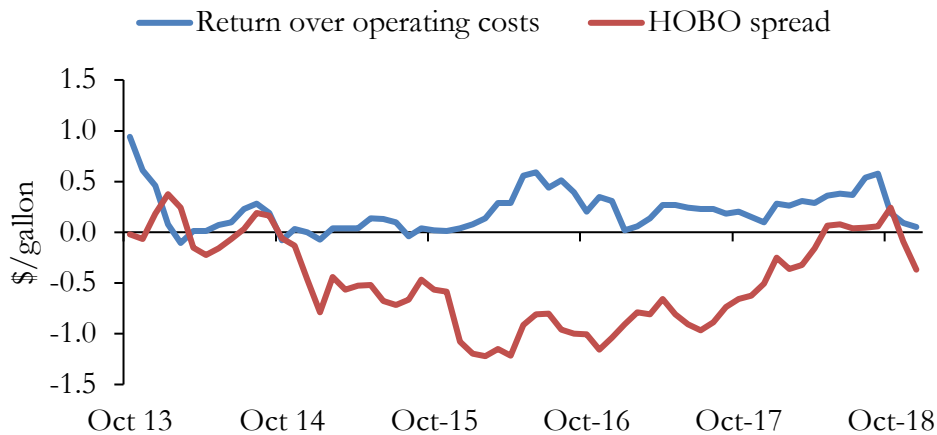


Figure 4-4. Comparison of HOBOSpread and biodiesel ROOC, October 2013 – December 2018. HOBOSpread is based on Iowa soybean oil and New York Harbor heating oil prices. Return over operating costs is based on Iowa soybean oil and biodiesel prices.^{6,8}

There is some evidence of biodiesel production margin seasonality, although identifying such a trend is made difficult by a lack of data and the effect of the frequent expirations of the BTC. Diesel fuel prices experience a large increase in the summer and a smaller (but still substantial) increase in the early winter due to demand for heating oil.¹⁶ Soybean oil prices, by contrast, begin to decline in August and remain low through late winter.¹⁷ Similar behavior by gasoline and corn prices has historically caused corn ethanol production facility production economics to be most favorable between July and December.¹⁸ A comparable effect can be expected for biodiesel production facilities, albeit to a lesser extent given that gasoline and, by extension, ethanol prices do not experience the winter increase to demand that distillate fuel oils do. Biodiesel has also experienced large December increases to demand in several recent years due to the year-end expirations of the BTC, however (see Section 1.3), and these events have made summer price increases look less substantial by comparison.

Biodiesel is not normally cost competitive with ULSD in the absence of subsidies and other policy incentives. On average between 2009 and 2018 the monthly breakeven price for Iowa biodiesel was \$1.75/gallon higher than the wholesale Iowa No. 2 distillate price. That difference has declined as petrodiesel and soybean oil prices have moved in opposite directions, averaging \$1.47 and \$1.14/gallon in 2017 and 2018, respectively. The biodiesel breakeven price, which is the price that a gallon of biodiesel must receive in order to cover a facility's operating costs (including costs of capital),¹⁹ has historically been mostly a function of the soybean oil price, with the latter having

explained 99.7% of the former's variability between 2009 and 2018 for biodiesel production facilities in Iowa. This relationship, in conjunction with the historical relationship between the prices of Iowa wholesale distillate and WTI crude, allows for the WTI crude price that is necessary for biodiesel to be competitive with petrodiesel to be calculated for a 30 MMGY soybean oil-derived biodiesel facility located in Iowa (see Table 4-1). When the price of soybean oil is \$0.30/lb, which was its average price in 2017, then a WTI crude price of approximately \$100/bbl is needed for biodiesel to be competitive with petrodiesel on an unsubsidized basis. Both conditions have been present on multiple occasions over the last decade, although they have not been simultaneously present since 2010.¹⁹

Table 4-1. Relationship between soybean oil and biodiesel breakeven prices, and the WTI crude price needed for biodiesel to be competitive with petrodiesel, 2009-2018. Author calculations.^{7,19}

Soybean oil price threshold (\$/lb)	Biodiesel breakeven price (\$/gallon)	WTI crude price (\$/bbl)
>\$0.60	>\$5.70	>\$181
>\$0.50	>\$4.90	>\$154
>\$0.40	>\$3.87	>\$127
>\$0.30	>\$3.10	>\$100
>\$0.20	>\$2.29	>\$74

Table 4-1 presents the results for a common type of biodiesel production facility, but these should not be assumed to be identical for all U.S. production facilities. Facilities in other states and PADD regions utilize feedstocks that have different costs bases (for soybean oil) or prices (for other feedstocks) in facilities with varying capacities and, by extension, economies of scale (as a rule, larger facilities have lower unit operating costs than smaller facilities, although the inverse is true for feedstock costs). As an approximation, though, Table 4-1 represents the price environment that a “typical” PADD 2 biodiesel facility needs to operate within in order to be competitive with petrodiesel on an unsubsidized basis.

An important caveat is that this unfavorable comparison excludes the value of biodiesel's positive environmental and human health externalities (or the costs of petrodiesel's negative environmental and human health externalities), which are discussed in more detail below. The price premium on an energy-equivalent basis that Midwestern blenders have been willing to pay for biodiesel relative to ULSD has varied since 2011 from above \$3/gallon to below \$0.25/gallon, but it has consistently

been a premium during that time.¹⁵ This does not just reflect biodiesel's production costs, however, but also accounts for the RFS mandate, the federal BTC, and California's LCFS. The expiration of the BTC has historically caused the price that blenders have been willing to pay for biodiesel to increase by up to \$1/gallon, for example, in order to maximize their generation of the tax credits; the biodiesel/ULSD spread has on average been \$0.74, \$0.77, and \$0.67/gallon diesel eq. in the Chicago, Gulf Coast, and New York Harbor markets when the BTC has been in effect compared to when it has not been.¹⁵ Regional differences in the biodiesel premium are attributable to a combination of infrastructure constraints and differences in state- and local-level biodiesel subsidies.*

The U.S. Renewable Fuel Standard (RFS) and California's Low Carbon Fuel Standard (LCFS) both internalize biodiesel's positive environmental externalities by linking their subsidies to biodiesel's greenhouse gas (GHG) emission reductions (see Section 1.3), and biodiesel can be expected to be priced at a premium over ULSD so long as that internalization occurs. The LCFS's current credit price of \$196/Mg results in a subsidy to biodiesel that achieves a 50% GHG emission reduction relative to ULSD of \$1.22/gallon, with larger subsidies for biodiesel that achieves larger emission reductions, in California.²⁰ Notably, a subsidy of \$1.22/gallon is comparable to the midpoint of the 2011-2018 biodiesel price premium relative to ULSD.¹⁵ Biodiesel's market value is greater in the presence of such policies since the markets in those jurisdictions are required to internalize biodiesel's environmental benefits (to date, in the form of reduced GHG emissions). While the mechanism employed by each policy varies, each has a similar effect on the biodiesel price premium by increasing demand for the fuel relative to ULSD.

The importance of such positive externality internalization for biodiesel is illustrated by the historical difference between the breakeven price of biodiesel produced in Iowa and that state's No. 2 distillate wholesale price on an energy-equivalent basis. Between 2009 and 2018 biodiesel's breakeven price was an average of \$1.56/gallon higher than the No. 2 distillate wholesale price (see Figure 4-5). This difference has ranged from as much as \$2.49/gallon to as low as \$0.72/gallon despite the positive effect that petrodiesel prices have on the price of soybean oil. This difference has moved lower since 2016 as soybean oil and petrodiesel prices have moved in different directions, however.

* E.g., blenders are willing to pay more for biodiesel in states that provide it with fuel excise tax credits than in those that do not, other things being equal, since the credits effectively increase the biodiesel retail price that consumers will pay relative to petrodiesel.

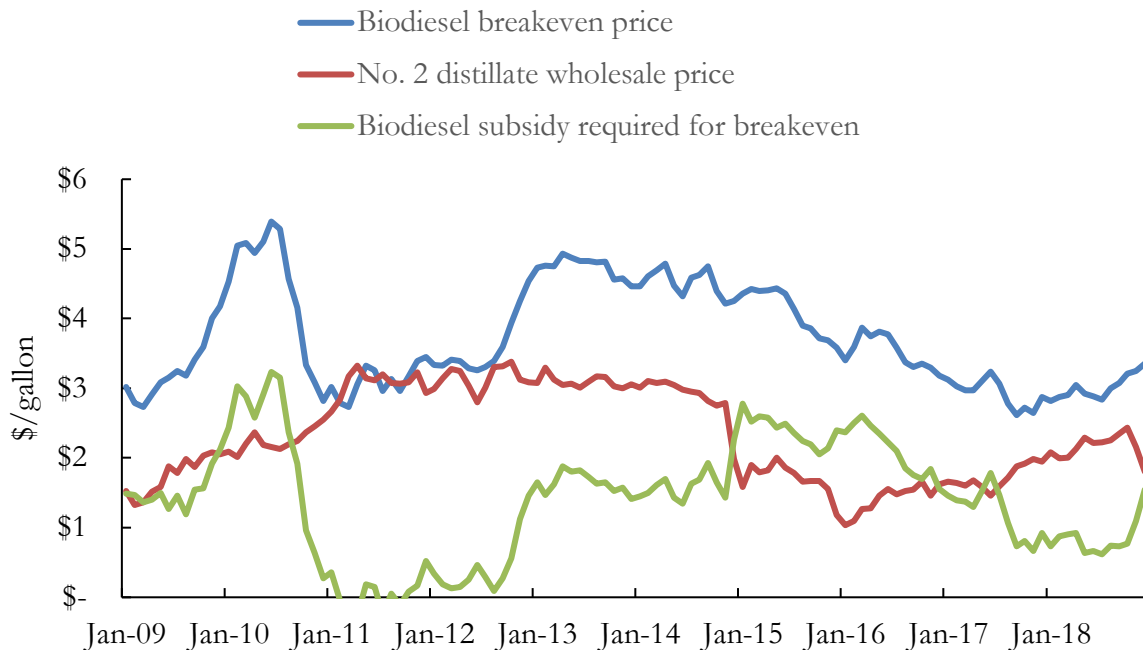


Figure 4-5. Difference between biodiesel breakeven price and No. 2 distillate wholesale price in Iowa, 2009-2018.^{10,21}

LCFS data shows that soybean oil-derived biodiesel generated an average of 0.006 credits/gallon in 2017 and 2018.²² During that same period soybean oil-derived biodiesel in Iowa required an average subsidy of \$1.32/gallon to equal the No. 2 distillate wholesale price. (The differences in transportation costs to and distillate wholesale prices in California and Iowa are assumed to offset for the purpose of this calculation.) Soybean oil-derived biodiesel in Iowa would have needed to receive a LCFS credit price of \$238/Mg during that period in order to be competitive with petrodiesel as a result. While this carbon credit value is higher than the actual price that prevailed at the time, the calculation also shows the impact that the price of petrodiesel has on the positive externality value that is required for biodiesel to be competitive: in the second half of 2018, when rising petrodiesel and declining soybean oil prices caused biodiesel's breakeven point to fall, biodiesel would have needed to receive a LCFS credit price of only \$160/Mg. By comparison the average credit price was \$177/Mg over the same period.³⁸ Finally, it should be noted that soybean oil results in biodiesel with a comparatively low credits/gallon ratio: UCO-derived biodiesel's required credit price in the second half of 2018 was only \$63/Mg (assuming comparable breakeven points for biodiesel from both feedstocks).

Renewable diesel

Renewable diesel's lack of commercialization to date relative to biodiesel has prevented its production economics from being studied as extensively. The two pathways have several notable similarities with regard to production margins, however. First, both utilize lipid feedstocks and, while the prices of different feedstocks vary relative to one another over time, these prices have historically been positively correlated.²³ Second, while biodiesel reacts its feedstock with methanol and renewable diesel instead utilizes hydrogen, both of these inputs are primarily derived from natural gas in the U.S., causing the prices of both to be positively correlated. Third, biodiesel and renewable diesel are affected by many of the same federal and state subsidies and other incentives. Finally, both renewable fuels replace petrodiesel, causing their market values to be positively correlated as well.

The production economics for renewable diesel do have some important differences compared to biodiesel, however. A 2009 study that was conducted by researchers at Michigan Technological University and Honeywell UOP, the latter of which has commercialized the Ecofining™ process that is utilized at multiple existing and planned renewable diesel production facilities, concluded that the fuel's price premium over biodiesel could be as high as \$0.90/diesel gallon-equivalent (DGE) due to its superior technical performance alone.²⁴ A more recent analysis calculated a capital cost for a standalone renewable diesel facility that was almost 90% higher than that of a standalone biodiesel facility due to the former's more severe (i.e., higher pathway pressures and temperatures) operating conditions.²⁵ Despite this high capital cost, however, the analysis further calculated a production cost for renewable diesel that was only 24% higher than that of biodiesel if produced at a standalone facility and 9% lower if produced at a facility co-located with an existing refinery.

Data on renewable diesel purchase sales prices is limited due to a lack of derivative instruments and reported rack prices for the fuel.³⁴ Biodiesel prices can serve as an imperfect analog after accounting for energy content differences between the two: both fuels are derived from the same feedstocks for use in the same types of engines and receive similar subsidies. They have different technical parameters, though, and renewable diesel's market value is sometimes calculated as the sum of the ULSD price, the D4 RIN price, and the California LCFS credit value (since California is a major source of U.S. renewable diesel demand).²⁶

The company Darling Ingredients publishes financial data on the Diamond Green Diesel (DGD) renewable diesel production facility from which average renewable diesel prices, price premiums relative to ULSD, and production margins can be calculated (see Figure 4-6).^{7,27} This data shows that the renewable diesel premium, measured as the difference between Darling Ingredients's reported average annual sales price and the average spot price of Gulf Coast No. 2 ULSD, increased from \$1.16/gallon in 2014 to \$2.26/gallon in 2018. While the data does not show the LCFS credit value received by DGD, using the average value of the facility's certified pathway intensities²⁸ to calculate an annual average credit value^{20,29} that is added to the annual average RIN price yields values for 2017 and 2018 (\$2.44 and \$2.17/gallon, respectively) that are within 5% of the calculated premium values for those years. While this is an approximation based on a single U.S. renewable diesel production facility, albeit its largest, it does suggest that the renewable diesel price premium is mostly based on its environmental rather than technical performance.

The data published by Darling Ingredients also indicates that renewable diesel's production margins are, at least in the PADD 3 region, substantially higher than those of biodiesel. With the exception of 2017, when the data was likely affected by the start of a major capacity expansion at the DGD facility, the Darling Ingredients data has reported average production costs, including costs of capital, ranging from a low of \$2.03/gallon to a high of \$2.72/gallon; 2018's value was \$2.28/gallon.²⁷ The company has also reported an average net income of \$1.04/gallon from 2014 to 2018 for the DGD facility. Its average renewable diesel sales price of \$3.69/gallon over the period was only slightly higher than that of biodiesel on an energy-equivalent basis, though, leaving the DGD facility's substantial economies of scale as the likely explanation for its relative profitability.

4.2. Demand economics

The economics of biodiesel demand are different from its production economics. (This subsection focuses on biodiesel due to a lack of renewable diesel price data at the retail level,³⁴ but the demand economics of the two fuels are likely to be similar.) There are two reasons for this unique behavior: federal policies that affect blenders and state policies that affect retailers. The RFS, BTC (when active), and the LCFS all affect blending operations. The RFS and LCFS require the addition of biodiesel to the transportation fuel supply and, due to equipment constraints, this takes the form of blended biodiesel. The BTC provides an incentive rather than an obligation but resembles the two

mandates in that it is earned via blending activities. The stage of the biodiesel supply chain at which each of these policies takes effect has a substantial impact on retail price behavior.

Blenders, when the BTC is active, receive a financial incentive of \$1 for every gallon of biodiesel that they blend into the transportation fuel supply. This in turn allows them to pay up to \$1 more for every gallon of biodiesel that is purchased from producers than they otherwise would. Whereas a higher purchase price by blenders would in theory be recouped via higher sales prices to retailers and ultimately consumers in the absence of the BTC (and, in reality, consumers would be unwilling to pay the premiums for pure biodiesel discussed in Section 4.1), with the BTC blenders can sell the biodiesel on for up to \$1/gallon less than they purchased it.

The RFS and LCFS both have a similar effect on biodiesel prices at the blending stage of the supply chain, albeit via a different mechanism. Both mandates are imposed on refined fuels producers (refiners) and importers that either purchase biodiesel as a blending operation input or, for those entities that are constrained by technical limitations (e.g., a lack of access to blending infrastructure that is downstream of the pipeline), purchase blending credits from other blenders. These blenders,* both obligated and non-obligated, have a financial incentive that is equal to the value of the credits to pay a premium for the biodiesel that they must purchase in order to receive the credits. This premium is then recouped by the blenders in the form of higher refined fuel retail prices.^{20,30,31} The primary difference between the BTC and the RFS/LCFS is that taxpayers bear the cost of the subsidy under the former and consumers bear the costs of the mandates, but this does not change the programs' effects on retail prices.

The average retail price of 20 vol% biodiesel blends in the U.S. has historically been competitively priced with petrodiesel: from 2009 to 2018 the blend's retail price was an average of 9% higher than that of petrodiesel on an energy-equivalent basis (see Figure 4-6).³² This premium slowly declined from \$0.26/gallon in early 2009 to -\$0.24/gallon. The 20 vol% biodiesel blend discount grew during the BTC's extended period of inactivity in 2018 and 2019. Early evidence from biodiesel producers' earnings reports suggests that the absence of the BTC caused blenders to reduce the premium that they were willing to pay to producers due to uncertainty about the BTC's reinstatement, and one large producer reported accepting lower prices for its biodiesel than in the past as a result.³³ It is

* This subsection uses the RFS's definition of blenders, which refers to those entities, primarily refiners, that are required by the mandate to blend biofuels. The blenders referred to here are not usually the same as the bulk terminal operators and fuel jobbers discussed in Section 2.

possible that this trend has been reflected in lower 20 vol% biodiesel blend retail prices relative to petrodiesel.

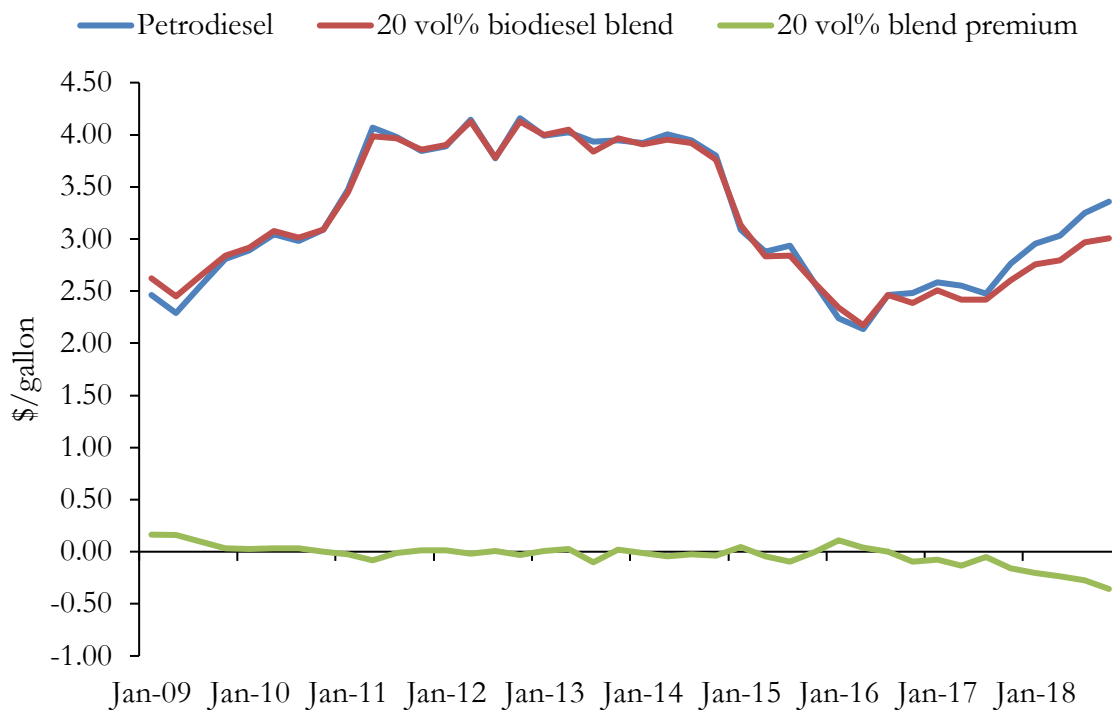


Figure 4-6. Comparison U.S. average petrodiesel and 20 vol% biodiesel blend retail prices, 2009-2018.³²

Biodiesel blend prices at retail stations experience a substantial amount of regional variation. Retail price data collected by the U.S. Department of Energy's (DOE) Clean Cities Coalition shows that retail 20 vol% biodiesel blends sell at a discount in the PADD 1 and PADD 5 regions and a premium in the PADD 2, PADD 3, and PADD 4 regions (see Table 4-2).³⁴ In addition to the aforementioned regional variation factors, retail prices are also affected by the fuel excise tax credits that are available in some states but not in others (see Section 1.3). The effect of such tax credits is to reduce the price of 20 vol% biodiesel blends at the retail pump relative to petrodiesel, which must pay the full excise tax amount (an average of \$0.304/gallon to the state on top of the federal fuel excise tax amount of \$0.244/gallon).³⁵ (This effect is illustrated by the fact that the retail price of pure biodiesel, which commonly receives the same excise tax credit per gallon as ≤ 20 vol% biodiesel blends, was an average of \$0.75/gallon more expensive than petrodiesel in the U.S. when the average U.S. 20 vol% biodiesel blend was \$0.15/gallon less expensive.)³⁴ While U.S. average 20 vol%

biodiesel blends have not always been less expensive than petrodiesel, the regional variation shown in Table 4-2 has largely remained unchanged in recent years.³⁶

Table 4-2. Petrodiesel price discount relative to 20 vol% biodiesel blend price, retail basis, April 2019.³⁴

Region	20 vol% biodiesel blend prices (\$/gallon)	Petrodiesel fuel prices (\$/gallon)	Petrodiesel discount (\$/gallon)
PADD 1A	\$2.89	\$3.22	-\$0.33
PADD 1B	\$2.56	\$3.16	-\$0.60
PADD 1C	\$2.65	\$2.95	-\$0.30
PADD 2	\$2.99	\$2.97	\$0.02
PADD 3	\$2.91	\$2.72	\$0.19
PADD 4	\$3.24	\$2.96	\$0.28
PADD 5	\$3.12	\$3.83	-\$0.71
U.S. average	\$2.88	\$3.09	-\$0.21

The PADD-level biodiesel and petrodiesel retail price data also illustrates the effect of California's LCFS, which simultaneously increases petrodiesel prices³⁷ and reduces biodiesel prices. The PADD 5 region has had the country's highest petrodiesel retail prices but also the largest petrodiesel premium relative to 20 vol% biodiesel blend retail prices.³⁶ The 20 vol% biodiesel blend discount has increased from \$0.21/gallon in January 2017 to \$0.64/gallon in April 2019 as the LCFS carbon credit price has roughly doubled to almost \$200/Mg over the same period.³⁸ By contrast, the PADD 4 region has historically had the largest petrodiesel price discount relative to 20 vol% biodiesel blends, and its states have few biodiesel production and/or consumption incentives compared to other PADD regions (see Section 1). The correlation between the 20 vol% biodiesel blend price discount and consumption volume does break down for the PADD 1 and PADD 2 regions, showing that other factors such as regional production and infrastructure also affect both outcomes. However, the price behaviors in the PADD 4 and PADD 5 regions are in keeping with the broader supply and demand characteristics of both as discussed elsewhere in this report (see Section 1 and Section 2).

The identification of seasonal trends in the 20 vol% biodiesel blend price premium/discount relative to petrodiesel is limited by a lack of granular data (the DOE's Clean Cities coalitions report data on a quarterly basis, for example). The databases that are available shows that, on average between 2009 and 2018, the premium has been highest at the beginning of the year and progressively lower with each subsequent quarter.³⁴ Specifically, the premium relative to January has on average been lower by

\$0.03, \$0.04, and \$0.06/gallon in April, July, and October, respectively. Excluding 2017 and 2018 from the calculation (due to the steady decline of the premium in those years) yields a very similar result, with the premium in July and October both being lower relative to January by \$0.05/gallon.

The price premium of 20 vol% biodiesel blends relative to petrodiesel is strongly affected by whether the blend is being sold to the public or to a private fleet instead (i.e., the retail station is only available to select fleets). This biodiesel blend has consistently been sold at a premium to petrodiesel at public retail stations but a discount, sometimes quite large, to petrodiesel at private retail stations over the last decade. The private retail station discount has generally been largest in the PADD 2 region: in April 2019 it was \$0.86/gallon compared to the U.S. average discount of \$0.51/gallon.³⁴ The difference between the retail price of petrodiesel at private and public stations has been much smaller over the same period. This is a notable finding given that fleets, particularly those that are government-owned, have inelastic demand due to the presence of government mandates and corporate policies that require or encourage the consumption of 20 vol% biodiesel blends. The driving public, on the other hand, has greater flexibility to switch between biodiesel blends and pure petrodiesel based on the retail price alone.

The Clean Cities coalition unfortunately does not publish retail price data on ≤ 5 vol% biodiesel blends, stating that the data is limited due to the blend being “not widely used.”³⁴ This reflects the lack of labeling requirements for such blends by the federal and many state governments as well as the ability for such blends to meet the ASTM D975 specification (see Section 3.1).

4.3. Consumption costs

The differences between the production and demand economics of biodiesel and petrodiesel mean that the two cannot be substituted for one another without incurring different financial implications. The widespread ability of motor vehicle diesel engines to utilize ≤ 20 vol% biodiesel blends means that these implications primarily affect operational rather than capital costs. The use of >20 vol% blends can necessitate higher capital costs due to the need to upgrade and otherwise modify the vehicles that will use them (e.g., modifications to seals and gaskets, and installation of tank, fuel line, and fuel filter heaters). This subsection focuses on ≤ 20 vol% biodiesel blends since they are the form that most U.S. biodiesel consumption takes.

From the perspective of a vehicle owner, the primary financial implication of utilizing a ≤ 20 vol% biodiesel blend is the price premium (see Section 4.2) that has prevailed in the U.S. for most of the last decade and continues to exist in some PADD regions. A U.S. driver would have paid an average of \$0.02/gallon less between 2015 and 2018 for each gallon of 20 vol% biodiesel blend purchased compared to diesel fuel. That amount has been declining, though, from an annual average premium of \$0.06/gallon in 2015 to a discount of \$0.19/gallon in 2018.³⁶ The actual amount paid by the driver would have also been heavily influenced by the location of the retail station. Except for the PADD 3 region, every PADD region had a lower biodiesel blend premium (or larger discount) at the end of 2018 than it did at the beginning of 2015. The average premium over that period ranged from -\$0.19/gallon (PADD 5) to \$0.16/gallon (PADD 4). Substantial variation has existed even within PADD regions: the PADD 1A (New England) region's premium averaged -\$0.11/gallon from 2015 to 2018 compared to -\$0.20/gallon in PADD 1B (Central Atlantic) and -\$0.18/gallon in PADD 1C (Lower Atlantic).

Assuming that the vehicle driver is using a fully loaded Class 8 tractor-trailer truck on a mixed drive cycle with fuel consumption of 17.2 gallons per 100 miles³⁹ and is driving an average of 68,155 miles per year,⁴⁰ then on average in the U.S. the driver would experience annual fuel cost savings relative to pure ULSD consumption of \$166 by using a 20 vol% biodiesel blend (see Figure 4-7). The same driver operating strictly in the PADD 1B, PADD 1C, or PADD 5 regions would experience annual reduced fuel costs of between \$1,710 and \$3,067. Alternatively, operating in the PADD 2, PADD 3 or PADD 4 regions would result in higher average annual fuel costs of \$713, \$1,866, and \$2,657, respectively.



Figure 4-7. Average annual fuel cost difference of using 20 vol% biodiesel blend relative to ULSD baseline. Assumes a fully loaded Class 8 tractor-trailer truck, a mixed drive cycle with fuel consumption of 17.2 gallons per 100 miles, and 68,155 average annual vehicle miles. Based on average prices from January 2015 to December 2018.^{39, 40}

Retail price data is not available for 5 vol% and 10 vol% biodiesel blends. If these scale proportionately with 20 vol% biodiesel blends, however, the effect would be to reduce the size of the premium/discount. On average the additional cost of consuming a 5 vol% biodiesel blend in the U.S. rather than ULSD is so small as to be insignificant, for example, although the variation across PADD region still exists. That said, the effect is not necessarily the same for >20 vol% biodiesel blends due to the way that fuel excise tax credits in many states operate: in Iowa, for example, 11 vol% biodiesel blends receive the same tax credit amount as 99 vol% blends.⁴¹ The availability of >20 vol% biodiesel blends is also more limited than that of ≤ 20 vol% blends, incurring additional transportation and infrastructure costs that are recouped via higher retail prices.³⁴

An important caveat to this assessment is that maintenance costs are assumed to be the same when consuming ≤ 20 vol% biodiesel blends as when consuming pure ULSD. This is based on a review of the literature on biodiesel blend technical performance (see Section 3.1). This assumption is certainly valid for 5 vol% biodiesel blends: a study of fleet maintenance costs before and after the adoption of that blend in Pennsylvania found no statistical difference, for example.⁴² Short-term studies comparing 20 vol% biodiesel blends with ULSD in buses have found comparable maintenance costs

for both fueling options.^{43,44} There is limited evidence of slightly lower longer-term maintenance costs (<1%) for heavy-duty vehicles that utilize 20 vol% biodiesel blends that has been built into the Argonne National Laboratory's GREET model.⁴⁵ Specifically, fuel filter replacements have been found to be more frequent but engine wear lower with 20 vol% biodiesel blends relative to ULSD.⁴⁶ However, the National Renewable Energy Laboratory noted in 2016 that “long-term engine durability data have not been established” for 20 vol% biodiesel blends, and recommends “good maintenance practices” as a result.⁴⁷ This is especially true given a paucity of research into the effects of 20 vol% biodiesel blends on the maintenance costs of newer diesel engines containing advanced emissions controls.

Conclusions

Biodiesel production economics are quantified via two different metrics. The more common metric is the HOBO spread, which measures the difference between the approximate value of a gallon of biodiesel, as represented by the price of heating oil, and the cost of soybean oil (“bean oil”). The HOBO spread is a rudimentary metric that has the advantage of being easily calculated, although it excludes important input costs (capital, catalysts, methanol, and natural gas) and coproduct values (glycerol). A more comprehensive metric quantifies the return over operating costs of a biodiesel facility, from which the price that biodiesel must receive in order for a production facility to avoid losses (the breakeven price) can be derived.

Renewable diesel production is not as developed as biodiesel production and it lacks the type of widely used metrics that have been developed for the biodiesel sector. That said, literature estimates of renewable diesel production indicate that it is the more expensive of the BBD fuels to produce but also the more valuable due to its higher energy content and lack of technical and performance constraints. This finding is supported by the limited financial data that has been published by renewable diesel producers.

The price that biodiesel producers receive for biodiesel is determined as a function of the price of petrodiesel and the effect of any policies or other incentives under which biodiesel is produced and/or consumed. The price of biodiesel has historically been strongly influenced by that of petrodiesel due to the substitution that occurs between the two fuels. This has been to biodiesel's

disadvantage since the price of petrodiesel has been substantially lower than biodiesel's breakeven price over the last decade, although the difference has decreased since 2017 as the price of soybean oil has fallen relative to that of petrodiesel. Biodiesel production margins have remained high enough to support rising production volumes because of major federal and state mandates (e.g., the RFS and LCFS) and incentives (e.g., the BTC). The combined effect of these policies has been to increase the price for biodiesel that blenders and retailers have been willing to pay to producers relative to the biodiesel breakeven price.

Biodiesel production margins experience both regional and seasonal variability. The cost of feedstocks varies widely even within states, let alone across the U.S. Likewise, the value of biodiesel also differs across PADD regions due to differences in petrodiesel prices and state-level policies between them. Biodiesel production margins have shown a limited seasonal effect by frequently rising as the year progresses, although analysis of this is complicated by a lack of data and the impact of the frequent BTC expirations, the latter of which have caused biodiesel prices to increase late in expiration years.

The primary biodiesel blend for which retail price data is available, 20 vol%, has historically sold at a small premium to petrodiesel such as ULSD, although that premium has become a discount in recent years. The biodiesel blend retail price premium does vary widely across PADD regions, with the PADD 3 region having a large premium and the PADD 5 region having a large discount. There are also large differences between the retail prices of biodiesel blends at private and public retail stations, with the former being characterized by large discounts that do not necessarily exist for other fuels, including ULSD.

BBD economics are properly viewed within the context of market externalities, particularly with regard to the environmental benefits of BBD consumption relative to petrodiesel consumption. Data published by California as part of its LCFS program makes it possible to calculate the value of the benefit internalization that biodiesel and renewable diesel must receive as a function of the carbon credit price in order to be cost-competitive with petrodiesel. This value changes in response to the prices of lipid feedstocks and petrodiesel, declining when feedstocks become inexpensive relative to petrodiesel and vice versa. It also varies by feedstock due to the different carbon intensities of biodiesel based on the feedstock from which it is derived: waste feedstocks require a lower credit price to be competitive than agricultural feedstocks, for example.

Vehicle drivers have incurred almost no increase to average annual costs relative to ULSD from the use of 5 vol% biodiesel blends since 2015 and only small increases to average annual costs from the use of 20 vol% biodiesel blends over the same period. There is a large amount of variability regarding costs across PADD regions, however, with annual average costs relative to petrodiesel being as much as \$3,331 higher (PADD 4) and \$2,237 lower (PADD 1B) for 20 vol% biodiesel blends. A review of the literature indicates that short-term maintenance costs are comparable for ≤ 20 vol% biodiesel blends and ULSD, although it should be noted that there is a lack of longer-term studies on the use of biodiesel blends in new diesel engines in the literature.

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Conclusion

U.S. BBD consumption has increased rapidly in a relatively short timespan to become a leading source of alternative transportation fuel.

The availability of lipid feedstocks has grown at the same pace as higher agricultural oilseed productivity and the sourcing of residual and waste feedstocks have supported increased domestic production. The last decade has also seen biodiesel complemented by the arrival of renewable diesel, and U.S. production capacity for the latter is on track to equal that of the former within the next five years. U.S. BBD consumption has also been met by substantial import volumes, although these have declined sharply since 2016.

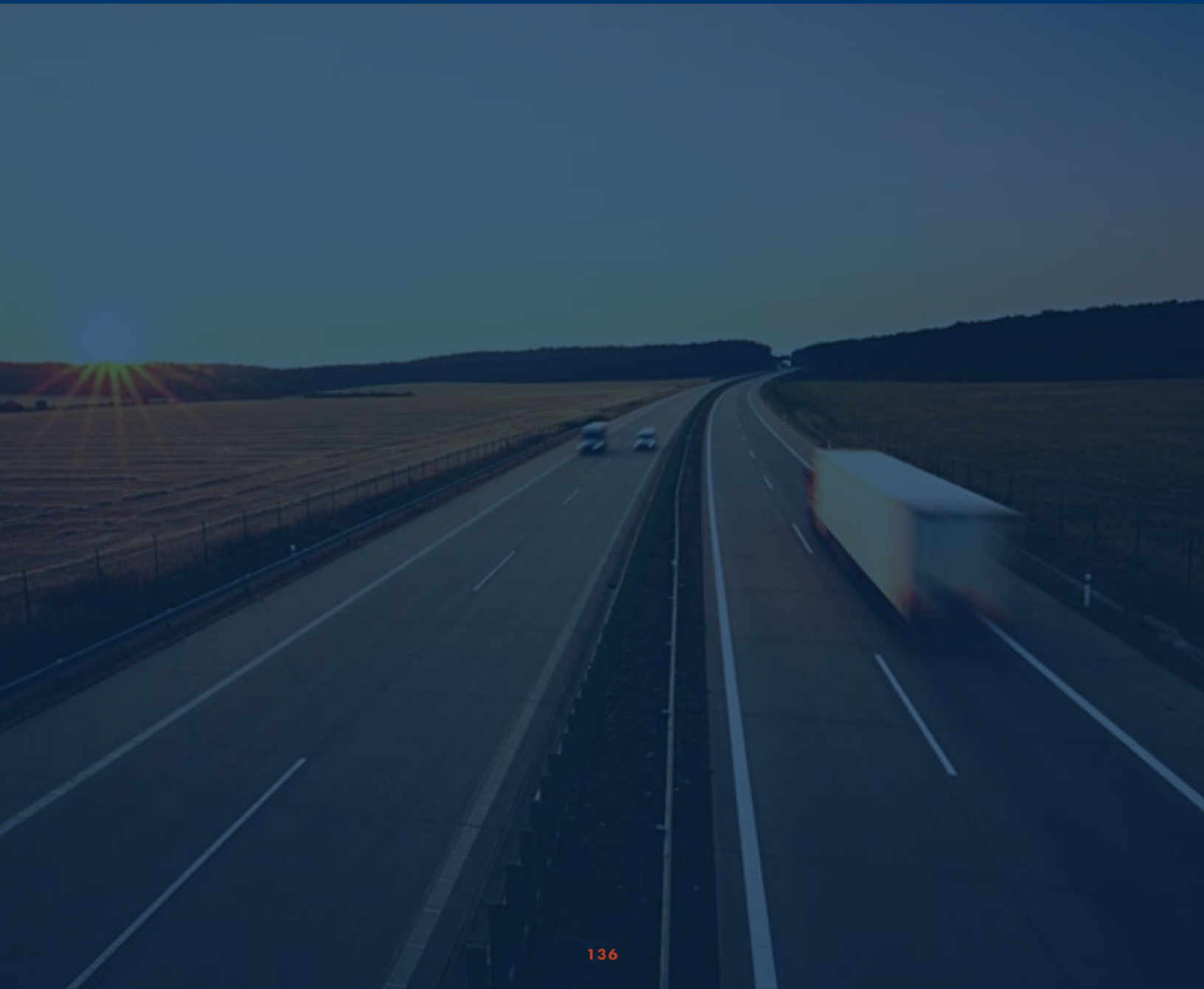
BBD's widespread acceptance in the U.S. can be attributed to its broad compatibility with the U.S. transportation fuel infrastructure and positive environmental attributes. Biodiesel and renewable diesel are both miscible with petrodiesel and are commonly utilized as blends of 20 vol% or more. While biodiesel does encounter blending constraints at higher blend rates, current U.S. consumption volumes remain well below the levels permitted by existing infrastructure. Both BBD fuels provide improvements to technical performance relative to ULSD, although the specific advantages are different for biodiesel and renewable diesel.

Likewise, while both BBD fuels also provide substantial environmental performance benefits relative to ULSD, especially with regard to lifecycle GHG emissions, these also vary by fuel type.

BBD production economics are driven by the combination of feedstock and ULSD prices. BBD fuels have had a breakeven price over the last decade that has been \$1-2/gallon higher than the ULSD wholesale price. The widespread recognition by state and national governments of BBD fuels' environmental benefits have resulted in the implementation of a variety of government policies for the purpose of the internalization of these benefits. These policies, particularly those that have a carbon intensity component, have been an important driver of U.S. BBD demand over the last decade. The important role that carbon intensity has in many of these policies has also contributed to the expanded role of residue and waste feedstocks over the same period. These policies have also had the combined effect of BBD prices that are slightly less expensive than petrodiesel prices in the U.S. on average, although that discount does not exist in all U.S. regions.

Appendix I

PADD- AND STATE-LEVEL BBD SUPPLY PROFILES



Appendix I – PADD- and State-Level BBD Supply Profiles

I.1. Biodiesel supply – PADD 1

The PADD 1 region’s facilities have the smallest average capacity at 8.7 MMGY (see Table A-1). Most of these facilities have capacities of 4 MMGY or less and are characterized by their close proximity to urban centers and their advertised use of UCO as a partial or even sole feedstock. Producers in PADD 1 states, especially those in New England, do not have close access to major oilseed crops such as soybean oil and corn oil. UCO is available from urban areas but its supply chain is highly fragmented and not as developed as are those of oilseed and other waste feedstocks, constraining the production capacity that is supported by local feedstock availability.

Table A-1. Number of biodiesel facilities and their average annual capacity in 2018.¹

Region	# of production facilities	Avg. capacity (MMGY)
PADD 1	20	8.7
PADD 2	43	31.6
PADD 3	17	37.5
PADD 4	1	33.8
PADD 5	15	15.2
U.S.	96	25.1

The PADD 1 region’s larger facilities are clustered in Pennsylvania and the Lower Atlantic states. Delaware, Maryland, New Jersey, New York, Vermont, and West Virginia did not host any active biodiesel capacity in 2018 despite having a combined population of 38 million and large urban centers such as New York City. Biodiesel production facilities in Massachusetts, Maine, New Hampshire, and Rhode Island all have capacities of 4 MMGY or less. Approximately half of the PADD 1 region’s capacity is in Pennsylvania alone despite the state hosting only two facilities, and this percentage rises to 70% if the capacities of Florida and Georgia are included. The PADD 1 region has the country’s lowest amount of annual biodiesel production capacity per capita at 1.5 gallons/person.

PADD 2 facilities, by contrast, are much larger than the PADD 1 facilities with an average capacity of 31.6 MMGY. The PADD 2 region also contains 43 active facilities, the most of any PADD region. It has the country’s largest amount of annual biodiesel production capacity per capita at 16.2

gallons/person. Both the number of facilities and their large average capacities are supported by the vast quantities of oilseeds, especially soybeans, that are produced in the region. Just five states that are collectively responsible for 50% of U.S. soybean production – Illinois, Iowa, Minnesota, Indiana, and Missouri – host 75% and 42% of the active biodiesel production capacity in the PADD 2 region and U.S., respectively (see Table A-2). While not all states that have a large soybean sector also have a large volume of biodiesel production capacity, with Nebraska and South Dakota being two notable exceptions, soybean productivity is positively correlated with biodiesel capacity.

Table A-2. Soybean production and active biodiesel production capacity by state, 2018.²

State	Soybean production (million bushels)	Biodiesel production capacity (MMGY)
Illinois	716.1	177
Iowa	590.4	443
Minnesota	387.0	83
Indiana	370.8	104
Nebraska	337.9	3
Ohio	286.5	71
South Dakota	277.3	0
Missouri	269.3	212
North Dakota	235.8	85
Kansas	197.2	51

Soybean production in the PADD 2 region is characterized by highly developed supply chains and markets that support comparatively large biodiesel production facilities. Many PADD 2 biodiesel facilities are located along major waterways (e.g., the Mississippi River and Ohio River) and/or rail main lines that carry large volumes of soybean and soybean oil shipments.³ The larger PADD 2 facilities are equipped with substantial railhead and/or barge dock infrastructure in addition to road access. The PADD 2 region also contains a large amount of oilseed storage capacity that ensures a constant supply of oilseed feedstock throughout the year rather than just following the harvest months. Finally, the presence of an active futures market for oilseeds allows PADD 2 biodiesel producers to establish hedges and minimize their exposure to feedstock price volatility.

The PADD 3 biodiesel facilities have an average capacity of 37.5 MMY and are characterized by their use of a variety of feedstocks, including both agricultural crops and waste products. This

feedstock flexibility is made possible by the access that the facilities have to main line rails, the Mississippi River, and deepwater ports rather than due to their proximity to rural agricultural regions.⁴ More than 60% of the region's production capacity was located in Texas in 2018 despite the state's status as a marginal producer of oilseed crops. Texas hosts North America's largest biodiesel production facility, the 180 MMGY RBF Port Neches facility. Approximately half of the state's capacity, including the RBF Port Neches facility, is located in and around Houston at facilities that have access to road, rail, barge, and deepwater shipping.

The PADD 3 facilities are similar to those in the PADD 2 region in that they have a high volume of per capita annual biodiesel production capacity at 13.4 gallons/person. These facilities exceed the PADD 2 facilities in terms of scale, however. Of the 10 largest biodiesel production facilities in the U.S., four are located in the PADD 3 region.⁴ Facilities in the PADD 3 region are able to achieve larger scales due to their access to multiple feedstock supply chains. In addition to the access that many of the facilities in Texas have to deepwater shipping, multiple facilities in Arkansas and Mississippi have barge access via the Mississippi River in addition to the main line rail and road access.

PADD 3 biodiesel production facilities have access to multiple feedstocks due to the region's well-established supply chains. The U.S. is a major exporter of soybeans, over half of which leave the country via the Mississippi Delta.³ Multiple major rail lines also connect the PADD 2 region's soybean production areas to Gulf Coast ports. In addition to this supply from elsewhere, the PADD 3 region produces large quantities of its own feedstocks in the form of tallow and inedible animal fats from the Gulf Coast's many animal processing facilities. Finally, urban centers such as Dallas and Houston produce UCO that is collected and utilized as a partial feedstock at nearby biodiesel production facilities. This ability to utilize multiple feedstock types that continuously arrive via multiple supply chains allows the PADD 3 region to support a disproportionate share of the country's largest biodiesel production facilities.

Operational biodiesel capacity in PADD 4 was limited to a single 40 MMGY in Utah in 2018.¹ As a result the region has a low volume of active annual biodiesel capacity per capita of 3.3 gallons/person despite having the smallest population of the five PADD regions. Even that number is uncertain following the news in early 2019 that the U.S. government was moving to seize the facility as part of legal investigation into fraud by the facility's owner.⁵ The PADD 4 region suffers

from mountainous terrain, disruptive weather conditions, a lack of barge traffic, and limited main line rail routes. This lack of feedstock supply chains is a major hurdle in a region that produces neither large volumes of oilseeds nor waste feedstocks such as UCO.

The PADD 5 region has experienced the largest amount of active biodiesel capacity growth since 2011 other than the PADD 2 region. The region's large population means that its volume of annual capacity per capita is only slightly larger at 3.5 gallons/person than that of PADD 4. Its average active facility size is also relatively small at 15.2 MMGY. California hosts nine of the region's 15 production facilities, although these are small relative to those in the PADD 2 and 3 regions despite the presence of major rail lines and large ports in the state. Much of California's operational biodiesel capacity is instead located in its major urban centers (Los Angeles, San Diego, and San Francisco) where UCO is utilized as feedstock. The state's larger facilities (>10 million gallons) are inland where proximity to main line rail allows them to utilize both oilseed and waste feedstocks.

Roughly 50% of active PADD 5 biodiesel production capacity is located in Washington in the form of just two facilities. These include one of the country's largest, the 100 MMGY REG Grays Harbor facility, which resembles the large PADD 3 biodiesel facilities with its access to truck, rail, barge, and deepwater shipping. The state is a substantial outlet for U.S. soybean exports³ but also has access to canola and UCO. The state's total biodiesel capacity has remained relatively flat since 2011 as the shuttering of some facilities has offset expansions at others, and the increase to the PADD 5 capacity that has occurred in recent years has largely been focused on California as a result.

U.S. biodiesel production growth has been unequal across PADD regions and is largely correlated with regional capacity volumes. The PADD 1 region's biodiesel production has increased from 37 million gallons in 2009 to 114 million gallons in 2018, meaning that the entire Eastern seaboard produces only slightly more biodiesel per year than do some individual facilities in the PADD 2, 3, and 5 regions. While the PADD 1 region's utilization rate increased from 22% in 2011 to 61% in 2018, there is sufficient operational capacity in existence to increase annual PADD 1 biodiesel production by an additional 74 MMGY. Furthermore, operational capacity in the region has been as high as 260 MMGY in the last decade, and some of this idle capacity could be brought back online without necessitating new construction.

PADD 1 biodiesel producers face two major competitive constraints. The first is a reliance on UCO that limits producers' ability to achieve favorable processing economics via economies of scale at

facilities outside of Pennsylvania. Second, the PADD 1 region imports most of the biodiesel that it consumes from other PADD regions and other countries (see Figure A-1). Biodiesel volumes from other PADD regions have equaled or exceeded PADD 1 production in seven of the last 10 years, and imports from other countries over the last decade have been almost twice as large as PADD 1 production. In the last decade the PADD 1 region has imported almost as much biodiesel from other countries (1,196 million gallons) as it has obtained from within the U.S. (1,375 million gallons). Over the same period PADD 1 facilities have shipped small volumes of biodiesel to other PADD regions (PADD 2 and PADD 3) and countries (primarily Canada, Norway, the UK, and Switzerland, although intermittent shipments have also been made to various EU-28 countries).⁶ Biodiesel trade flows have overwhelmingly moved into the PADD 1 region, though, and the volume of inflows exceeded outflows by a 42:1 ratio between 2009 and 2018.

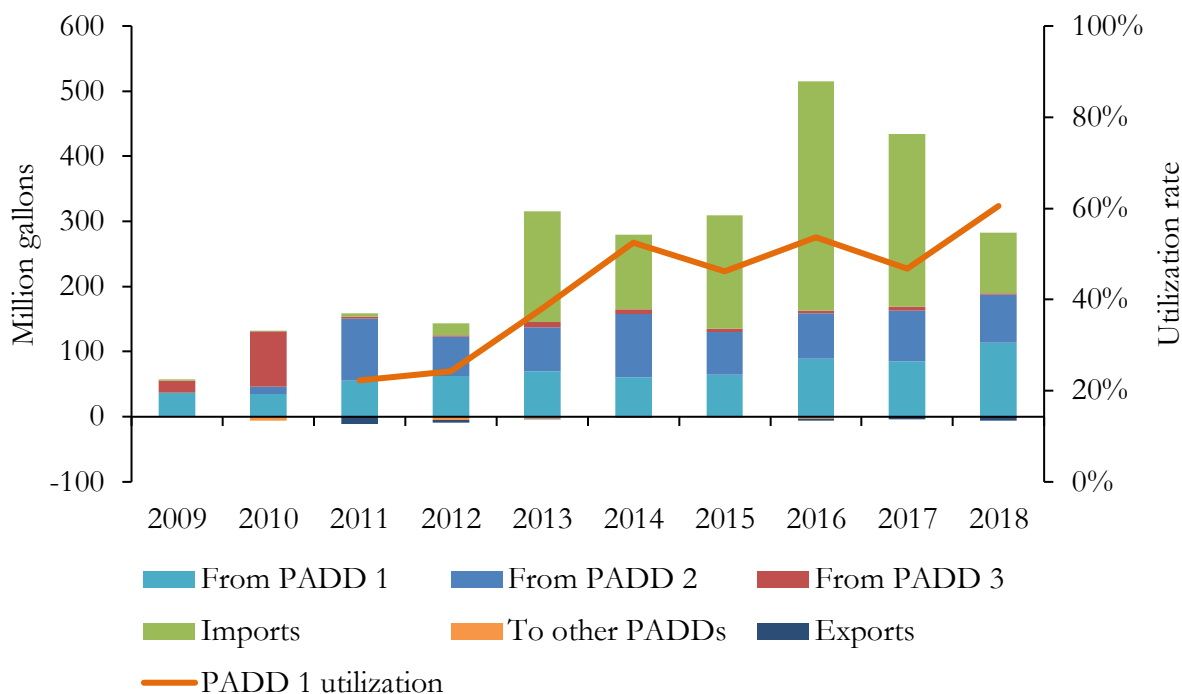


Figure A-1. Sources of PADD 1 biodiesel supply and PADD 1 capacity utilization rate.¹⁷

Data from the EIA on the inter-PADD movement of biodiesel via rail, barge, and pipeline shows that PADD 2 biodiesel producers have been the largest domestic source of the PADD 1 region's

biodiesel supply over the last decade.* PADD 3 producers were briefly the largest overall supplier to the PADD 1 region in 2010 when 85 million gallons was moved between the two via pipeline as part of tests on the movement of biodiesel through refined fuels pipelines that were being conducted at the time.⁸ Most biodiesel that has been supplied to the PADD 1 region from other PADD regions, primarily the PADD 2 region, has been moved by rail since 2011. This has been complemented by small annual volumes that have been moved from the PADD 3 region to the PADD 1 region over water (see Figure A-2). Only a marginal amount of biodiesel, 17.8 million gallons, has moved from the PADD 1 region to other PADD regions since 2009, and almost all of that has been by rail.⁷

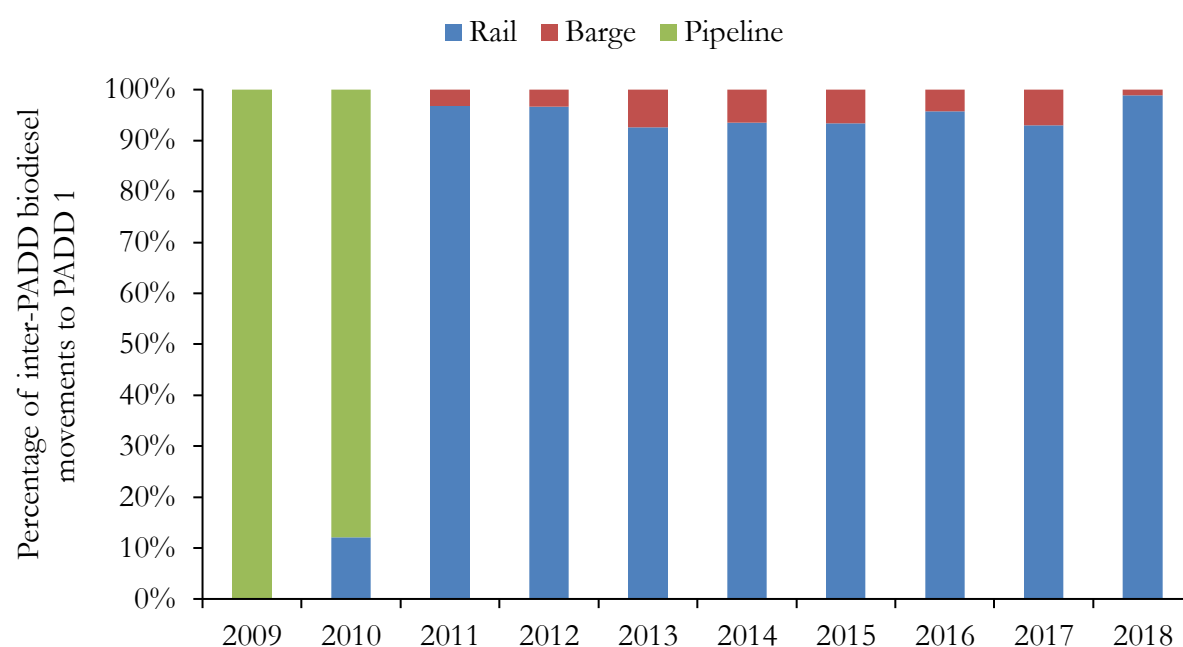


Figure A-2. Forms of biodiesel movement to PADD 1 from other PADD regions and Canada.⁷

Almost 50% of the last decade's PADD 1 biodiesel supply has been in the form of imports from other countries. 58% of these imports, or 27% of the total PADD 1 biodiesel supply over the period, originated in Argentina and then shipped by deepwater vessel to ports all along the Eastern seaboard (see Figure A-3).⁹ Canada has been a reliable, if smaller, source of imports since 2013, most of which have crossed the land border with New York. Germany and Indonesia have also shipped

* This data does not account for movement via trucks. Conversations with industry stakeholders during the drafting of this report revealed that it is not normally cost-effective to move biodiesel more than 150 miles. The large majority of PADD 2 and PADD 3 biodiesel capacity is located more than 150 miles from the PADD 1 and PADD 5 borders, making it unlikely that substantial volumes are moving between PADDs by truck.

more than 90 million gallons apiece to the PADD 1 region since 2013. European countries such as Norway, France, Belgium, Spain, and the Netherlands have shipped small volumes (<14 million gallons) to the PADD 1 region over the last decade, although these have largely consisted of a limited number of shipments that have occurred over short periods of time.

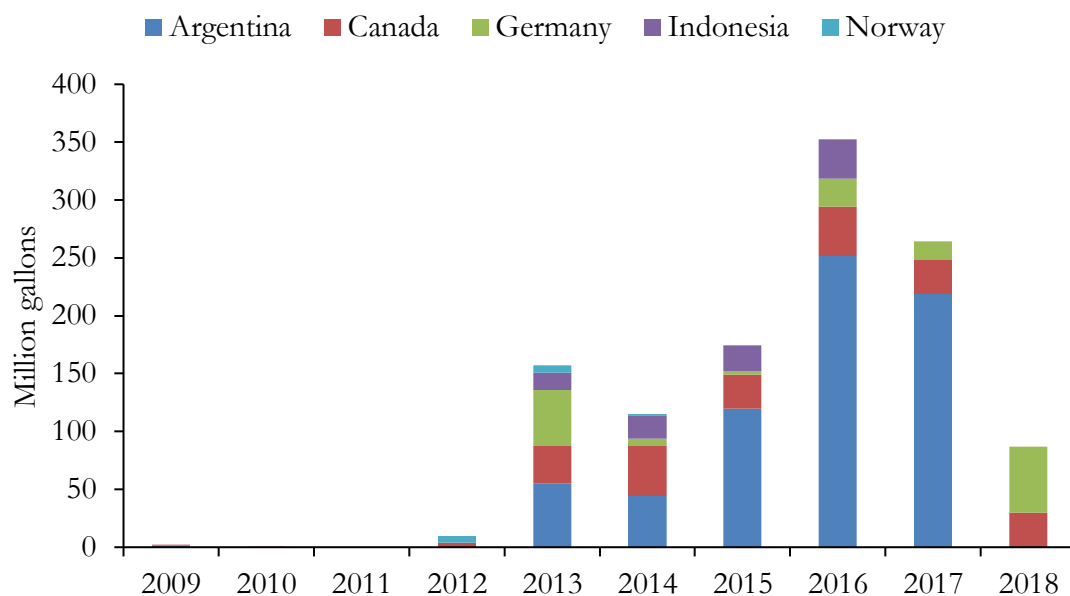


Figure A-3. Five largest foreign sources of PADD 1 biodiesel imports.¹⁰

The supply of biodiesel in the PADD 1 region declined by 40% between 2017 and 2018 in an episode that illustrated the region's hurdles to obtaining domestic biodiesel. In 2017 the U.S. Commerce Department imposed large countervailing duties on imported biodiesel from Argentina and Indonesia.¹¹ PADD 1 imports of biodiesel from Indonesia fell to zero in 2017 while those from Argentina did the same the following year. While these volumes were partially offset by increased PADD 1 biodiesel production and higher biodiesel imports from Germany, the net effect was to cause the 2018 volume of biodiesel supply in the region to fall to 288 million gallons from 480 million gallons in the prior year.

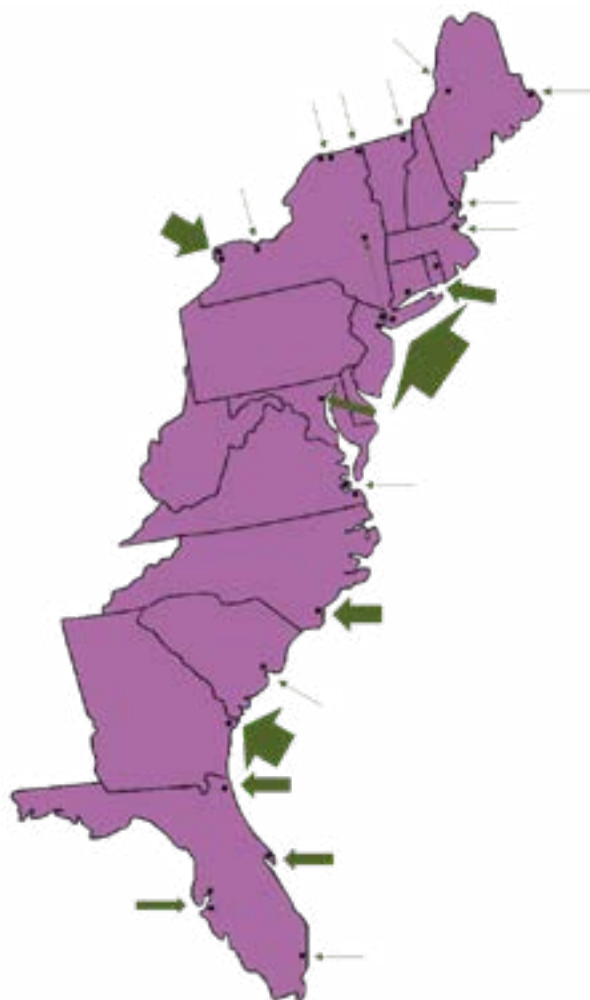


Figure A-1. PADD 1 biodiesel imports by volume and port of entry, 2009-2018. Arrows are scaled to represent volumes.⁹

The New York City and Newark harbors have been the primary ports of entry for PADD 1 biodiesel imports since 2009 (see Figure A-4). Smaller volumes have entered across the Eastern seaboard, although the New England states, Pennsylvania, and Virginia have imported only small volumes over the last decade.

Data is not available on the feedstock mix that is used to produce biodiesel in individual PADD regions, let alone for the specific biodiesel volumes that are moved between PADDs. The USDA's Foreign Agricultural Service (FAS) does provide comprehensive data on the feedstocks that are utilized by foreign biodiesel producers such as Argentina and Indonesia, however, and from this an approximate feedstock mix can be developed for the biodiesel that has been imported into each

PADD region from abroad over the last decade. Argentina has solely utilized soybean oil as biodiesel feedstock over the last decade.¹² Almost 61% of the biodiesel that the PADD 1 region has imported from abroad has been derived from soybean oil as a consequence (see Figure A-5). Similarly, Indonesia's production has come entirely from palm oil, making that feedstock a notable (if much smaller) contributor to the PADD 1 biodiesel supply feedstock mix. Canada and the EU-28 countries rely on a variety of feedstocks, however, including UCO, rapeseed, canola, and tallow, and these lipids therefore all show up in the feedstock mix.

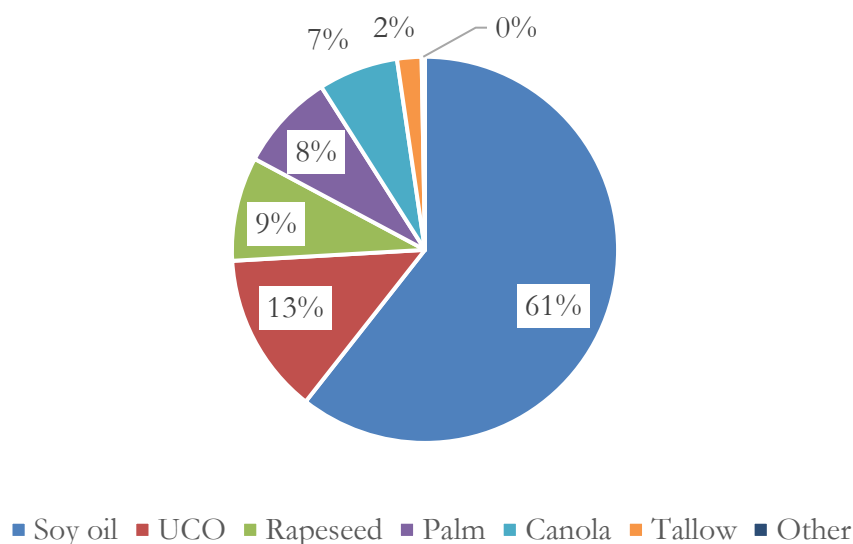


Figure A-5. Feedstock mix for PADD 1 imports of foreign biodiesel, 2009-2018. Source: Author calculations based on USDA FAS “Biofuels Annual Reports” for Argentina, Canada, the EU-28, Germany (separate from the EU-28), and Indonesia.¹²

I.2. Biodiesel supply – PADD 2

PADD 2 biodiesel production has almost tripled since 2009, rising from 366 million gallons in that year to 1,214 million gallons in 2018.¹ The region's active biodiesel capacity has increased by almost 300 million gallons since 2011, although most of the production gain has been due to a rising utilization rate over the course of the decade rather than construction of new capacity (see Figure A-6). PADD 2 biodiesel production facilities have regularly achieved the highest utilization rates of the U.S. PADD regions, and at 90% in 2018 they are approaching the maximum effective rate of 90-

95%.* PADD 2 facilities are able to operate near full capacity throughout the year despite their large capacities (and corresponding feedstock requirements) due to the region's abundant production of and storage capacity for agricultural lipids. The PADD 2 region also benefits from a highly developed oilseed supply chain due to its historic lack of internal soybean consumption, giving biodiesel producers there access to extensive oilseed storage, transport, and crush infrastructure.

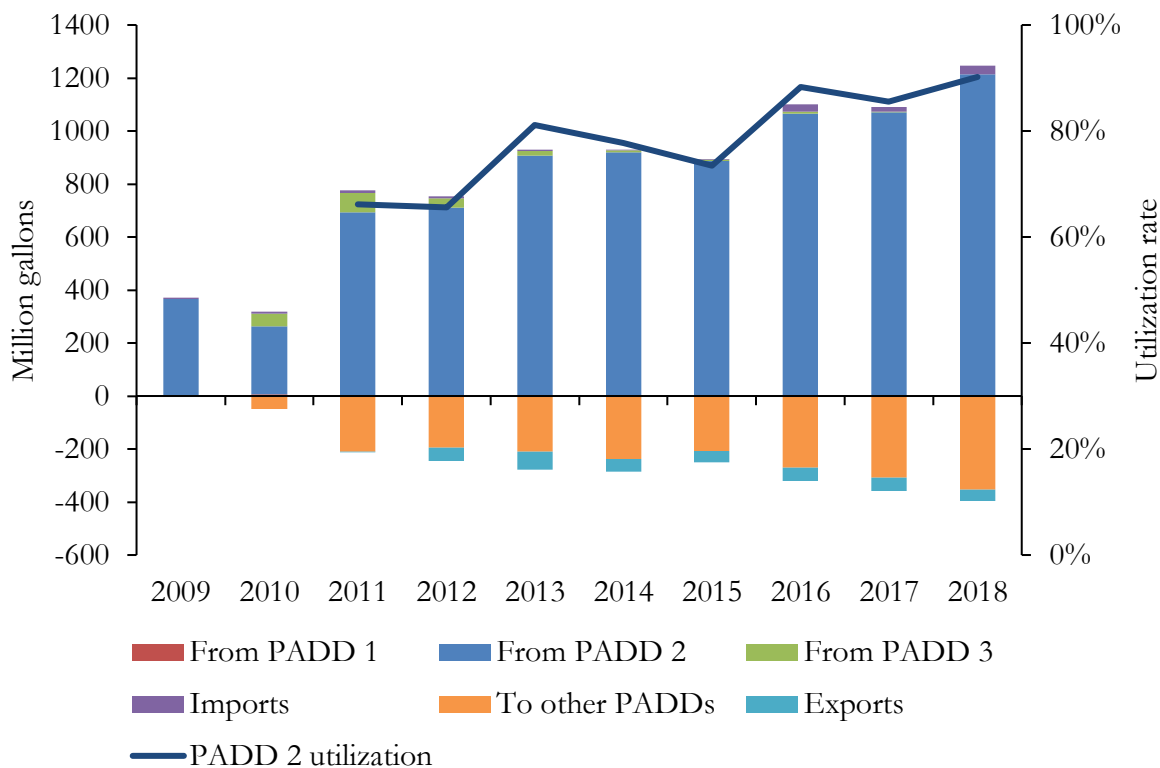


Figure A-6. Sources of PADD 2 biodiesel supply and PADD 2 capacity utilization rate.^{1,7}

PADD 2 producers have historically used soybean oil as their primary feedstock given the proximity of much of the region's production capacity to soybean acres. Additional feedstocks have entered the mix in recent years, though, especially as CDO production has become widespread, and a 2017 survey found that fewer than half of PADD 2 production facilities reported using a feedstock mix entirely comprised of soybean oil.¹⁸ Iowa hosted 33% of the PADD 2 region's production capacity in 2018 and 81% of those gallons were derived from soybean oil, followed by corn oil at 10%, tallow at 5%, and UCO at 4%.¹³ North Dakota's (6% of PADD 2 production capacity) sole biodiesel

* Biodiesel facilities, like petroleum refineries, rarely exceed this range due to the need for planned turnaround downtime every year.

facility was built to utilize canola oil as its “primary” feedstock, and this remains the only feedstock that it has been certified for that facility through California’s Low Carbon Fuel Standard (LCFS).^{14,25} Minnesota (6% of PADD 2 production capacity) is the only other PADD 2 state to report its feedstock mix, which was 45% soybean oil, 31% corn oil, and 24% waste lipids in 2016 (the latest year for which data is available).¹⁵ While the specific feedstock mixes for the remaining PADD 2 states are not publicly available, data from the California Air Resources Board shows that producers in many of those states utilize a variety of feedstocks (see Table A-3).*

Table A-3. Biodiesel feedstocks utilized by PADD 2 producers as certified under California's LCFS.^{1,25}

State	Feedstocks	State's % of PADD 2 biodiesel production capacity
Missouri	CDO, soybean oil	15
Illinois	CDO, tallow, UCO	13
Oklahoma	Tallow, white grease	3
Michigan	Soybean oil, UCO	0.7
Nebraska	CDO, tallow, UCO	0.5

The PADD 2 region has a smaller population than the PADD 1 region, giving it the highest amount of annual biodiesel capacity per capita (16.1 gallons/person) in the U.S. While the PADD 2 region has the highest volume of consumption in the U.S., it has also shipped 25% of its total production over the last decade to other PADD regions (see Figure A-6). The PADD 3 region has been the largest domestic destination of this biodiesel, followed by the PADD 1, PADD 5, and PADD 4 regions (see Figure A-7). Shipment volumes to the PADD 3 and PADD 5 regions have experienced strong growth over the last five years, while the volume shipped from the PADD 2 region to the PADD 1 region was almost unchanged in 2018 relative to 2014. 97% of PADD 2 biodiesel shipments to other PADDs have been by rail, with the rest being moved by barge (see Figure A-8).

* Table A-3 is not likely to be representative of each state’s actual feedstock mix since the LCFS incentivizes the participation of biodiesel from feedstocks with lower carbon intensities (e.g., waste lipids) over those with higher intensities (e.g., soybean oil, canola oil). In the absence of more comprehensive data, though, it does illustrate the variety of different feedstocks that are utilized by PADD 2 producers.

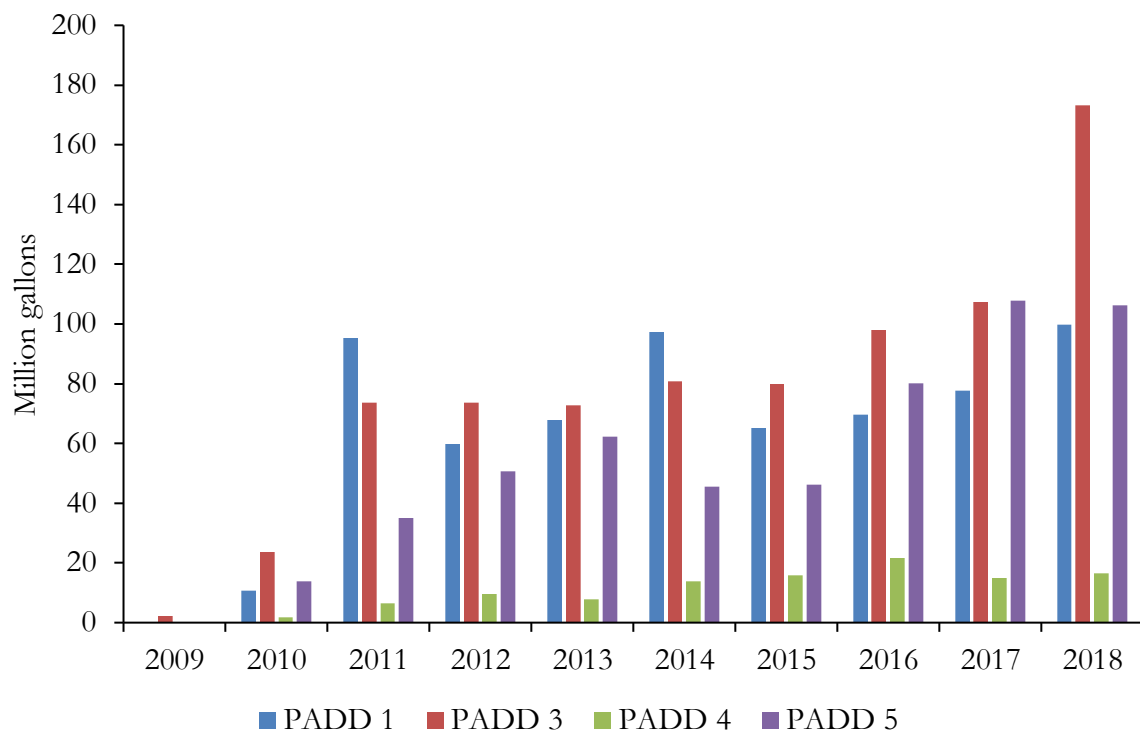


Figure A-7. Domestic destinations of inter-PADD biodiesel movements from PADD 2.7

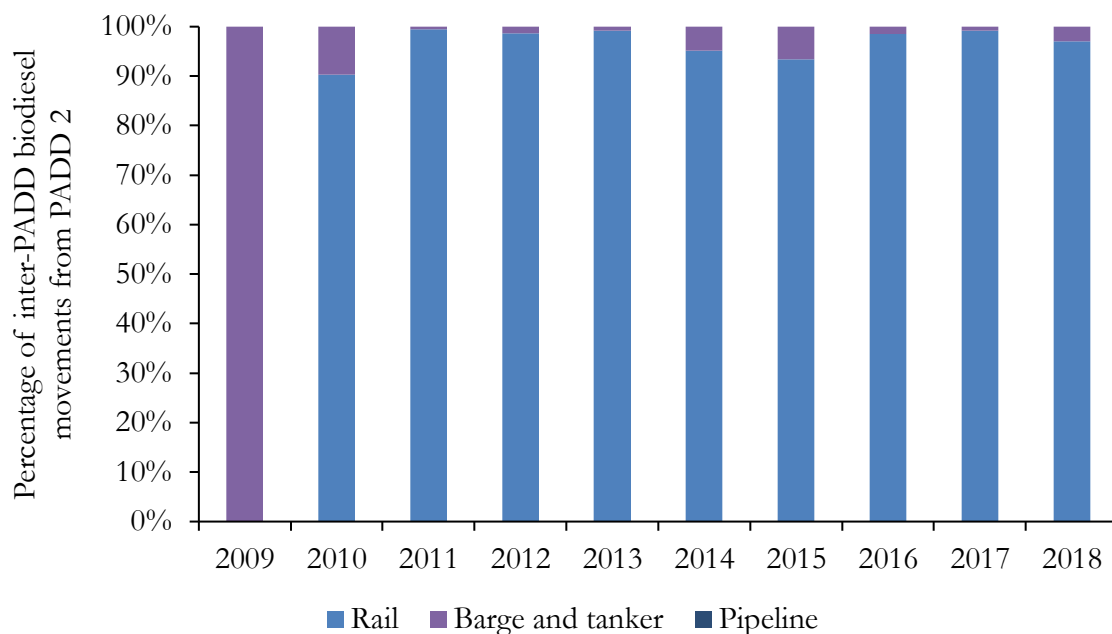


Figure A-8. Transportation method of inter-PADD biodiesel movements from PADD 2.7

The small volume of biodiesel that leaves the PADD 2 region by barge is notable given that most of the biodiesel that has entered that region from other PADD regions since 2009 was moved by barge. PADD 2 receipts of biodiesel from other PADDs has dwindled in recent years, however. The PADD 2 region has only received small (<20 million gallons) annual volumes of biodiesel from other PADD regions as its own production has increased, and in 2018 the ratio of outgoing biodiesel shipments relative to domestic incoming shipments exceeded 40:1.

The PADD 2 region does have a limited biodiesel trade with a single foreign country, Canada, and the region has been a net exporter since 2009 by a 3:1 volume ratio (see Figure A-9). The primary ports of entry for the PADD 2 region's imports from Canada since 2009 have been Port Huron, MI and International Falls, MN, although limited volumes have also entered via North Dakota, Illinois, and Indiana (see Figure A-10).⁹ PADD 2 exports to Canada since 2009 (119 million gallons) have been substantially exceeded by the region's shipments to other PADD regions (2043 million gallons), making the U.S. market the most important demand driver for Midwestern biodiesel producers.

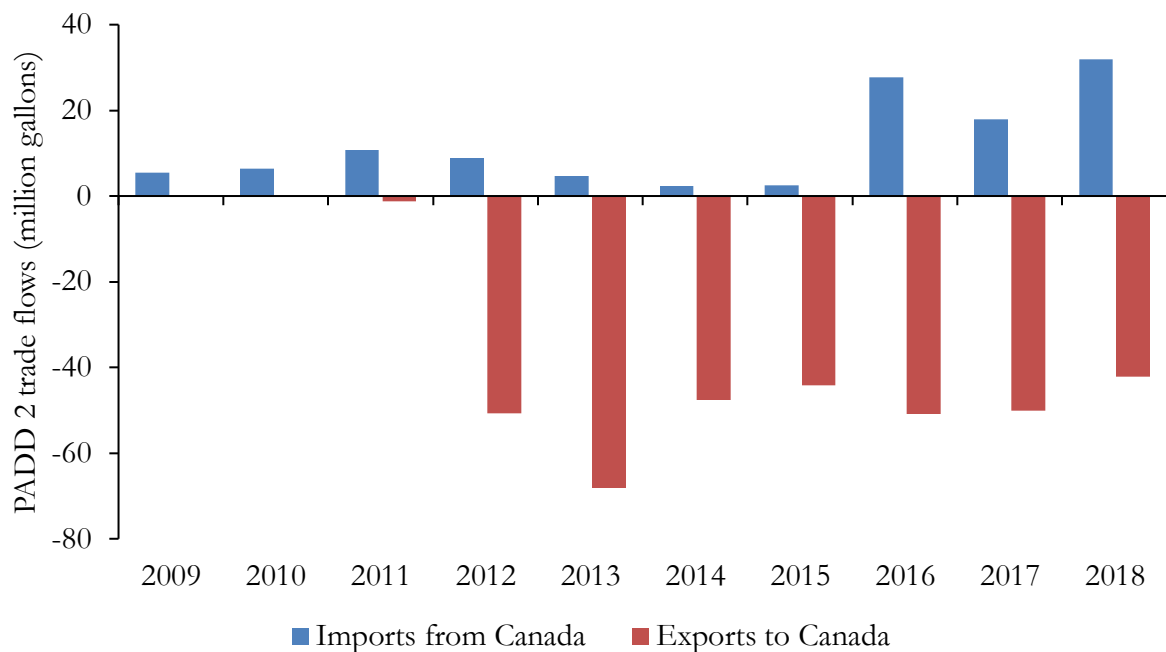


Figure A-9. Annual PADD 2 biodiesel trade flow volumes with Canada.⁷



Figure A-2. PADD 2 biodiesel imports by volume and port of entry, 2009-2018.⁹

Almost half of Canada's biodiesel is produced from UCO, 25% from canola, and the balance from tallow and soybean oil (see Figure A-11). While PADD-level feedstock composition data is not available for the U.S., the heavy presence of PADD 2 biodiesel production facilities in counties with high levels of soybean production and the fact that soybean oil accounts for more than 50% of U.S. biodiesel production makes it reasonable to assume that soybean oil is

the PADD 2 region's largest biodiesel feedstock.¹⁶

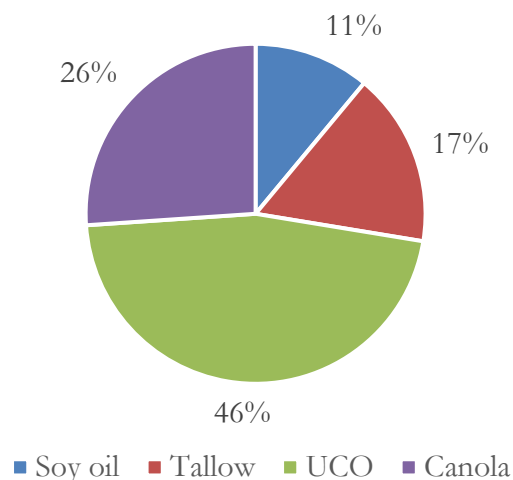


Figure A-11. Share of feedstock sources for PADD 2 imports of foreign biodiesel, 2009-2018. Source: Author calculations based on USDA FAS “Biofuels Annual Reports” for Canada.¹²

I.3. Biodiesel Supply – PADD 3

The PADD 3 region’s total biodiesel production capacity in 2018 of 612 million gallons was slightly lower than its 2011 total, although the level has varied substantially over that time. At 13.2 gallons/person, the region’s annual production capacity is large relative to its population. This capacity has been historically underutilized, though, allowing for PADD 3 production to increase from 171 million gallons in 2011 to 363 million gallons in 2018 even though the region’s total capacity volume has remained almost unchanged over the same period. In 2011 the region’s capacity operated at only a 30% utilization rate; this figure increased to almost 60% by 2018, making the production volume growth over the interim possible despite the lack of capacity growth (see Figure A-12).

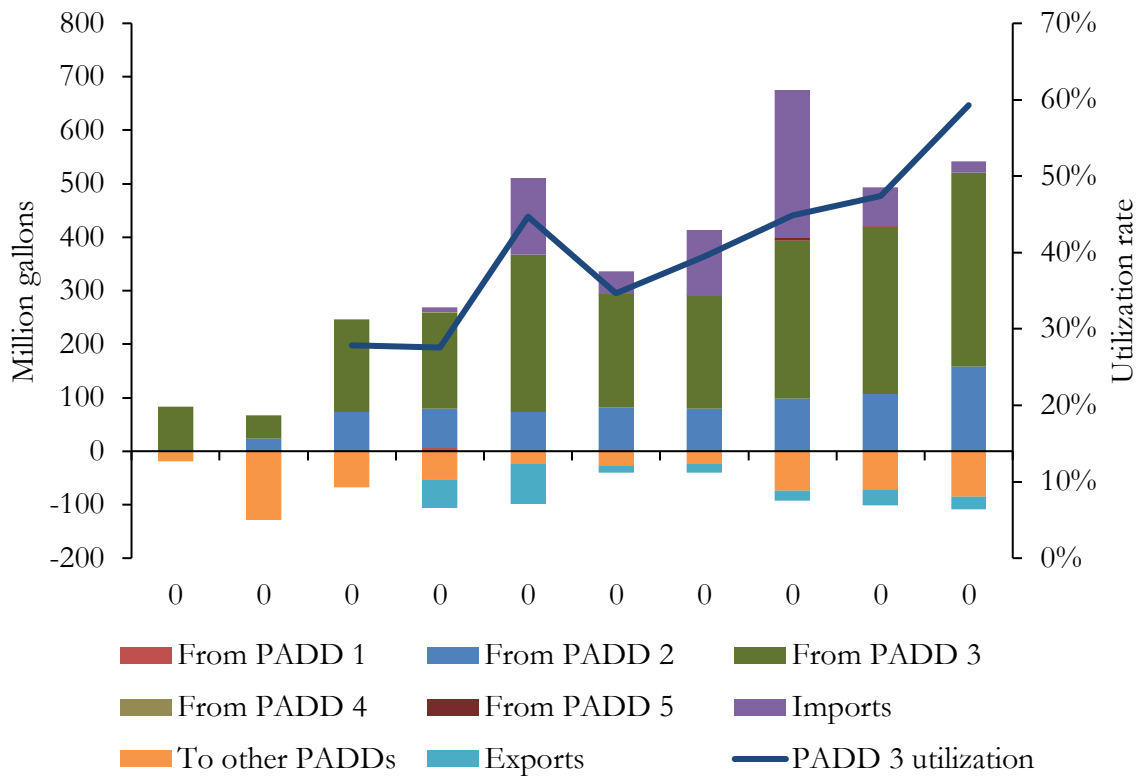


Figure A-12. Sources of PADD 3 biodiesel supply and PADD 3 capacity utilization rate.^{1,7}

In contrast to PADD 2 biodiesel production capacity, which is located near areas with intensive soybean production but mostly limited to truck and rail transportation infrastructure, much of the PADD 3 biodiesel production capacity has access to water-borne transportation due to its location near major Gulf ports and waterways. This flexibility is indicated by the wide array of feedstocks that are reportedly utilized by the region's largest biodiesel production facilities (although specific feedstock mixes are not available). The 180 MMGY RBF Port Neches facility, located outside of Houston, "at some point has processed virtually every other feedstock [in addition to soybean and canola oil], including UCO, beef tallow, and corn oil."¹⁷ The 90 MMGY World Energy Biox Biofuels facility, also located near Houston, is categorized as "multifeedstock", as is the 40 MMGY Double Diamond Energy facility.¹⁸ Only 16% of the biodiesel production capacity in Texas utilizes fewer than three feedstock types, according to a 2017 National Biodiesel Board report.¹⁸

The PADD 3 region also hosts a high number of high protein animal units (HPAU), or livestock that is fed with soybean meal, at its numerous feedlot operations.³ Many of these HPAUs are processed in the region, giving biodiesel producers there access to substantial quantities of beef tallow and inedible chicken fat. All 102 MMGY of production capacity in Arkansas is able to utilize

animal processing residues,^{19,25} for example, and at least 27 MMGY of capacity in Texas is certified under the LCFS as utilizing tallow as a partial feedstock.^{18,25} UCO is also an important feedstock in the region, being the sole feedstock at an 18 MMGY facility in Texas¹⁸ and a 20 MMGY facility in Mississippi,^{20,25} as well as a partial feedstock at an additional 87 MMGY in Arkansas and Texas that is certified under the LCFS.²⁵ Only 10% of biodiesel capacity in Texas and 35% of capacity in Arkansas, which together account for 88% of PADD 3 production capacity, utilizes soybean oil as a primary feedstock.¹⁸

The PADD 3 region produces most of the biodiesel that it consumes. It has supplemented this with a growing volume of biodiesel from the PADD 2 region, and shipments from PADD 2 equaled 44% of PADD 3 production in 2018. Comparatively tiny volumes have been obtained from PADD 1, PADD 4, and PADD 5 producers since 2009. The PADD 3 region has become an important source of the biodiesel that is consumed in other PADD regions, however, and PADD 5 has replaced PADD 2 as an important destination for PADD 3 biodiesel since 2014 as California's LCFS has increased in scope (see Figure A-13). This shift has also corresponded with the PADD 3 region becoming a major recipient of PADD 2 biodiesel, however, and the volume of biodiesel entering PADD 3 from other PADDs has exceeded the volume moving in the opposite direction by 39% since 2009 due to this influx.

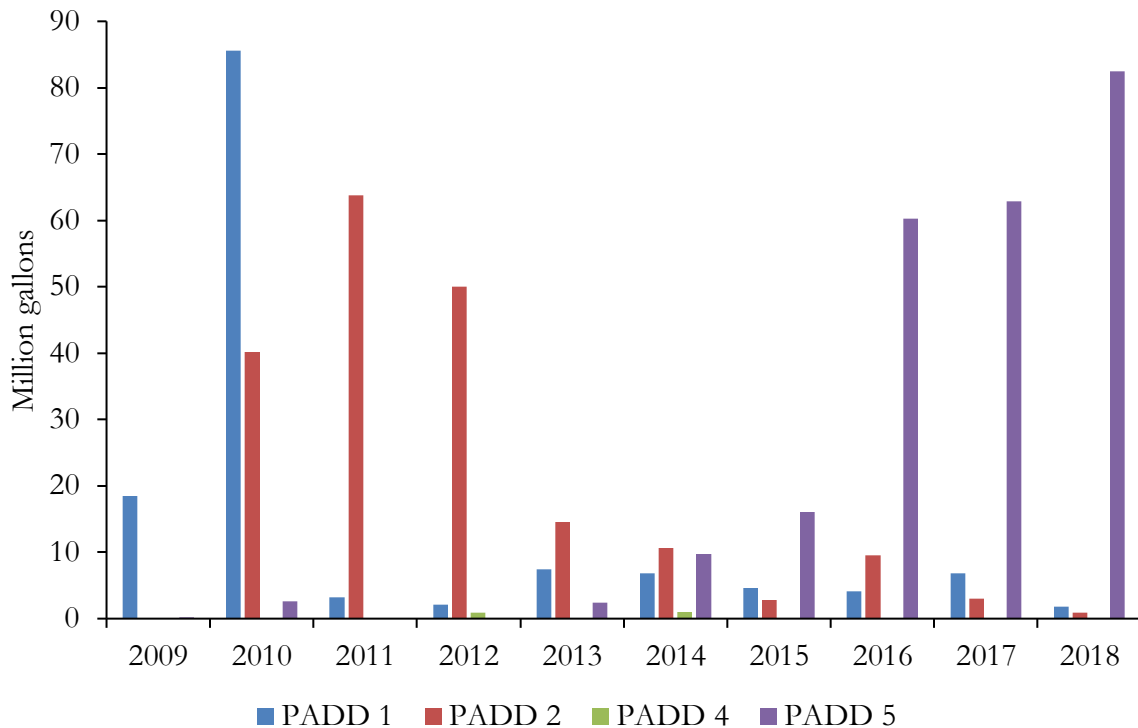


Figure A-13. Destinations of biodiesel shipped from the PADD 3 region to other PADD regions.⁷

60% of the biodiesel that has been shipped from the PADD 3 region to other PADD regions since 2009 has been transported via barge or tanker (see Figure A-14). Different forms of transportation have been utilized over that time period, however, depending on the PADD region to which the biodiesel has been shipped. 103 million gallons were moved via pipeline to PADD 1 in 2009-2010 during trials to determine the feasibility of shipping biodiesel in refined products pipelines. PADD 2 became the primary destination for PADD 3 biodiesel after those trials ended, though, and water-borne transport became widely used from 2011 to 2014 as the biodiesel was moved up the Mississippi River on barges. Water-borne transport was again the most common mode of transport in 2017-2018 as the PADD 5 region became the primary destination for PADD 3 biodiesel, although a lack of major navigable waterways between the two regions meant that ocean-going vessels replaced river barges.

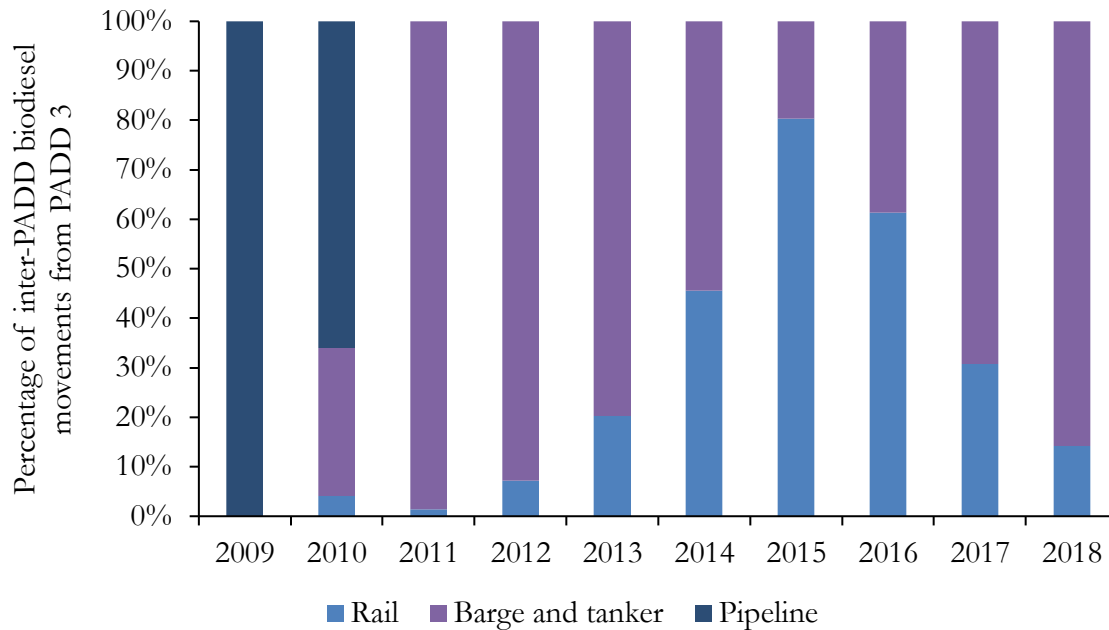


Figure A-14. Transportation modes of inter-PADD shipments from PADD 3.7

The PADD 3 region has, at various times over the last decade, been a source of both exports to international markets and demand for biodiesel from foreign producers. The region has exported an average of 32 million gallons of biodiesel annually since 2011, although 2013 was the high point with 74 million gallons exported in that year. It has averaged 98 MMGY of imports over the same period, although the 2018 import volume represented a 92% decline from the 2016 volume of 277 million gallons. Since 2009 imports have exceeded exports by a 3:1 ratio. Over 60% of these imports have originated in Argentina, although the imposition of countervailing duties by the U.S. on Argentine biodiesel caused this volume to decline in 2017 and fall to zero in 2018 (see Figure A-15). Imports from Indonesia have contributed 29% of the total volume since 2009, although this biodiesel has also been subject to U.S. trade restrictions and was not imported in 2018. France, Germany, and Canada became the primary sources of PADD 3 biodiesel imports in 2018 but the total import volume in that year was far below its levels from before the trade restrictions were imposed. As in the PADD 1 region, the supply of imported biodiesel in the PADD 3 region has been highly elastic to biodiesel cost, and in both cases increased imports from EU-28 producers have only replaced a small fraction of the volumes from Argentina and Indonesia that have gone missing in response to the imposition of duties.

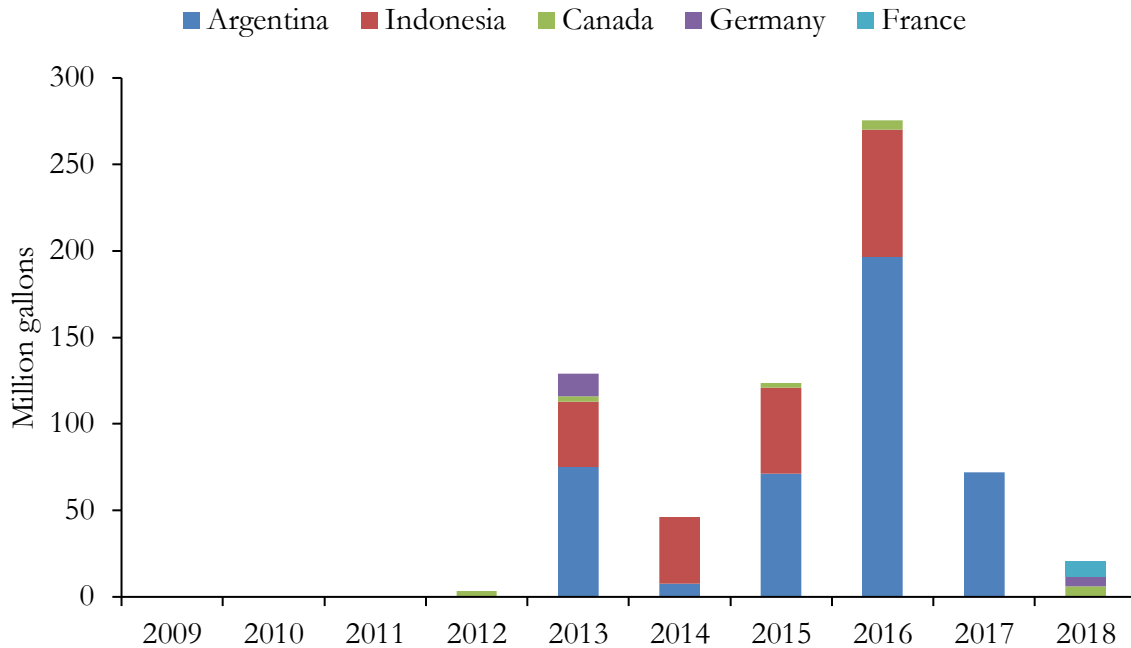


Figure A-15. Five largest foreign sources of PADD 3 biodiesel imports.¹⁰

78% of PADD 2 imports between 2009 and 2018 entered the region through ports in the state of Texas, primarily Houston although Brownsville was also utilized in 2016 (see Figure A-16).⁹ Smaller volumes were moved through ports of entry in Alabama (Mobile) and Louisiana (New Orleans, Gramercy, and Baton Rouge), although these largely ended after 2016. While data on export ports is not available, much of the PADD 3 region's biodiesel production capacity is clustered near the same ports that foreign biodiesel is imported to the region through. Just over 50% of PADD 3 biodiesel production capacity, and 81% of that of Texas, is located in or around Houston.¹⁰ Another 22% is located on the Mississippi River with barge access to the ports in Baton Rouge and New Orleans.



Figure A-16. PADD 3 biodiesel imports by volume and port of entry, 2009-2018.⁹

The primary feedstock from which the PADD 3 region's imported biodiesel has been derived is soybean oil (see Figure A-17) due to its historical imports of Argentine biodiesel, which is only produced from that feedstock.¹² Palm oil has also been an important source of the region's imported biodiesel since it is the only feedstock utilized by Indonesia. The balance has been obtained from UCO, rapeseed, tallow, canola, and other feedstocks that are utilized in small quantities by biodiesel producers in France, Germany, and Canada. It is feasible that future biodiesel imports into the PADD 3 region will be obtained from feedstocks other than palm and soybean oil so long as the trade restrictions on Argentine and Indonesian biodiesel remain in place. Over the last decade, though, most of the region's biodiesel imports have been derived from those two vegetable oils due to the large volumes that were imported from Argentina and Indonesia in 2016.

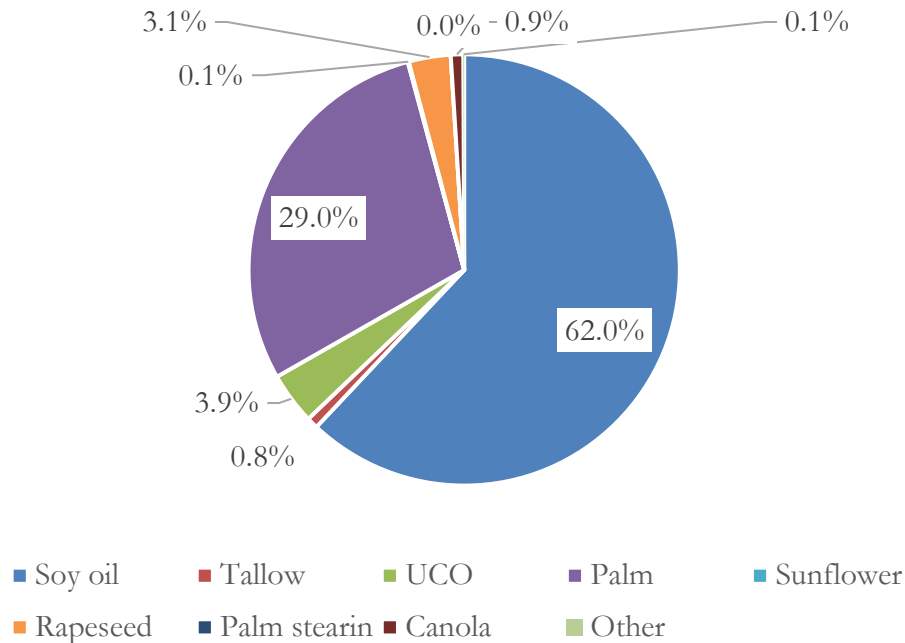


Figure A-17. Feedstock mix for PADD 3 imports of foreign biodiesel, 2009-2018. Source: Author calculations based on USDA FAS “Biofuels Annual Reports” for Argentina, Canada, the EU-28, Germany (separate from the EU-28), and Indonesia.¹²

I.4. Biodiesel Supply - PADD 4

The PADD 4 region has a very limited amount of biodiesel production capacity (40 MMGY) and virtually no biodiesel production volumes since 2015.¹ The region’s utilization rate has never exceeded 30% even in the few years in which production has occurred. In addition to the region’s small population, it is constrained by a lack of oilseed production and limited transportation infrastructure. The region has increased its biodiesel consumption over the last decade, however, and it relies on inter-PADD and international trade to meet this demand (see Figure A-18). Except for small volumes that were produced between 2012 and 2014, the PADD 4 region has obtained most of its biodiesel supply from PADD 2 producers, supplemented by smaller volumes from PADD 3 (2012 and 2014) and PADD 5 producers (since 2016). While a substantial fraction of the biodiesel that the PADD 4 region received from other PADD regions earlier in the decade was shipped onward to the PADD 3 and PADD 5 regions by rail, virtually all of the biodiesel that is moved into PADD 4 is now consumed there.

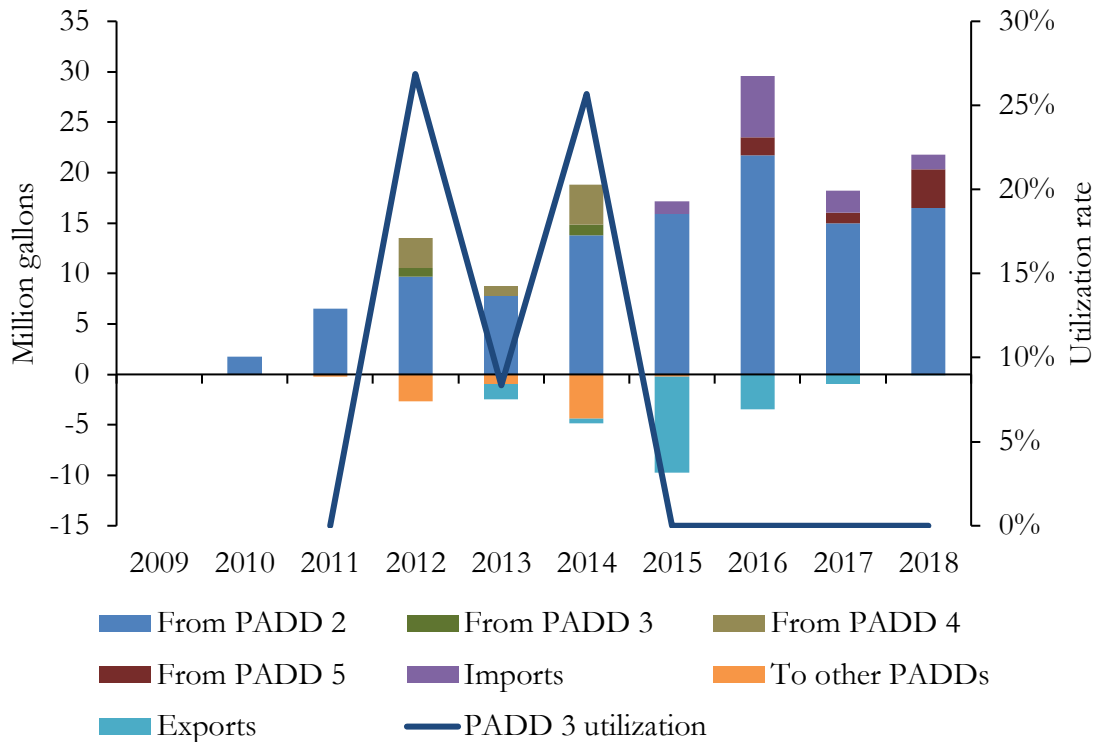


Figure A-18. Sources of PADD 4 biodiesel supply and PADD 4 capacity utilization rate.^{1,7}

The PADD 4 region's lack of coastline and navigable waterways means that biodiesel is moved in and out of the region by rail.⁷ The region also relies more heavily on rail for internal biodiesel shipments than do the other PADD regions, likely due to its rugged terrain and longer distances between major consumption centers. The use of rail to ship biodiesel into the region means that it can only trade biodiesel internationally with Canada via Idaho and Montana. Since 2009 the PADD 4 region's exports have exceeded imports by a 1.4:1 ratio. Imports from Canada enter the region through Sweetgrass, MT (54%) and Eastport, ID (46%) (see Figure A-19).⁹ Most of the PADD 4 region's biodiesel supply is obtained from other PADD regions, however, and these combined domestic shipments have exceeded Canadian imports by a 11:1 ratio over the last decade.

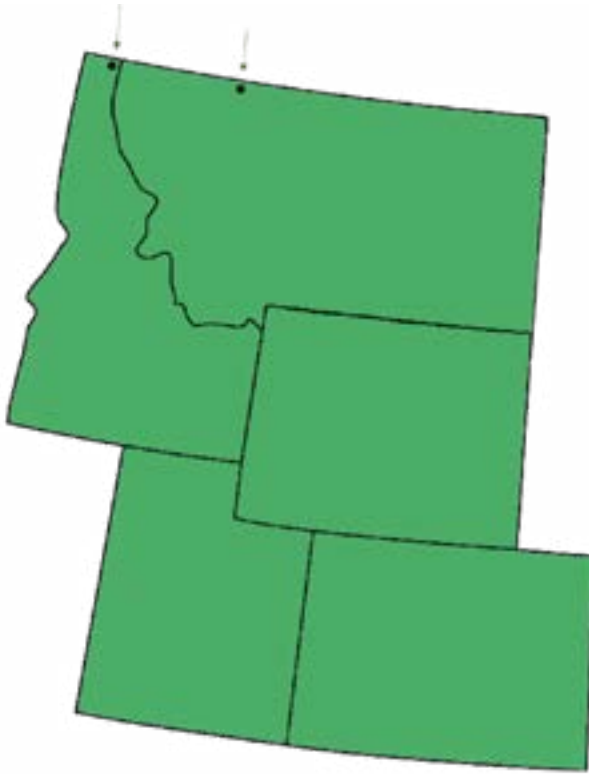


Figure A-3. PADD 4 biodiesel imports by volume and port of entry, 2009-2018.⁹

I.5. Biodiesel supply – PADD 5

In 2009 the PADD 5 region had, with the exception of the PADD 4 region, the lowest amount of biodiesel production capacity in the U.S.¹ In 2010 its biodiesel production was only 9 million gallons and an additional 16.5 million gallons was shipped in from other PADDs (no imports arrived from other countries in that year) (see Figure A-20). Since 2011 the region has experienced the country's 2nd-largest increase to its biodiesel production capacity, surpassed only by the PADD 2 region, and a corresponding increase to its actual biodiesel production. In addition to the additional

production capacity, the PADD 5 region has also increased its capacity utilization double since 2011. Its capacity remains quite small compared to its population, though, and the region's production capacity per capita is almost as low as that of the PADD 4 region at 3.4 gallons per person in 2018.¹

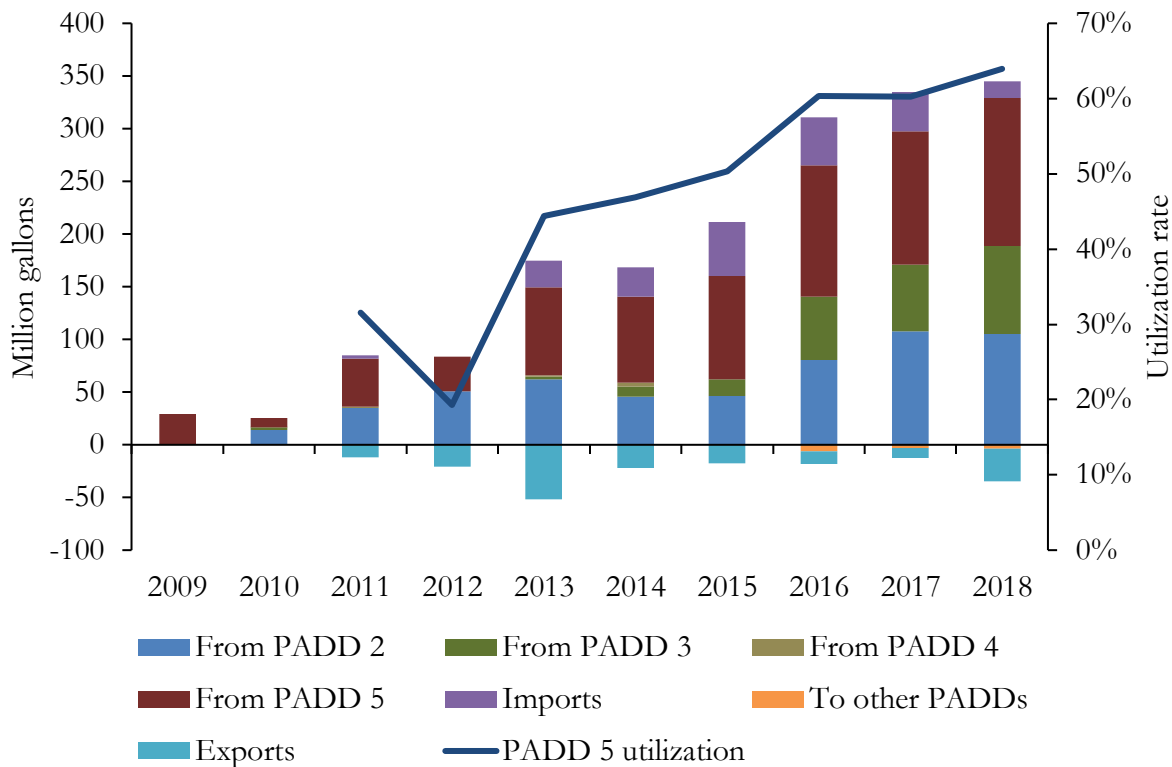


Figure A-20. Sources of PADD 5 biodiesel supply and PADD 5 capacity utilization rate.^{1,7}

The PADD 5 region's lack of soybean production has prevented that feedstock from being widely utilized at its production facilities. All of Washington's capacity (50% of the PADD 5 region's total) is advertised as being multi-feedstock, with canola oil and UCO being listed as the certified feedstocks under the LCFS.²⁵ None of California's capacity, which is equal to 39% of the regional total, reported using soybean oil as a primary feedstock in a 2017 survey.¹⁸ At least five of the state's nine production facilities are certified under the LCFS as using feedstocks such as CDO, tallow, and UCO sourced from a variety of different PADD regions and countries.²⁵ Finally, Oregon's capacity is certified for only UCO under the LCFS. The notable presence of UCO in the PADD 5 feedstock mix can be explained by the presence of several large urban centers in the region.

The PADD 5 region's growth in biodiesel production and capacity has corresponded with the implementation of California's LCFS in 2011. The LCFS requires steady reductions to the carbon intensity (CI) of the state's collective transportation fuels, including ULSD, that are sold within the state, and biodiesel has become an important contributor to the mandated reductions.²¹ The last decade has seen PADD 5 biodiesel production complemented by growing volumes that have been shipped in from the PADD 2 and PADD 3 regions and imported from other countries (see Figure

A-20). Movements from PADD 3 have increased rapidly and are approaching the volume that is received from the PADD 2 region despite the large difference in the production capacities between the two regions (see Figure A-21). Some biodiesel volumes move in the opposite direction to other PADD regions and countries, although these peaked in 2016 and 2013, respectively.

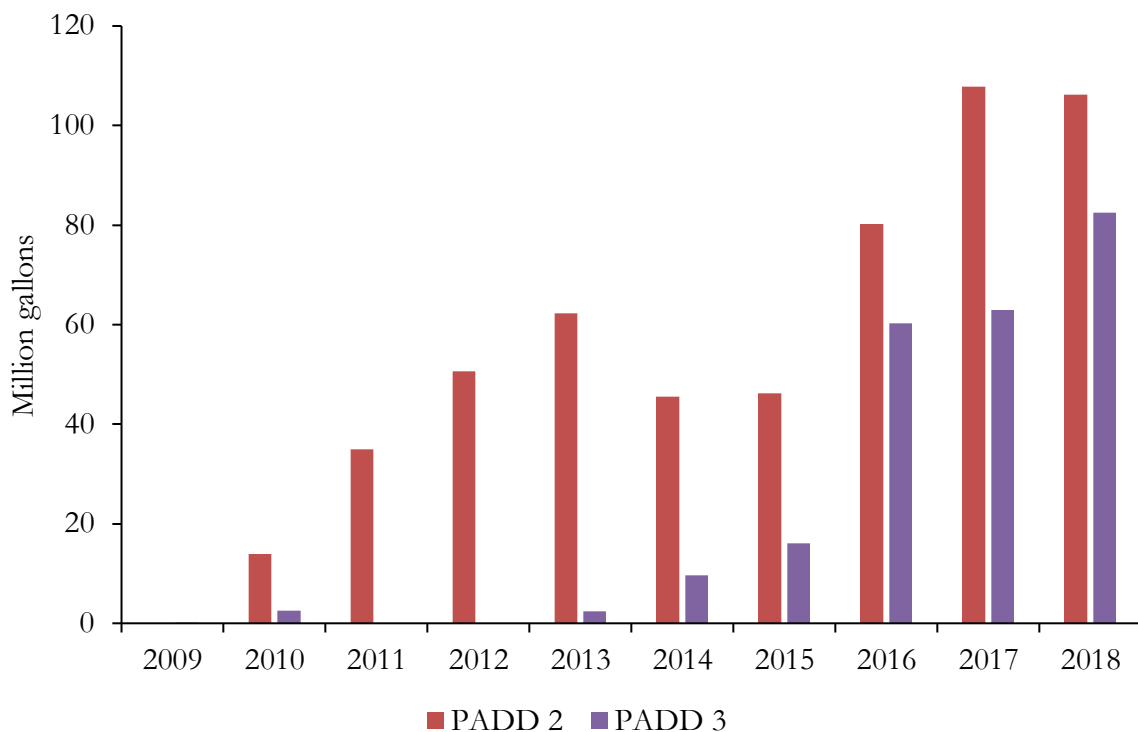


Figure A-21. Inter-PADD biodiesel shipments to PADD 5, 2009-2018.⁷

The PADD 5 region receives most of the biodiesel that it obtains from other PADD regions via rail, although water-borne transport has been employed in recent years as PADD 3 producers have shipped increasing volumes to California (see Figure A-22). All the biodiesel that is shipped to the PADD 5 region from the PADD 2 region since 2009 has been moved by rail. The volume moved by water from the PADD 3 region, on the other hand, first exceeded the volume moved by rail between those two regions in 2017, and in 2018 the water-borne volume exceeded the rail volume from PADD 3 by a 7:1 ratio. Finally, a small volume of biodiesel was moved from the PADD 3

region to the PADD 5 region via pipeline in 2009, but the EIA data does not show any subsequent pipeline movements between the two regions.^{7*}

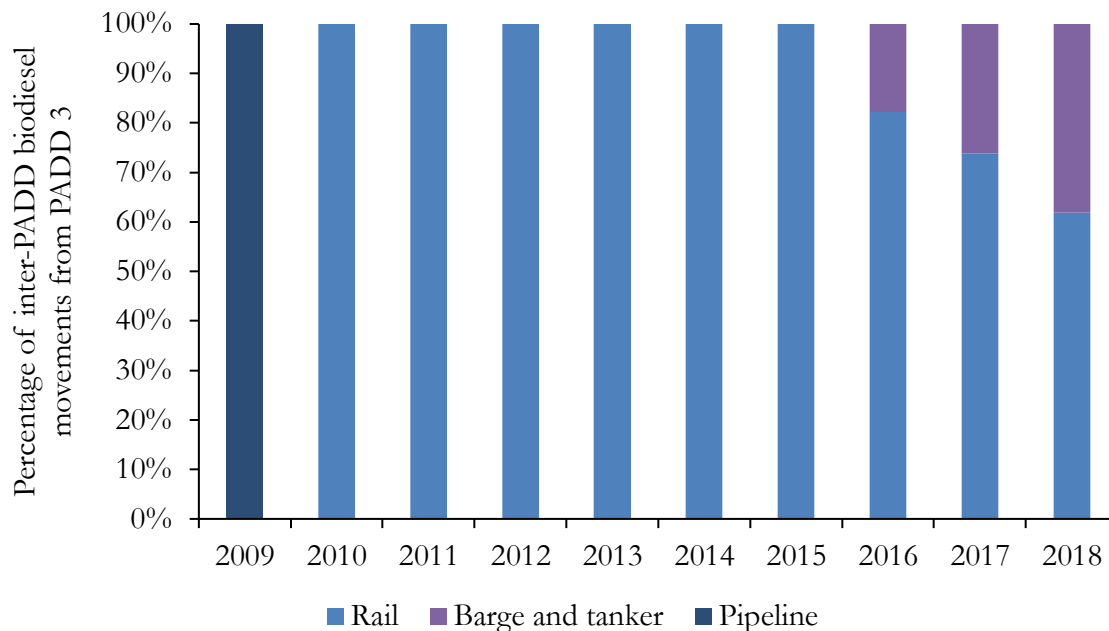


Figure A-22. Transportation modes of inter-PADD shipments to PADD 5.⁷

The presence of California’s LCFS provides a greater level of insight into the feedstock mix for the PADD 5 region’s domestic biodiesel supply than is available for the other PADD regions. (California is responsible for more than 50% of the PADD 5 region’s diesel fuel supply²² and, while the state’s biodiesel supply is not fully representative of PADD 5 biodiesel supply, it does provide important insights into the region’s biodiesel supply situation.) The largest domestic biodiesel feedstock under the LCFS over the last decade has been corn oil (see Figure A-23).²³ While not a true recycled lipid feedstock like UCO, corn oil is properly considered to be a byproduct feedstock (rather than an oilseed) and it has a CI that falls between oilseeds and recycled feedstocks as a result. Its CI gives it an important subsidy advantage over oilseed-derived biodiesel under the LCFS to the point that PADD 2 corn oil and corn oil-derived biodiesel is shipped in large volumes to the PADD 5 region, although the same is not true for PADD 2 oilseeds and oilseed-derived biodiesel.²⁵ All of the corn oil-derived biodiesel pathways that have been approved under the LCFS are sourced from domestic feedstock.

* This does not mean that biodiesel is not being moved via pipeline between the two regions. Biodiesel blends of 5 vol% or less meet the ASTM D975 specification for diesel fuel and are not included in the EIA’s movements data as a result. This subject is discussed in greater detail in Section 3.

Soybean oil-derived biodiesel, by contrast, whether from the U.S. or abroad, has only contributed a small share of California's biodiesel supply.

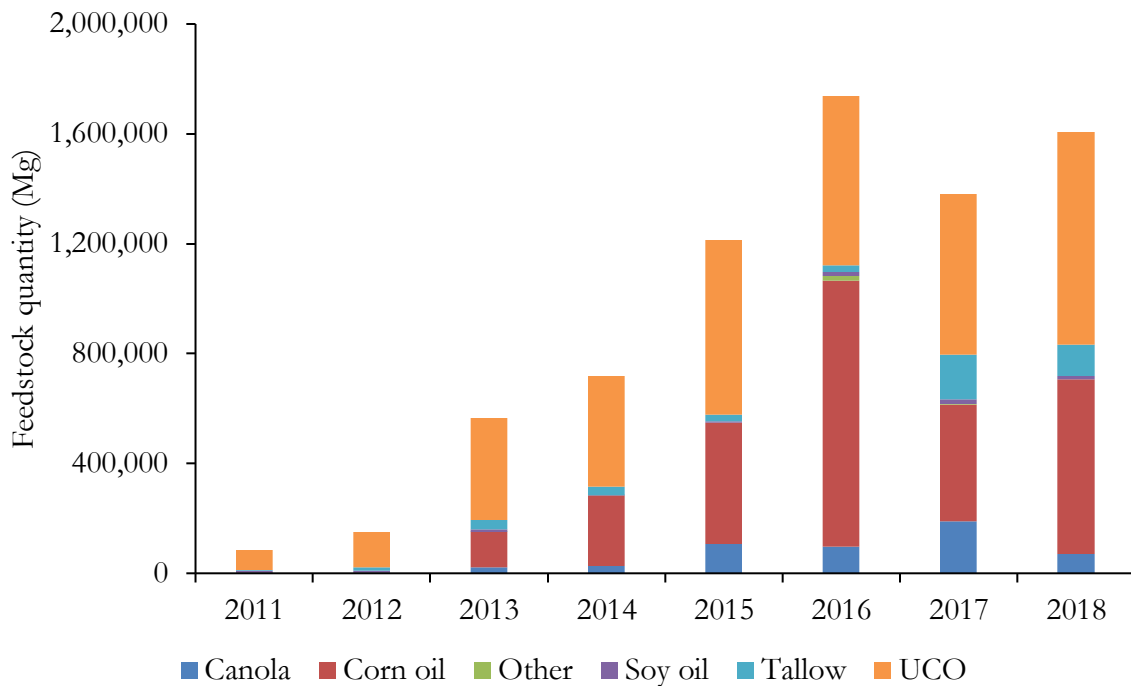


Figure A-23. Feedstock types and amounts utilized for biodiesel (produced in both the U.S. and abroad) sold under California's LCFS.²³

The higher proportion of waste feedstocks in the PADD 5 region's biodiesel supply reflects an important distinction between the LCFS, which only covers imported fuel sold into California's market,* and the U.S. RFS, which covers imported fuel that is sold into the national market. Whereas the credit that biodiesel receives under the LCFS is a direct function of the biodiesel's CI, the RFS simply requires biodiesel to achieve a 50% reduction to the CI of diesel fuel in order to receive the national program's credit. Producers of biodiesel with especially low CIs, such as that produced from waste feedstocks rather than unrecycled vegetable oils, therefore have an additional incentive to sell into California's market. The presence of PADD 2 corn oil but not PADD 2 soybean oil indicates that the difference in CIs between biodiesels derived from the two feedstocks is large enough to justify

* While Oregon now has a LCFS-like program of its own, the EIA data does not show any volumes being imported through that state's ports of entry.

the cost of transporting the former but not necessarily the latter from the Midwest to California by rail.

Biodiesel production in California, where 39% of PADD 5 biodiesel production capacity is located, has followed a similar trend toward the adoption of non-oilseed feedstocks. The state's biodiesel production volume from waste and byproduct feedstocks increased by 355% between 2011 and 2018 (see Figure A-24).²⁴ The volume of in-state production from oilseed feedstocks declined slightly over the same time period and the ratio of waste and byproduct feedstocks to oilseed feedstocks increased from 2.2:1 in 2011 to 10.4:1 in 2018. The specific feedstock mix for biodiesel produced in California is not available but 10 of the 18 approved LCFS pathways for California biodiesel production are for UCO, which suggests that at least some of the growth of in-state biodiesel production from waste and byproduct feedstocks has been made possible due to increased waste feedstock collection and utilization.²⁵

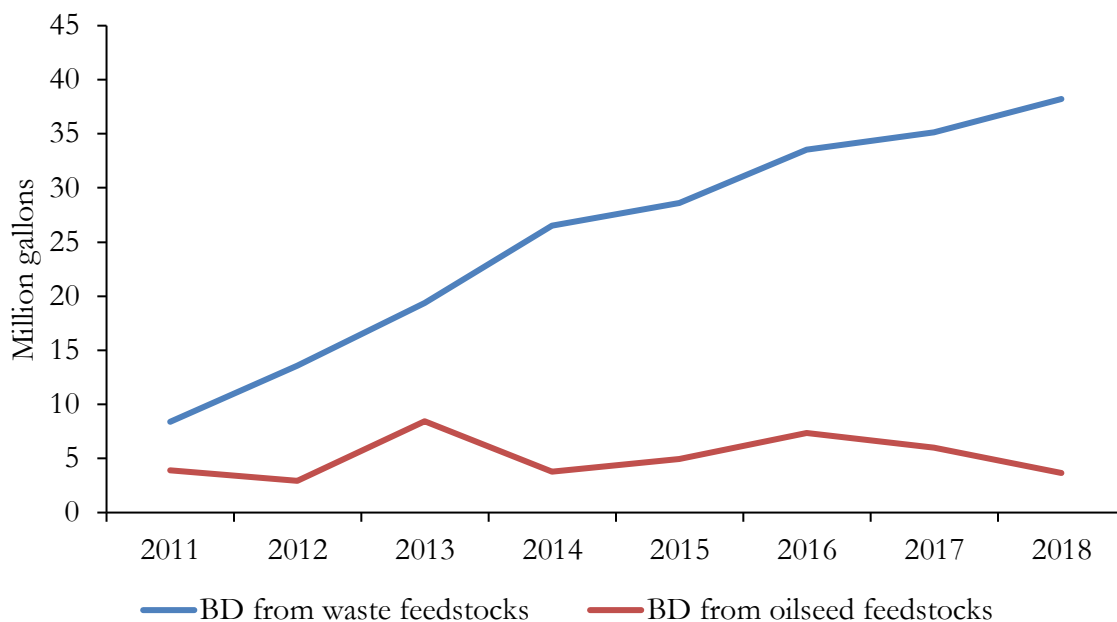


Figure A-24. Volumes of biodiesel produced in California from waste feedstocks and from oilseed feedstocks.²⁴

The impact that California's LCFS has had on PADD 5 biodiesel supply is also evident in the list of countries from which the region has imported biodiesel over the last decade. Individual biodiesel producers under the LCFS must have a specific CI attributed to the production facility that they employ before participating in the LCFS program. To date no biodiesel pathway that utilizes palm oil

has been approved²⁵ on the grounds that palm plantations displace rainforest and palm-derived biodiesel therefore has a CI that is higher than that of diesel fuel. With the exception of a single shipment from Singapore that arrived in July 2011,⁹ the only Asian country from which the PADD 5 region has received biodiesel is South Korea,¹⁰ which utilizes UCO as feedstock.¹² Indonesian biodiesel, by contrast, has been shipped to the PADD 1 and PADD 3 regions despite being further away due to a lack of similar restrictions in those markets.

The large majority of the biodiesel that has been imported by the PADD 5 region has come from Canada and South Korea (see Figure A-25). Smaller volumes have been imported from Argentina, Norway, and Singapore, although these were limited in terms of frequency and size; imports have only arrived from Canada and South Korea since 2016. The PADD 5 region also regularly exports biodiesel to Canada, much of it by rail.²⁶ The region's total imports have exceeded its total imports by a 1.2:1 ratio since 2009. This ratio has been skewed by the presence of large, one-time shipments to Malaysia and the Netherlands at the beginning of the decade, though, and shipments of biodiesel out of the state peaked in 2013 whereas movements into the state have steadily increased since then.

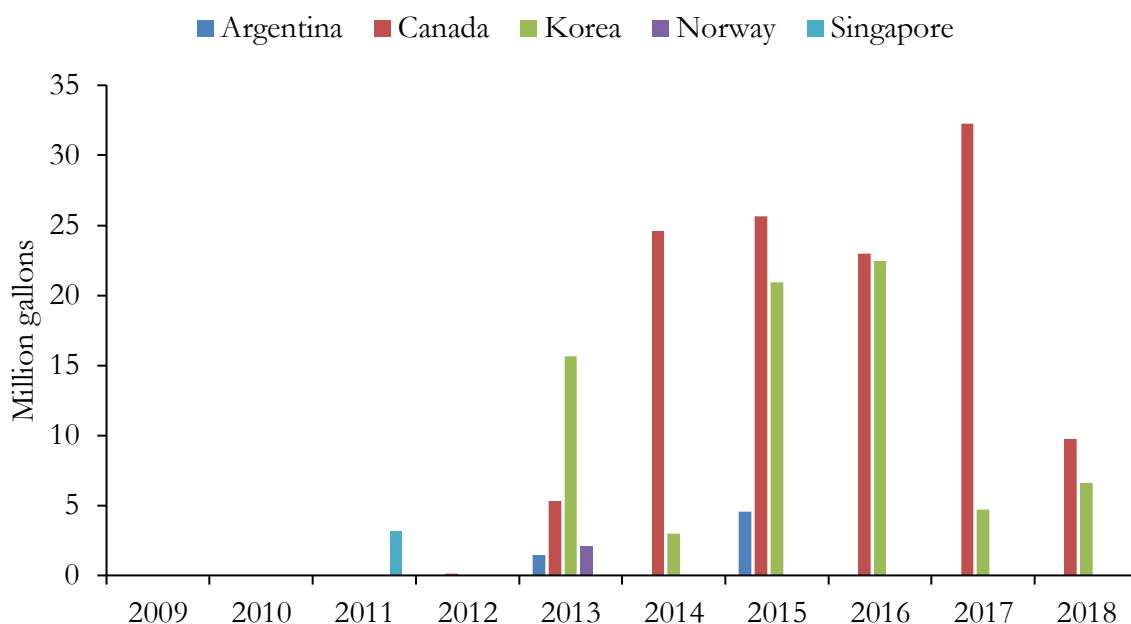


Figure A-25. Five largest foreign sources of PADD 5 biodiesel imports.¹⁰

93% of the PADD 5 region's biodiesel imports since 2009, and all of the imports from countries other than Canada, have entered the region through ports of entry in California.¹⁰ Of the amount

imported by California, 70% has entered through ports in and immediately around Los Angeles and 30% has entered through ports in and immediately around San Francisco (see Figure A-26). 79% of the total biodiesel that has been imported from Canada into the PADD 5 region has entered through those ports, showing the attraction of California's market to Canadian producers despite the longer transportation distance relative to Washington and Oregon. The remaining imports from Canada have moved across Canada's land border into Washington.



The emphasis of California's LCFS on feedstocks that produce low-CI biodiesel is reflected in the feedstock mix of the PADD 5 region's biodiesel imports. Only 8% of the imports that occurred between 2009 and 2018 were derived from soybean oil, in sharp contrast to the PADD 1 and PADD 3 regions (see Figure A-27). Over 60% were derived from UCO due to that feedstock's utilization by producers in Canada and South Korea. 33% of the PADD 5 region's biodiesel imports have been derived from unrecycled vegetable oils, with the rest having been derived from waste feedstocks such as animal processing residues and UCO.

Figure A-4. PADD 5 biodiesel imports by volume and port of entry, 2009-2018.⁹

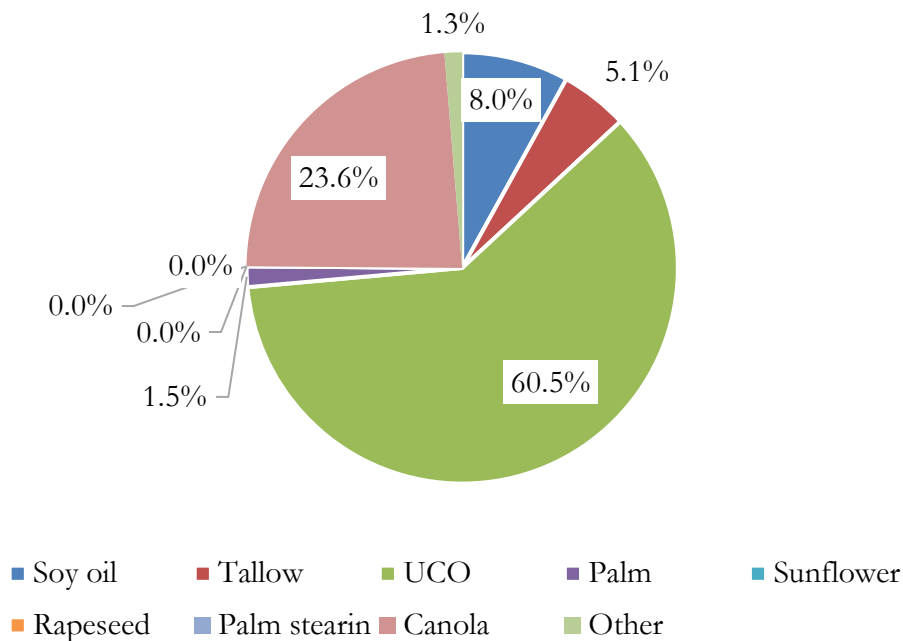


Figure A-27. Feedstock mix for PADD 5 imports of foreign biodiesel, 2009-2018. Source: Author calculations based on USDA FAS “Biofuels Annual Reports” for Argentina, Canada, the EU-28, Indonesia, and South Korea. Due to a lack of data Norway is assumed to have the same feedstock mix as the EU-28, Singapore is assumed to utilize 100% palm oil as biodiesel feedstock, and Taiwan’s feedstock is treated as “other.”¹²

I.6. Renewable diesel supply - PADD 1

The PADD 1 region, as noted above, does not host any renewable diesel capacity and therefore has not produced renewable diesel at commercial scales in the last decade. It was supplied with renewable diesel between 2012 and 2016, though, in the form of imports of fuel produced by Neste Oil and smaller shipments from the PADD 3 region (see Figure A-28). Of the 99.2 million gallons that were imported, 57% came from Singapore, 40% came from Finland, and 3% came from Aruba. 77% of the imports entered the U.S. through ports of entry in New Jersey (primarily Perth Amboy, but also Newark and Paulsboro) and the rest entered through Maine, Boston, and Pennsylvania (see Figure A-29).⁹

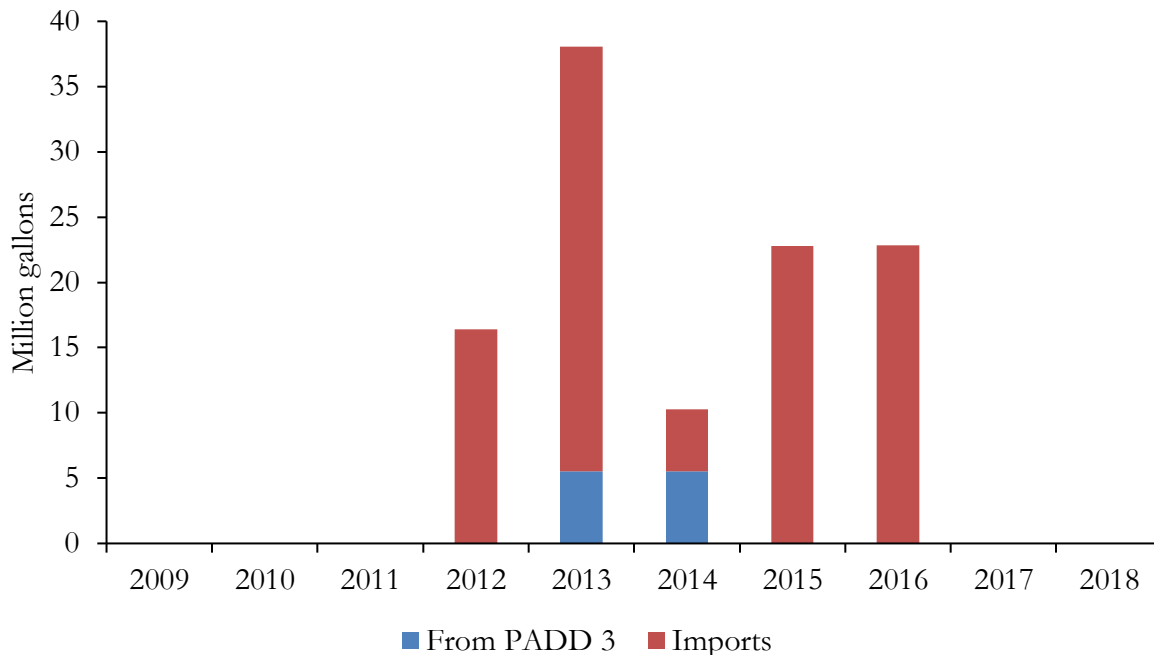


Figure A-28. PADD 1 renewable diesel supply, 2009-2018.^{7,9}



Figure A-5. PADD 1 renewable diesel imports by volume and port of entry, 2009-2018.⁹

Neste Oil does not publish the feedstock mixes employed by its individual facilities, so it is not possible to determine the specific feedstocks from which the PADD 1 region’s renewable diesel imports have been derived. That said, virtually all the renewable diesel that was imported into the U.S. between 2009 and 2018 received D4, and only D4, Renewable Identification Number (RIN) credits under the RFS. BBD from palm feedstock cannot receive D4 RINs, so the renewable diesel that has been imported into the PADD 1 region (as well as the rest of the U.S.) by Neste Oil must have been produced from other feedstocks. The company’s own data for the period reports that “waste and residues” such as inedible animal processing residues were the only other feedstocks utilized by its facilities, so it can be assumed that the PADD 1 imports were derived from waste feedstocks since Neste Oil was the region’s only source of imports.²⁷

Individual transportation mode data is not available for renewable diesel from the U.S. Energy Information Administration (EIA); inter-PADD shipments for the fuel are aggregated as a single “pipeline, tanker, barge, and rail” category.^{7,*} It can be assumed with regard to renewable diesel movements from PADD 3 to PADD 1 that trucking is not being utilized given the large distances between the PADD 3 renewable diesel production facilities and the PADD 1 borders. It is possible that additional volumes are being transported via pipeline but do not show up in the EIA data since they are at blends of 5 vol% or less. Given the lack of blending restrictions for renewable diesel and the low level of renewable diesel production relative to consumption in the PADD 3 region, though, this is also improbable. The limited inter-PADD movements of renewable diesel into the PADD 1 region shown in the EIA data most likely reflect an actual lack of supply there, database ambiguities notwithstanding.

I.7. Renewable diesel supply – PADD 2

The PADD 2 has had very limited renewable diesel production capacity over the last decade in the form of the 3 MMGY Green Energy Products facility and 3 MMGY East Kansas Agri-Energy (EKAE) facilities, both in Kansas. Public data on the Green Energy Products facility has been lacking since the parent company was not publicly traded and efforts to contact corporate representatives during the drafting of this report were not successful. This report assumes that the facility produced 3 MMGY of renewable diesel in 2015 prior to being shutdown in 2016 following the bankruptcy of its parent company. There is also no indication that the EKAE facility, which was commissioned in late 2017, has contributed substantial volumes over the last decade: the facility is not certified under the LCFS despite a 2017 marketing agreement to sell its renewable diesel in

* Confusingly, the EIA data on inter-PADD shipments presents data for a “biodiesel” category that is nested within a larger “renewable diesel fuel” category. While no definition is provided for “renewable diesel fuel”, the EIA database does define a “renewable diesel fuel (other)” category as “diesel fuel and diesel fuel blending components produced from renewable sources that are co-processed with petroleum feedstocks and meet requirements of advanced biofuels”; no definitions are provided for “biodiesel” and “advanced biofuels.” Very little co-processing occurs within the U.S., let alone at a scale that would permit volumes of inter-PADD movements in excess of inter-PADD biodiesel movement volumes, as a strict interpretation of the EIA data would indicate occurs. Furthermore, co-processed fuels do not meet the definition of “biomass-based diesel” under the RFS, so the only way to interpret the data is by reading the EIA’s “renewable diesel fuel” category to mean the same as the category that RFS and this report refer to as biomass-based diesel: i.e., both biodiesel and renewable diesel. This report obtains the inter-PADD movement data for renewable diesel by subtracting the EIA’s “biodiesel” volumes from its larger “renewable diesel fuel” volumes. This approach has been validated by industry contacts as yielding results that are in-line with their understanding of the renewable diesel volumes that are moved between PADDs. See Appendix III for more details on definitions and sources.

California under the LCFS,^{25,28} and recent news items suggest that production had yet to reach its nameplate capacity as of late 2018.²⁹ This lack of production has meant that the majority of the renewable diesel that has been consumed in the PADD 2 region over the last decade has been sourced from outside of the region, with the PADD 3 region being the point of origin for most of the PADD 2 region's renewable diesel supply (Figure A-30). The PADD 2 region's supply of renewable diesel peaked in 2011 and has been non-existent since 2014 (with the possible exception of the EKAE facility in 2018).

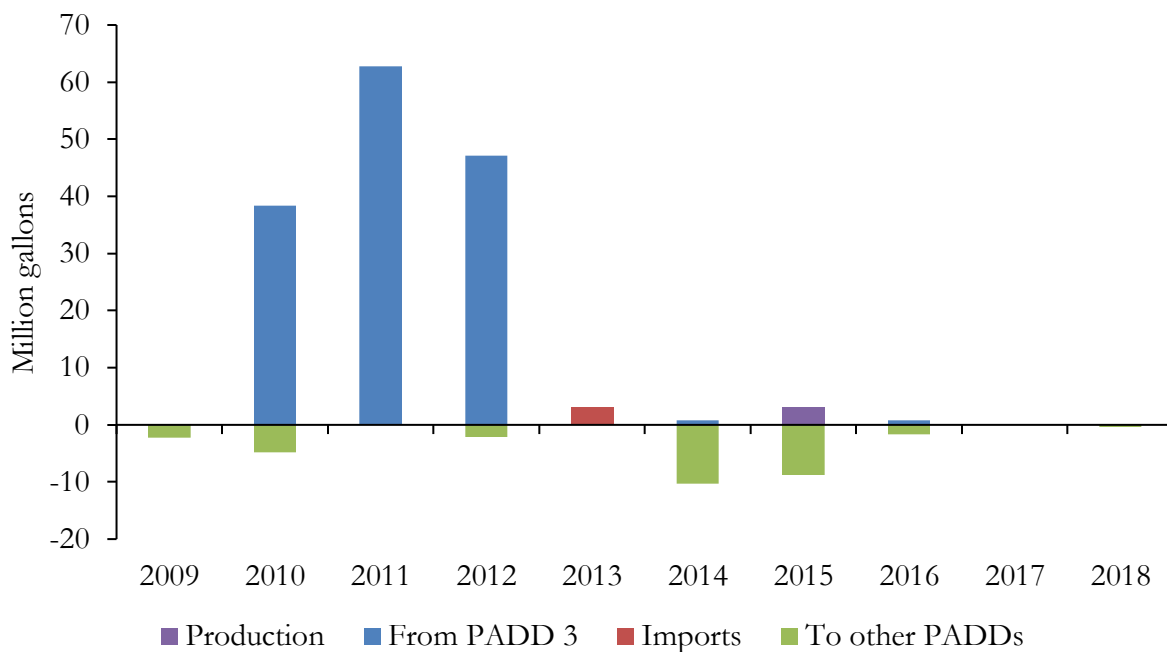


Figure A-30. PADD 2 renewable diesel supply, 2009-2018.^{7,9}

The PADD 2 region has imported a total of 3.1 MMGY of renewable diesel, all of it from Finland in 2013. This renewable diesel was most likely produced by Neste Oil at its Finnish renewable diesel facility, in which case it can be assumed to have been derived from waste and residual feedstocks for the reasons described in the PADD 1 renewable diesel supply section (see above). The PADD 2 region's renewable diesel imports have only moved through ports of entry in Michigan and Wisconsin (see Figure A-31). The PADD 2 region has also shipped renewable diesel to the PADD 3 region. The total volume of these shipments has greatly exceeded the volume of production by PADD 2 producers and PADD 2 imports, which suggests that the renewable diesel that was shipped to the PADD 3 region was originally produced there.

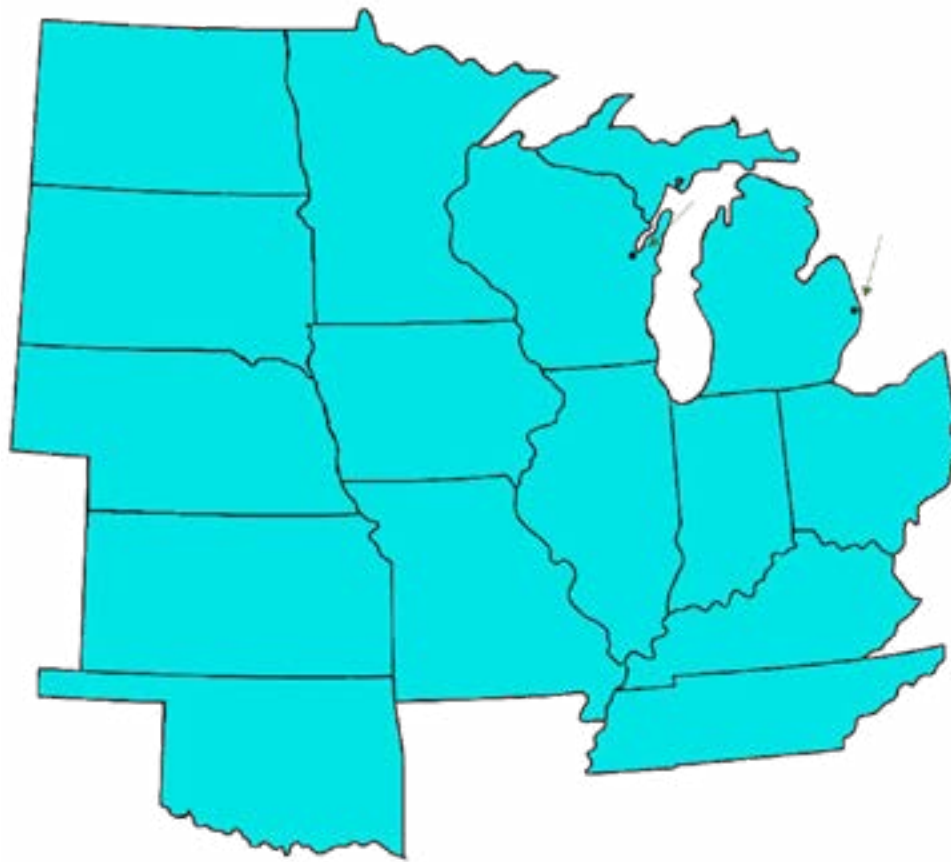


Figure A-31. PADD 2 renewable diesel imports by volume and port of entry, 2009-2018.⁹

I.8. Renewable diesel supply – PADD 3

The PADD 3 region has the country's largest volume of production and accounted for 90% of the U.S. total in 2018.¹ The region ships some of this to other PADD regions, particularly the PADD 5 region, but most of its production contributes to the PADD 3 supply (see Figure A-32). Its renewable diesel utilization rate has been relatively low due to production outages that occurred at the Dynamic Fuels/REG Geismar facility between 2012 and 2015. The most recent decline to the region's average utilization rate, however, reflects additional capacity that was brought online rather than disrupted production.

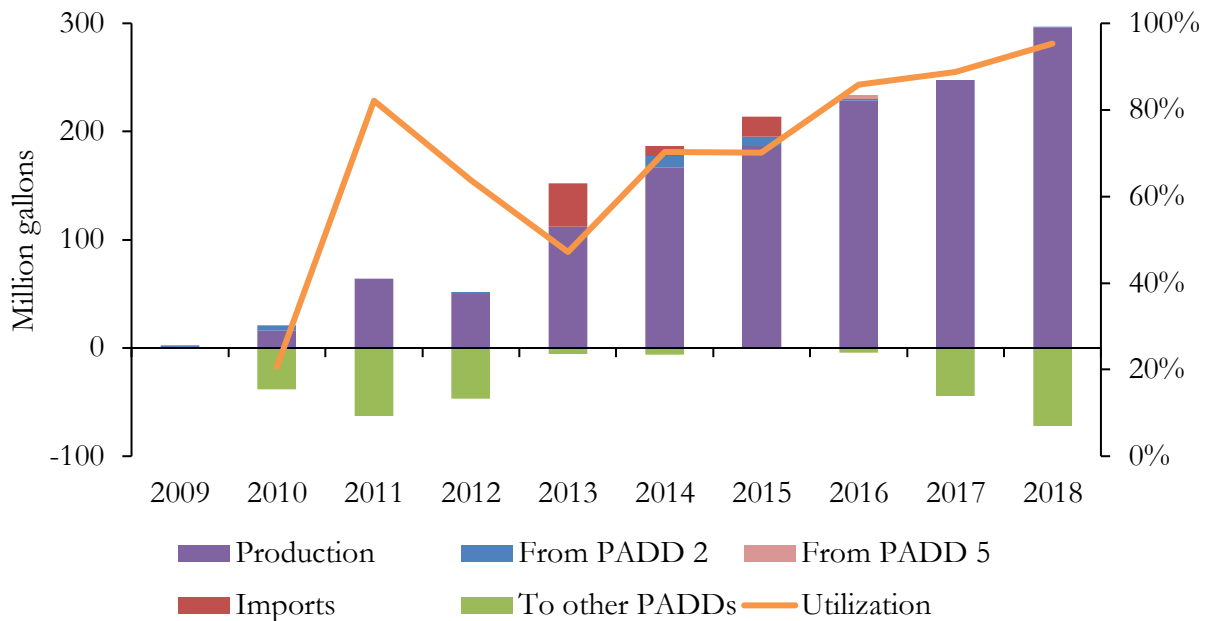


Figure A-32. PADD 3 renewable diesel supply, 2009-2018.^{7,9*}

68 million gallons of renewable diesel has been imported into the region over the last decade, all of it between 2013 and 2015. These imports came from Singapore and, to a lesser extent, Finland, and were likely produced at Neste Oil's renewable diesel production facilities at those two locations. The PADD 3 region's renewable diesel imports have mostly entered the region through Louisiana, although small volumes have entered through ports in Texas as well (see Figure A-33). Smaller volumes have also been moved from the PADD 2 and PADD 5 regions into the PADD 3 region, although such shipments have only comprised a small fraction of total PADD 3 supply. As discussed above, though, the volumes from the PADD 2 region have exceeded its renewable diesel production volumes, making it unlikely that they ultimately were produced there.

* PADD 3 renewable diesel production volumes are calculated from the following sources: the quarterly earnings presentations published by Darling Ingredients for Diamond Green Diesel; quarterly production data provided by Renewable Energy Group; the quarterly earnings statements published by Alon USA Energy and Delek US Holdings for AltAir Paramount (this is a PADD 5 facility but its production data was cross-referenced against the EPA's RIN generation database to determine the PADD 3 production volumes), and the EPA's RIN generation database for renewable diesel. Cetane Energy was assumed to produce 3 MMGY between 2010 and 2018. Green Energy Products, a PADD 2 producer, was assumed to produce 3 MMGY in 2015.



Figure A-33. PADD 3 renewable diesel imports by volume and port of entry, 2009-2018.⁹

I.9. Renewable diesel supply – PADD 4

The PADD 4 region neither produces nor ships in commercial-scale volumes of renewable diesel from other PADDs or countries. Renewable diesel supply data for the region is not expected to become available until its first commercial-scale production facility becomes operational in 2019.

I.10. Renewable diesel supply – PADD 5

The PADD 5 region has the country's largest volume of renewable diesel supply despite its lack of capacity compared to the PADD 3 region. The region only hosts one renewable diesel production facility that has been variously known as “AltAir Fuels” and “AltAir Paramount” over the course of multiple changes of ownership in the last decade. This facility commenced operations in 2016 and has contributed to the PADD 5 region's renewable diesel supply since then (see Figure A-34). Most of the region's supply has been obtained from the PADD 3 region, which commenced renewable diesel shipments in 2016, and via imports, the latter of which have supplied most of the region's renewable diesel volumes over the last decade. The movement of renewable diesel has been unidirectional with the sole exception of 3.4 million gallons that was moved from the PADD 5 region to the PADD 3 region in 2016.

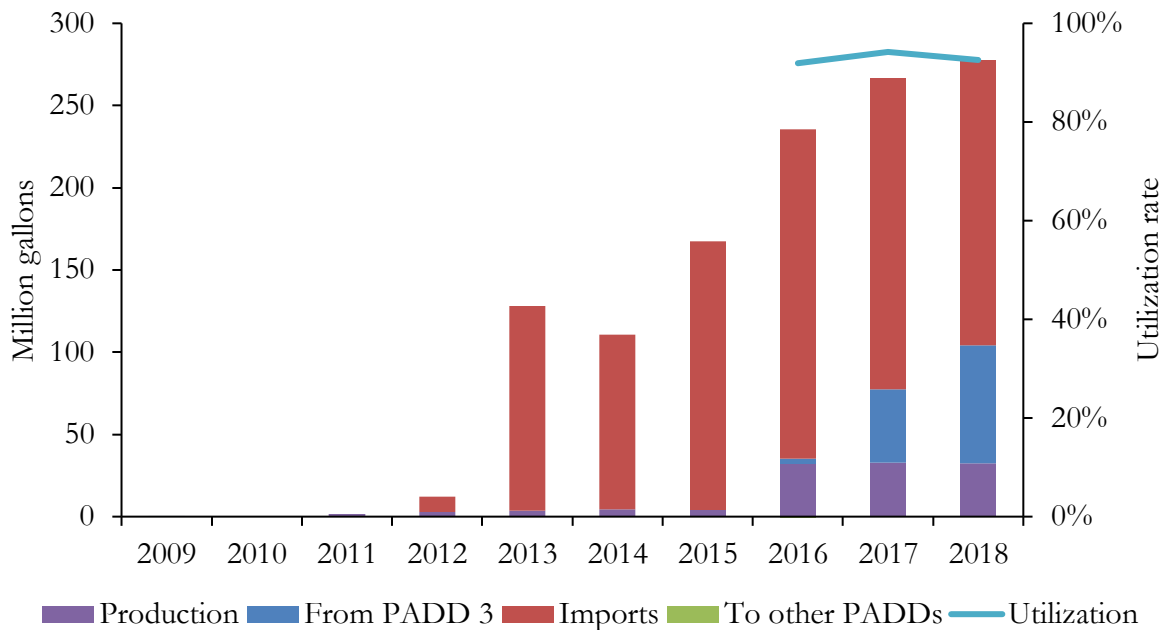


Figure A-34. PADD 5 renewable diesel supply, 2009-2018.^{7,9,30}

PADD 5 renewable diesel production is primarily obtained from animal processing residue feedstocks, although “small quantities” of vegetable oils are also utilized.^{30,31} 99% of the imported renewable diesel volume has been sourced from Neste Oil’s Singapore facility, with the balance consisting of one-time deliveries from Finland and Aruba by the same company.⁹ As with the PADD 3 imports of Neste Oil renewable diesel, it can be assumed that the PADD 5 region’s imports are derived from residue and waste feedstocks, especially since California’s LCFS does not recognize any pathways that utilize palm oil feedstock.²⁵ This assumption is supported by the fact that Neste Oil’s Singapore facility has been certified by the LCFS for the following feedstocks: CDO, inedible fish oil, tallow, and UCO.²⁵ Only 1% of the region’s imports entered through Oregon, while the rest entered through Californian ports of entry (see Figure A-35). The ports of Los Angeles, Long Beach, and Richmond accounted for 77% of the renewable diesel that was imported into the PADD 5 region between 2009 and 2018, although no fewer than 11 PADD 5 ports have been used in total.



Figure A-6. PADD 5 renewable diesel imports by volume and ports of entry, 2009-2018.⁹

Data collected by California shows that the transportation mode utilized to move renewable diesel into the PADD 5 region has been dependent on the fuel's place of origin.²⁵ Imports have been transported by ocean tanker. In some cases, multiple ocean tanker journeys have been required: the first journey to move feedstock from countries such as Australia, New Zealand, and even the U.S. to Neste Oil's production facility in Singapore, and the second journey to move the finished fuel to the PADD 5 region's deep-water ports. Shipments from the PADD 5 region, on the other hand, are reported to be conducted, depending on the producer, via a combination of barge, rail, and truck

(Diamond Green Diesel)³² or just rail (REG Geismar).³³

I.11. State blend mandates

In June 2019 New York State passed the "Climate Leadership and Community Protection Act" (CLCPA), which requires the state to reduce its GHG emissions relative to a 1990 baseline by 40% by 2030 and 85% by 2050.³⁴ Carbon-negative technologies are to be employed to bring the state's emissions to net zero by 2050. The legislation includes GHG emissions from the transportation sector in its mandated thresholds and expressly requires the reduction of emissions from motor vehicles, including both personal and freight transport. It does not dictate how the transportation sector's emissions are to be reduced but instead establishes procedures for developing the necessary mechanisms. One of these procedures requires NYS to consider GHG emission reduction programs in states such as California such as the LCFS. BBD will likely be considered a GHG emissions

reduction mechanism in NYS given that BBD fuels have been and continue to be the primary source of carbon credits under the LCFS.

NYS is one of the country's larger consumers of distillate fuel oil (including diesel fuel) at 2,365 million gallons in 2017.³⁵ Were the state to achieve the same BBD blending rate of 15 vol% as California has then additional BBD supply of up to 355 MMGY would be required (although some of this will have already accounted for by the bioheat mandates in NYS that are described below). While BBD supply in NYS and the PADD 1 region more generally is currently limited compared to the rest of the U.S., it is worth noting that 2,422 million gallons of BBD has been supplied to California under its LCFS even though its annual supply was only 16 million gallons in 2011. It is therefore feasible that PADD 1 BBD supply volumes will increase quickly if NYS adopts a transportation emission reduction program that is similar to California's LCFS.

On May 1, 2018 Minnesota adopted a particularly ambitious 20 vol% biodiesel summer blending mandate that went into effect in 2019. Between April 1 and September 30 all No. 2 diesel fuel supplied within the state must contain at least 20 vol% biodiesel.³⁶ Between October 1 and March 31 all No. 2 diesel fuel must contain at least 5 vol% biodiesel, reflecting the especially cold temperatures that characterize winters in Minnesota. The state's blending mandate initially took the form of a 2 vol% requirement in 2005 that was increased to 5 vol% in 2009 and 10 vol% in 2014. Each increase to the mandated blend rate has been preceded by an interagency review to determine whether the following four prerequisites were met:³⁷

- (1) The existence of an ASTM specification or equivalent federal standard for the new biodiesel blend;
- (2) The existence of a sufficient supply of biodiesel, of which at least 50% of the volume needed to meet the new blend is produced in Minnesota and 75% is produced in North America;
- (3) The existence of adequate blending infrastructure and regulatory protocol in order to promote fuel quality and avoid economic disruption; and
- (4) The production of at least 5% of the biodiesel necessary to meet the new blend requirement from a non-agricultural crop (i.e., waste or residue feedstocks).

Furthermore, Minnesota's definition of biodiesel explicitly excludes fuel derived from palm oil feedstock (unless the palm oil is a waste collected within North America).

Minnesota's experience with its blending mandate has demonstrated some of the challenges that such state supply incentives can experience. Its 10 vol% biodiesel blending mandate was postponed by two years after the interagency review determined that insufficient blending infrastructure and regulatory protocol existed, although it was enacted after a new BBD blending facility opened in South Dakota and a protocol was developed for tracking the biodiesel content of blended fuels. The 20 vol% biodiesel mandate was enacted after upgrades to the state's existing fuel terminals were made to ensure sufficient supply and the meeting of fuel quality requirements at the new blend level.³⁷

An interesting aspect of Minnesota's 20 vol% blend mandate is that the prerequisite review process includes the effects of federal policies in determining whether conditions relating to BBD supply availability and price are satisfied. The annual report accounts for the impacts of RFS RINs and the federal BBD tax credits on BBD prices and supply volumes in Minnesota, for example.³⁷ One implication of this is that the feasibility of Minnesota's mandate is potentially affected by changes to federal BBD policies. Such changes have not hindered implementation of the state's supply mandate to date, however.

Minnesota's blend mandate is the most ambitious state-level BBD mandate in the U.S., but other states have also enacted their own such mandates. Oregon requires all diesel fuel supplied within the state to be blended with at least 5 vol% biodiesel and/or renewable diesel;³⁸ this was increased from a 2 vol% requirement in 2011.³⁹ Washington requires all of its diesel fuel supply to contain at least 2 vol% biodiesel and/or renewable diesel, rising to 5 vol% 180 days after a state determination that enough in-state feedstock and oilseed crushing capacity exists to supply BBD equal to a 3 vol% blend.⁴⁰ Pennsylvania has adopted a graduated blend mandate that links the required blend rate to the volume of in-state biodiesel production capacity (see Table A-4); each blend rate increase goes into effect within one year of in-state production capacity having reached and sustained for three months the prerequisite volume.

Table A-4. Pennsylvania blend mandate schedule and prerequisites.⁴¹

Blend rate	In-state production capacity requirement	Scheduled implementation
2 vol%	40 million gallons	Within 1 year
5 vol%	100 million gallons	Within 1 year
10 vol%	200 million gallons	Within 1 year

20 vol%	400 million gallons	Within 1 year
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South Carolina has a narrow mandate that requires all state-owned diesel fueling facilities to provide biodiesel blends of at least 5 vol% at all diesel pumps.⁴²

New Mexico utilizes a 5 vol% biodiesel blend mandate for all on-road petrodiesel sales. The state's mandate resembles that of Illinois in that it is suspended if certain supply and price prerequisites are not met. Specifically, it is suspended if sufficient supply volumes of biodiesel are not available within the state, or if the price of the biodiesel blend “significantly exceeds” the price of diesel fuel for at least two months.⁴³ Each suspension can last for at least six months. The most recent suspension began in December 2018 after a finding that neither condition was being met: only 55% of the terminal blending capacity needed to supply a 5 vol% biodiesel blend was available, and the combination of the expired federal BBD tax credit, countervailing duties on biodiesel from Argentina and Indonesia, and low RIN prices resulted in an unfavorable 5 vol% biodiesel blend price differential with diesel fuel.⁴⁴ Moreover, the state's suspension was also based on a finding that, while the necessary blending infrastructure could be constructed within three years, there was no “economic incentive to undergo the construction” due to the unfavorable 5 vol% blend price differential. New Mexico's mandate is an example of how state-level supply policies can be negatively affected by changes to federal BBD policies such as those that were explicitly referenced in the state's suspension decision.

Massachusetts implemented a permanent suspension of its own 2 vol% blending mandate for diesel fuel and heating oil in 2010 on similar grounds as New Mexico's temporary suspension in 2018. The former state had earlier implemented its mandate with one of the country's strictest sustainability requirements: all participating biodiesel had to be derived from waste feedstocks.⁴⁵ Massachusetts subsequently abandoned its mandate in favor of a voluntary program on the grounds of “unreasonable cost.”⁴⁶ Specifically, the state determined that the expiration of the federal BBD tax credit at the end of 2009 caused the 2 vol% biodiesel blend to exceed petrodiesel on price by \$0.03/gallon at a time when it expected the mandate to incur infrastructure-related costs as well. Notably, the suspension was not reversed even when the tax credit was reinstated or when diesel fuel prices sharply increased between 2011 and 2014.

In 2006 Louisiana legislated a 2 vol% blending mandate for diesel fuel to be implemented within six months of the state's biodiesel production reaching at least 10 MMGY. To qualify the biodiesel must

be derived from domestically-grown feedstocks, and the proportion from Louisiana soybeans must equal the proportion of national biodiesel production that is obtained from soybeans.⁴⁷ At the time of the legislation's passage Louisiana's governor expected that the prerequisites for the mandate's implementation would be met by 2008.⁴⁸ Louisiana had sufficient biodiesel production capacity until 2013 to achieve the production prerequisite⁴⁹ and has had sufficient production for several years if renewable diesel is also considered. While there is a lack of recent public information regarding the status of Louisiana's 2 vol% biodiesel blend mandate, it is being complied with as of July 2019.⁴⁹

While not a mandate in the strict sense, Missouri incentivizes BBD supply via the use of a limited liability mechanism. Producers, suppliers, terminal operators, wholesalers, distributors, retailers, and motor vehicle manufacturers and dealers in the state cannot be held liable for property damage caused by a consumer's intentional purchase of biodiesel and biodiesel blends for use.⁵⁰

Multiple states in the Northeast U.S. have also implemented biodiesel blend mandates with heating oil ("bioheat"), reflecting the region's continued use of liquid fuels for space heating. In July 2018 New York State implemented a 5 vol% "renewable biofuels" (practically, BBD) blend mandate with heating oil in the downstate counties of Nassau, Suffolk, and Westchester in which most of the state's population lives.⁵¹ The state bioheat mandate runs parallel to New York City bioheat mandate that requires incremental increases to the supply of biodiesel that is blended with heating oil from 5 vol% in 2017 to 10 vol% in 2025, 15 vol% in 2030, and 20 vol% in 2034.⁵²

Connecticut has also adopted an incremental bioheat mandate, although it has yet to be implemented due to its unique prerequisites. The mandate requires the supply of biodiesel that is blended with heating oil in the state to increase from 2 vol% in 2011 to 5 vol% in 2012, 10 vol% in 2015, 15 vol% in 2017, and ultimately 20 vol% in 2020.⁵³ The mandate also requires the creation of a "Distillate Advisory Board" that is tasked with determining whether sufficient in-state biodiesel production exists to supply the required biodiesel volumes. Fatally to the mandate thus far, the final prerequisite is that New York, Massachusetts, and Rhode Island each "have adopted requirements that are substantially similar" to Connecticut's mandate. While New York and Rhode Island have both passed heating oil mandates, the latter only requires a 5 vol% biodiesel supply by 2017,⁵⁴ and Massachusetts now employs a voluntary rather than mandated biodiesel program for heating oil (in addition to transportation fuel).

Similarly, Vermont has also adopted a bioheat mandate that has yet to be implemented due to a lack of action by all its neighboring states. The mandate requires biodiesel to be blended with heating oil starting with a 3 vol% blend in 2012 that increases to 5 vol% in 2015 and 7 vol% in 2016.⁵⁵ The prerequisite for enactment is that Massachusetts, New Hampshire, and New York must first adopt their own equally or more stringent bioheat mandates. Vermont's mandate has not been implemented as a result (in addition to the suspension of the Massachusetts mandate, New Hampshire only requires that biodiesel blends be supplied to some government fleet vehicles).⁵⁶

I.12. State supply incentives

Several states within the PADD 1 region provide at least one tax credit for qualifying BBD investments, although several do not (and West Virginia explicitly forbids the provision of subsidies to alternative fuels other than some coal-based liquid fuel pathways).⁵⁷ Besides West Virginia, the states of Connecticut, Delaware, Maryland, Massachusetts, New Hampshire, New Jersey, Vermont, do not provide tax incentives for the BBD sector as of June 2019 (excluding production by individuals for personal use). Maryland did provide between 2008 and 2017 a tax credit of \$0.03/gallon, up to a maximum of \$500, for entities that used biodiesel for space and water heating purposes.⁵⁸ Eight states and Washington D.C. currently provide tax incentives in the following forms:

- Florida provides a \$0.01/gallon excise tax exemption on biodiesel that is produced by municipalities, counties, or school districts for use with their vehicles.⁵⁹
- Georgia provides an annual tax credit for five years that can be earned by BBD producers; the amount of the credit is based on the producer's number of employees.⁶⁰
- The excise tax that Maine imposes on biodiesel blends of 90 vol% or more is \$0.025/gallon less than its diesel fuel excise tax.⁶¹
- New York biodiesel producers can earn a tax credit of \$0.15/gallon of biodiesel produced, up to \$2.5 million for four consecutive years per production facility. New York also prohibits the use of contracts by fuel retail franchises that prevent fuel dealers from purchasing or selling biodiesel blends of 2 vol% or greater.⁶²
- North Carolina exempts the retail sale, use, and storage of biodiesel from the state's retail sales and use tax.⁶³

- Rhode Island exempts biodiesel from the state's \$0.30/gallon fuel excise tax (only the biodiesel portion of biodiesel blends is exempted). Only biodiesel production that results in employment at a "manufacturing facility for biodiesel fuel" qualifies for the exemption.⁶⁴
- South Carolina provides a tax credit equal to 25% of the construction or renovation costs of a biodiesel production facility. Feedstock crushing and handling equipment is included in the state's definition of a production facility, allowing for co-located oilseed crushing equipment to also qualify for the tax credit. The state also provides a tax credit equal to 25% of the purchase, construction, or renovation costs for biodiesel distribution infrastructure that is exclusively used to distribute, dispense, and store unblended biodiesel.⁴² Similar to New York, South Carolina also prohibits contracts that prevent distributors and retailers from blending biodiesel for sale within the state.
- Virginia exempts BBD from state taxes if the fuel is either sold to a government entity for exclusive use by that entity or sold to a non-profit charity for use providing charitable services to low-income medical patients. BBD producers with at least 2 million gallons of annual production that do not qualify for the full tax exemption are eligible for a tax credit of \$0.01/gallon of BBD produced, although an individual producer can only generate annual credits worth up to \$5,000 and then only for the first three years of BBD production. BBD producers are also eligible for a \$500 tax credit per job created that has an annual salary of at least \$50,000, up to 350 jobs per employer. Finally, Virginia provides a feedstock incentive in the form of an exemption for state Department of Health registration and waiver of the corresponding application fee for individuals who transport UCO for conversion to BBD. The exemption and waiver only applies to those individuals who move the UCO in containers with less than 275 gallons of capacity and who own no more than 1,320 gallons of UCO and/or BBD.⁶⁵
- Washington D.C. grants an income tax credit (up to \$10,000) equal to 50% of the equipment and labor costs for installing biodiesel fueling infrastructure.⁶⁶

12 of the 15 state in the PADD 2 region provide a tax incentive in one form or another to the BBD sector. Only Missouri, Ohio, and Oklahoma do not provide tax incentives to the BBD sector (excluding production by individuals for personal use). The remaining states provide tax incentives in the following forms:

- Illinois only imposes its fuel excise tax on 80% of fuel sales in the state that contain between 1 vol% of 10 vol% of biodiesel, and no excise tax is imposed on fuel sales that contain a biodiesel blend of 11 vol% or greater.⁶⁷
- Indiana exempts biodiesel and biodiesel blends in internal combustion engines from the state gross retail tax.⁶⁸ Delaware waives excise taxes on alternative fuels that are used in government (local, state, and national) vehicles.⁶⁹
- Iowa provides an income tax credit equal to \$0.035/gallon of biodiesel sold in blends of 5 vol% to 10 vol% and \$0.055/gallon of biodiesel sold in blends of 11 vol% or greater.⁷⁰ The state also provides a tax credit for investments in biodiesel facilities and biodiesel research, refunds on taxes paid to contractors during facility construction, and local property tax exemptions for biodiesel facilities.
- Kansas provides an income tax credit equal to up to 40% (maximum of \$100,000) of the cost of installing biodiesel fueling infrastructure in addition to exempting biodiesel storage and blending equipment from state property taxes. Kansas also provides an incentive of \$0.03/gallon for every gallon of biodiesel sold (so long as minimum biodiesel sales volume thresholds are met).⁷¹
- Kentucky provides BBD producer and blenders with an income tax credit of \$1/gallon of pure BBD (the credit may only be granted once per gallon), up to a statewide cap of \$10 million. The state also provides sales tax refunds for purchases of biodiesel production and R&D equipment.⁷²
- Michigan provides property tax exemptions for qualified biodiesel production facilities.⁷³
- Minnesota provides grants of up to 35% of the cost of biodiesel blending equipment, including installation costs.⁷⁴
- Nebraska exempts biodiesel manufactured at and sold by biodiesel production facilities from certain state motor fuel taxes.⁷⁵
- North Dakota provides licensed fuel suppliers with a nonrefundable income tax credit of \$0.05/gallon for BBD blends of 5 vol% or greater. The state further provides a corporate income tax credit of 10% of the direct costs incurred by retrofitting or building new facilities capable of blending or selling BBD blends of 2 vol% or greater.⁷⁶
- South Dakota provides a tax credit to biodiesel blenders that is designed to offset any tax liability incurred via the blending of untaxed biodiesel. The state also provides a \$0.02/gallon

reduction to the state fuel excise tax of \$0.28/gallon for biodiesel sourced from an in-state biodiesel production facilities that has a nameplate capacity of at least 20 MMGY and production of at least 10 million gallons within one year.⁷⁷ Finally, the state allows biodiesel producers to obtain refunds of any state fuel taxes paid on methanol used as an input in biodiesel production.

- Tennessee prohibits contracts between fuel wholesalers and refiners or suppliers that prevents the former from blending biodiesel with diesel fuel. The state also requires refiners and refined fuels suppliers to make diesel fuel that is compatible for blending with biodiesel available to any wholesaler.⁷⁸
- Wisconsin forbids local entities from levying excise taxes, occupational taxes, licenses, or privileges on BBD or the purchase, sale, handling, or consumption of BBD.⁷⁹

Five of the six states in the PADD 3 region provide tax incentives for the BBD sector, with only Mississippi failing to do so. The remaining states provide tax incentives in the following forms:

- Alabama allows companies that invest in biofuel, including BBD, production facilities to earn a tax credit equal to 3% of the previous year's employee wages.⁸⁰
- Biodiesel suppliers in Arkansas can claim an income tax credit equal to 5% of their facilities and equipment costs.⁸¹
- Louisiana provides an income tax credit of between 7% and 18% of qualified biodiesel infrastructure project investment costs (up to \$1 million per project). A nonrefundable income tax credit of 30% is also provided for the cost of biodiesel fueling equipment.⁴⁷
- New Mexico exempts biodiesel distributed or used by government and other official entities from the state excise tax. Producers and distributors of biodiesel within the state are eligible for a tax deduction on the fuel. Blenders can receive a tax credit of up to 30% of the purchase and installation costs (up to \$50,000 per facility) on equipment used to generate biodiesel blends of at least 2 vol%.⁴³
- Texas exempts the biodiesel portion of biodiesel blends from the state excise fuel tax of \$0.20/gallon. Only those biodiesel blends that clearly identify the blend rate on the pump are eligible for the exemption.⁸²

Three of the five states in the PADD 4 region provide tax incentives to the BBD sector; Colorado and Utah do not. Those tax incentives that are provided in the region take the following forms:

- Idaho does not apply state excise tax on biodiesel that is used in state or federal government-owned vehicles.⁸³
- Biodiesel production facilities in Montana can qualify for a reduced property tax rate equal to 3% of the facility's market value. Biodiesel storage and blending equipment can receive a tax credit equal to up to 15% of its cost (up to \$52,500 for distributors and \$7,500 for retailers) on the condition that the biodiesel is made entirely from components produced in-state and its sales equal at least 2% of diesel sales. Tax refunds of \$0.02/gallon and \$0.01/gallon can be claimed by distributors and retailers, respectively, of biodiesel made entirely from components produced in-state.⁸⁴ Finally, biodiesel producers are exempt from the state's special fuel tax if they utilize UCO.
- Wyoming exempts BBD that is intended to be shipped outside of the state from its alternative fuel license tax.⁸⁵

Only two of the seven states in the PADD 5 region provide tax incentives to BBD producers; Alaska, Arizona, California, Nevada, and Washington do not provide blanket incentives, although Nevada has awarded more than \$9 million in tax abatements to Ryze Renewables for its Las Vegas renewable diesel facility.⁸⁶ Washington provided a business & occupation tax deduction for retail sellers and distributors of biodiesel as well as a sales tax exemption on machinery, equipment, and construction costs for biodiesel retail stations until July 1, 2015.⁸⁷ The state also offered a property tax exemption for biodiesel producers that expired at the end of 2015.

- Hawaii imposes an excise tax on biodiesel fuel sales that is equal to 25% of the tax on diesel fuel, plus \$0.0025/gallon;⁸⁸ in early 2019 this was worth \$0.16/gallon.⁸⁹ BBD producers in Hawaii may also claim for up to five years an income tax credit equal to \$0.20/76,000 BTUs of BBD sold for distribution in the state.⁸⁸
- Oregon exempts biodiesel blends of at least 20 vol% in which the biodiesel is produced from UCO from the state's \$0.34/gallon fuel excise tax (20 vol% blends used in certain heavy-duty vehicles are excluded). Biodiesel production facilities located in designed zones are eligible for property tax exemptions.³⁸

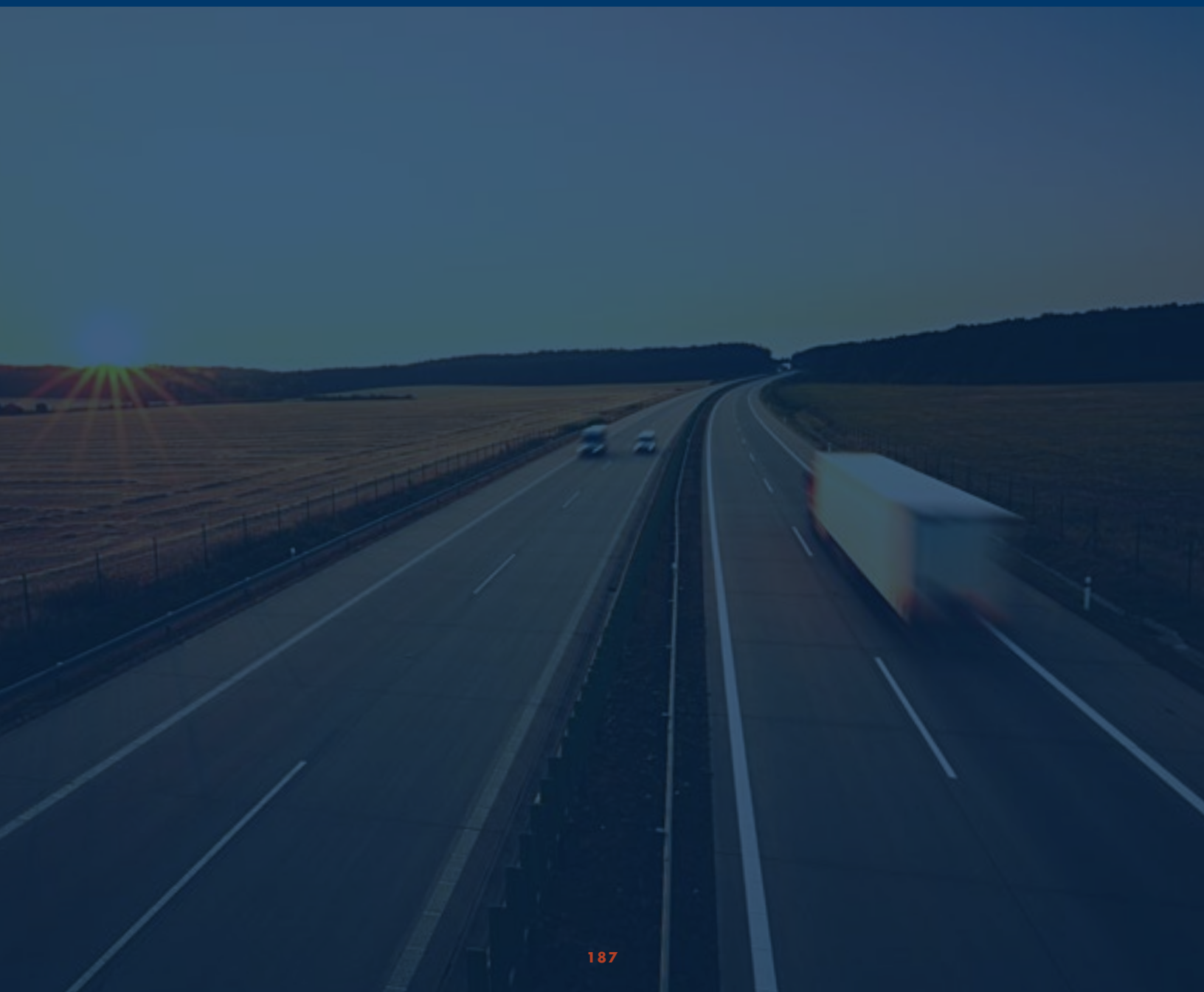
Competitive grants have also been employed to incentivize BBD supply, although the grants commonly apply to a broad range of alternative energy pathways and not all qualified applicants receive funding. The primary federal grant/loan guarantee program is the Advanced Biofuel

Production Grant that provides financial assistance of up to 50% of project costs for the development, construction, and retrofitting of commercial-scale advanced biofuel producers.⁹⁰ A second federal grant program is the Value-Added Producer Grant, which provides financial assistance for either planning or working capital (but not both) for agricultural entities that are entering or expanding into value-added activities. The federal government also provides grants of up to 50% of establishment costs for feedstocks, including BBD feedstocks, through the Biomass Crop Assistance Program.⁹⁰

Several states provide grant opportunities that the BBD sector is eligible for. Colorado provides grants for advanced industries, including biofuels, at stages of development from “Proof of Concept” to “Infrastructure Funding.”⁹¹ Iowa manages a Renewable Fuels Infrastructure Program that provides financial support for biodiesel retailers via multi-year cost-share grants.⁷⁰ Kentucky’s New Energy Ventures program provides cost-share grants to companies for purposes including the commercialization of alternative fuels.⁷² Minnesota’s Department of Agriculture provides cost-share grants for BBD blending equipment and BBD production.⁷⁴ Nebraska provides funding assistance for “innovative biofuels projects.”⁷⁵ Nevada’s Clean Energy Fund provides financial assistance to qualified alternative fueling infrastructure projects.⁹² Pennsylvania provides financial assistance for “innovative” advanced fuel commercialization and expansion projects through its Alternative Fuels Incentive Grant Program.⁴¹ Virginia’s Agricultural and Forestry Industries Development Fund provides cost-share grants of up to \$500,000 for BBD production facilities.⁶⁵

Appendix II

PADD- AND STATE-LEVEL BBD DEMAND PROFILES



Appendix II – PADD- and State-Level BBD Demand Profiles

II.1. *Regional demand and blending - PADD 1*

The distillate fuel oil consumption profile in the PADD 1 region has two major differences compared to the U.S. profile that affect BBD demand. The first difference is that MVNRLM diesel fuel consumption only made up 71% of PADD 1 distillate fuel oil demand in 2017 compared to an average of 83% in the U.S.⁹³ Important sources of MVNRLM demand at the national level such as the rail and farm sectors comprise substantially smaller shares of demand in the PADD 1 region (see Figure A-36).⁹³ The second difference is that the commercial and residential sectors comprise much larger shares of consumption in the PADD 1 region due to the continued use of home heating oil in the Northeast U.S. The shares of consumption from the on-road sector at the PADD 1 and U.S. levels are similar but the large amount of heating oil consumption in the former reduces the share of MVNRLM diesel fuel consumption in the PADD 1 region. Distillate fuel oil consumption increased by 5% between 2009 and 2017, one of the lowest growth rates in the country, to 18,767 million gallons. The on-road sector's consumption growth rate was substantially higher at 20% between 2009 and 2017, whereas the residential, commercial, industrial, electric utility, and rail sectors all recorded substantial declines to consumption over the same period. The PADD 1 region accounts for approximately 30% of U.S. distillate fuel consumption and 34% of total U.S. MVNRLM diesel fuel consumption.

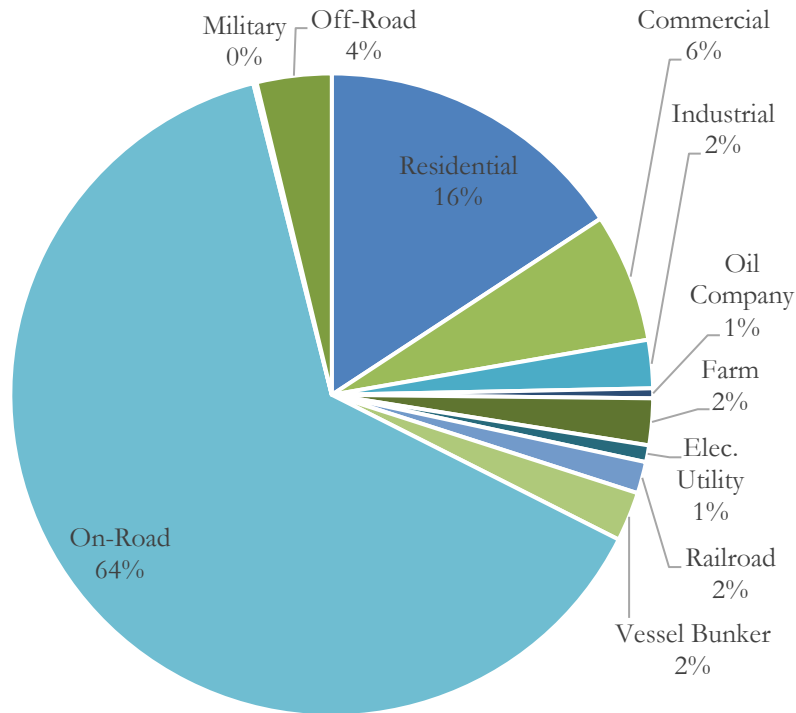


Figure A-36. PADD 1 distillate fuel oil (excluding kerosene) consumption by sector in 2017. Percentages are rounded to nearest whole digit.^{93,94}

The average BBD blend rate relative to MVNRLM diesel fuel consumption in the PADD 1 region increased from 0.5 vol% in 2009 to 3.5 vol% in 2017 (see Figure A-37).^{93,94} Most of this BBD consumption has been in the form of biodiesel, which reached a high average blend rate of 3.5 vol% of MVNRLM diesel fuel consumption in 2017. Renewable diesel consumption has been limited due to a lack of supply, and its highest average blend rate of 0.2 vol% was achieved in 2016. The average BBD blend rate relative to all PADD 1 distillate fuel oil consumption is substantially lower, reaching a high of 2.2 vol% (all in the form of biodiesel) in 2017. Renewable diesel's largest contribution in terms of distillate fuel oil consumption was 0.1 vol% in 2016. While sector-specific consumption data is not available, it can be assumed that the on-road sector is responsible for most of this demand, although the residential sector's consumption can be expected to increase over the next decade as bioheat mandates are enforced in states such as New York.

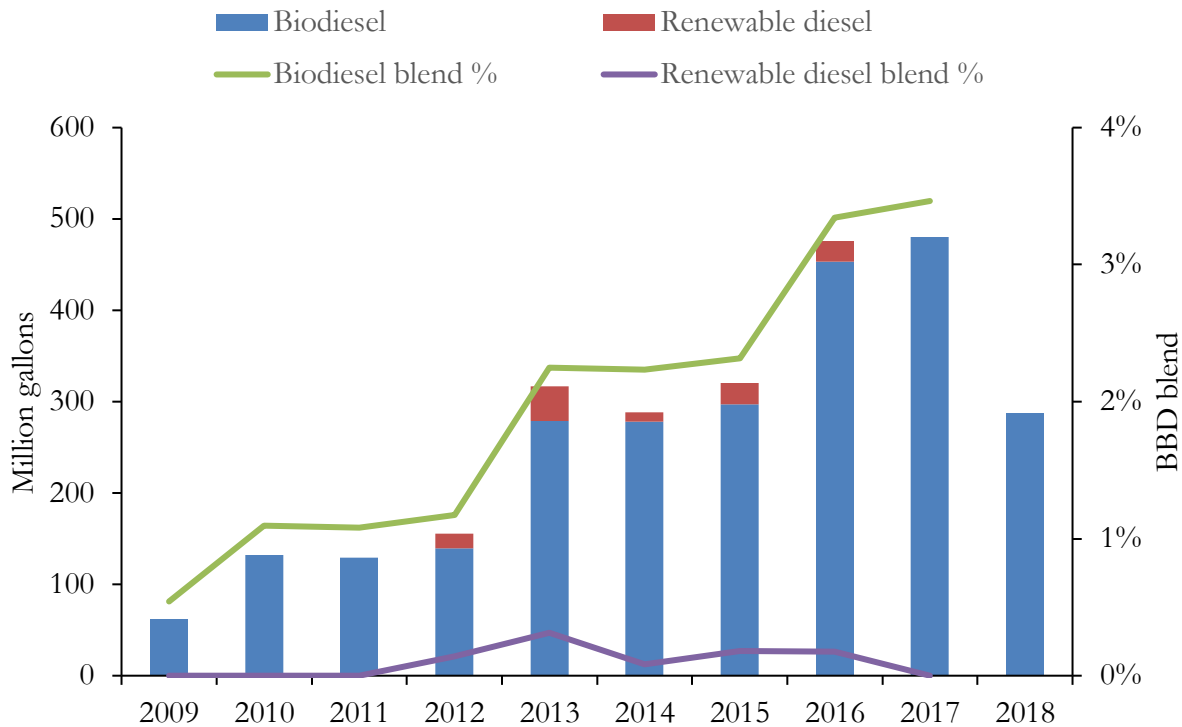


Figure A-37. PADD 1 BBD consumption volumes (2009-2018) and average blend rates as percentage of MVNRLM diesel fuel consumption (2009-2017).^{93,94*}

Granular data on blending volumes is very scarce within the PADD 1 region. An exception is New York City, which requires the consumption of biodiesel in local government fleets and buildings (the latter for space heating). In 2014 the city achieved a minimum biodiesel blend of 5 vol% in all its heating oil, an accomplishment that it described as being “problem-free.”⁹⁵ In that year New York City also used a 20 vol% blend in 68% of its No. 2 fuel oil consumption (the rest being supplied with a 5 vol% blend) as part of a multi-year pilot program, which it concluded was “successful” after encountering only minor issues relating to biodiesel’s solvent properties and lack of long-term storage capabilities.

New York City also requires the use of 5 vol% biodiesel in city fleets between December and March and 20 vol% between April and November. It has administered a 20 vol% biodiesel blend pilot

* The EIA publishes data on monthly and annual PADD-level BBD stocks but does not differentiate between biodiesel and renewable diesel (this is only done at the national level). At the PADD level this report utilizes the EIA’s methodology of calculating consumption as [production + receipts from other PADDs + imports – exports – changes to stocks]. The lack of fuel-specific stocks data at the PADD level means that this report slightly overestimates annual biodiesel consumption and annual blending rates per PADD region, although the total BBD blending and consumption volumes are accurate. This discrepancy only affects the PADD 3 and PADD 5 biodiesel consumption volumes presented below since renewable diesel consumption in the other PADD regions is limited.

program on part of the city fleet during the winter months as well to determine the feasibility of higher blends in cold weather. 93% of diesel fuel consumption by the city fleet was blended with biodiesel in 2018, of which 39% was blended with 5 vol% biodiesel, 3% with 10 vol% biodiesel, and 45% with 20 vol% biodiesel.⁹⁶ In 2018 the city fleet had an average 12.5 vol% biodiesel blend rate. In the winter of 2017-18 the city trialed the use of a 20 vol% biodiesel blend in 100% of its No. 1 ULSD consumption and 5% of its No 2. ULSD consumption (or 17% of its total diesel fuel consumption). It reported that “no operational or cold weather issues” arose from this trial.⁹⁶

Some bulk terminal operators and fuel wholesalers also publish company-level blending data. Sprague Resources L.P., which describes itself as “one of the largest independent wholesale distributors of refined products in the Northeast United States” in terms of total terminal capacity, reported that in 2018 biomass-based diesel “blended products accounted for 5% of the distillate fuel volumes” that it sold.⁹⁷ This blending ratio was possible due to “wide varieties” of biodiesel blending capabilities with heating oil and diesel fuel in multiple facilities, suggesting that 5 vol% was an overall average rather than an uniform blend. This equaled a biodiesel volume of 61.7 million gallons in 2018, or 21% of total PADD 1 BBD consumption, based on 1,581 million gallons of refined products sold in that year by the company, of which 78% was reported to be distillate fuel oil. This represented a large decline for Sprague Resources from 2015, when it reported a 14 vol% average biodiesel blend and an equivalent biodiesel volume of 170 million gallons, or 53% of total PADD 1 biodiesel consumption.⁹⁸

The PADD 1 region can experience major BBD consumption growth before blending constraints become a limiting factor. Assuming blend limits for biodiesel of 20 vol% in the on-road sector and 5 vol% in all remaining sectors, up to 2,730 million gallons of biodiesel could be consumed based on distillate fuel oil consumption in 2018. The on-road sector alone could consume 2,388 million gallons of biodiesel. Renewable diesel’s potential consumption is much higher at 11,941 million gallons for the on-road sector and 18,767 million gallons across all sectors due to its lack of blending constraints. By comparison, total BBD consumption in 2018 was 288 million gallons.¹

Only 3% of the BBD that was consumed in the PADD 1 region between 2009 and 2018 was blended by refiners (see Figure A-38).^{99,100} This low amount of refinery blending is due to a lack of PADD 1 refining capacity: the region hosts only 7% of the operational atmospheric crude distillation capacity by which distillate fuels are produced.¹⁰¹ The region is a major source of distillate

fuel oil demand, though, and has numerous bulk terminal operations as a result. Bulk terminal operators have accounted for 44% of the BBD blending that occurred between 2009 and 2018 in the PADD 1 region compared to 29% at the national level over the same period. The percentage of all BBD consumption over the last decade that was blended by refiners and bulk terminal operators in the PADD 1 region was 47%, substantially above the U.S. average.

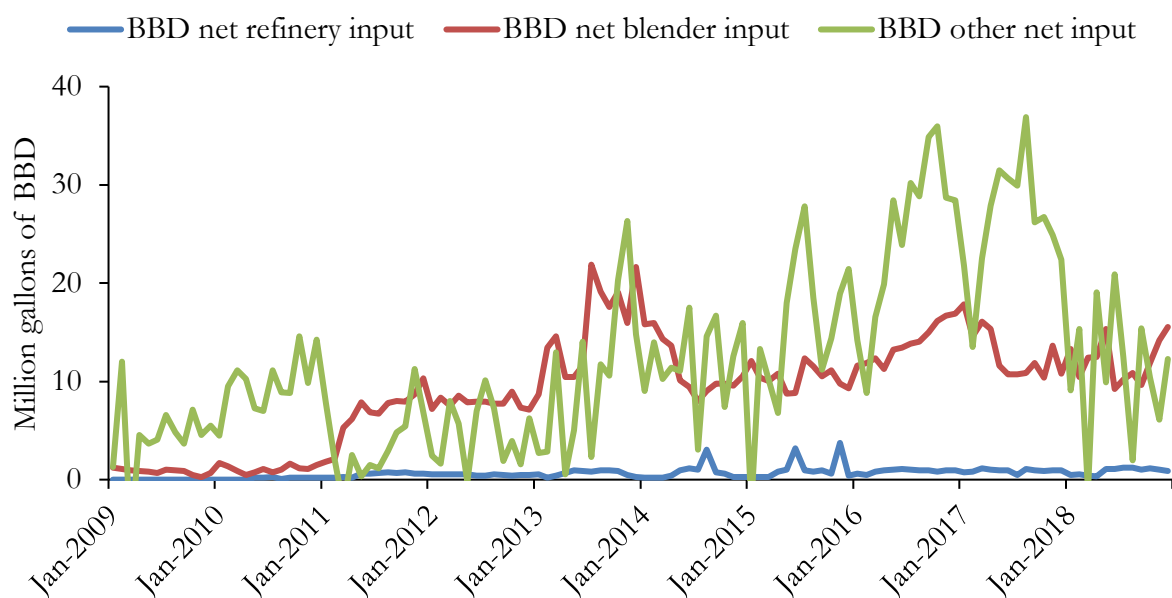


Figure A-38. PADD 1 net BBD inputs by blending category, 2009-2018.^{99,100}

Other sources of blending such as fuel jobbers were responsible for most of the BBD blending that occurred in 2009 and 2010. Bulk terminal operators became the largest source in 2011 with the implementation of the RFS mandate and arrival of RIN prices, however, and increased this share further to 66% of all BBD consumption in 2013 as RIN prices increased. Other sources of blending again accounted for a majority in 2015 and maintained this status until 2018, when a sharp decline in PADD 1 BBD consumption was matched by a corresponding decline in the blending volume attributable to other blending sources. It should be noted that 2015 was also the year when the share of total PADD 1 BBD consumption that was blended by Sprague Resources LP began a large decline.⁹⁸ The volume that was blended by bulk terminal operators in 2018 was equal to the 5-year average annual volume, whereas the 2018 volume from other blending sources was 35% lower than its 5-year average. Fuel jobbers and other sources of blending have performed the role of the PADD 1 region's marginal blender since 2011, blending higher volumes when BBD availability increases (with the exception of 2013) and lower volumes when supplies dwindle. PADD 1 fuel jobbers have

largely reflected the experience of jobbers at the national level in this way, although with greater variability due to a larger number of months in which monthly PADD 1 BBD supply fell to the volume that was normally blended by refiners and bulk terminal operators.

PADD 1 BBD blending by refiners and bulk terminal operators follows a different seasonal trend than is experienced at the national level. Whereas average national blending volumes peak in August or September before steadily declining, PADD 1 volumes peak in December with an average increase of 50% compared to the prior January (see Figure A-39). While it is tempting to attribute this late season blending to the blending of BBD with heating oil in the Northeast U.S., the trend was even more pronounced in those years in which Congress allowed the BTC to expire or almost expire, with the December volume being 84% higher than the prior January volume on average. In those years in which the BTC either did not expire or did not come close to expiring, on the other hand, the average blending volume was highest in January, again in sharp contrast to the comparable data at the national level.

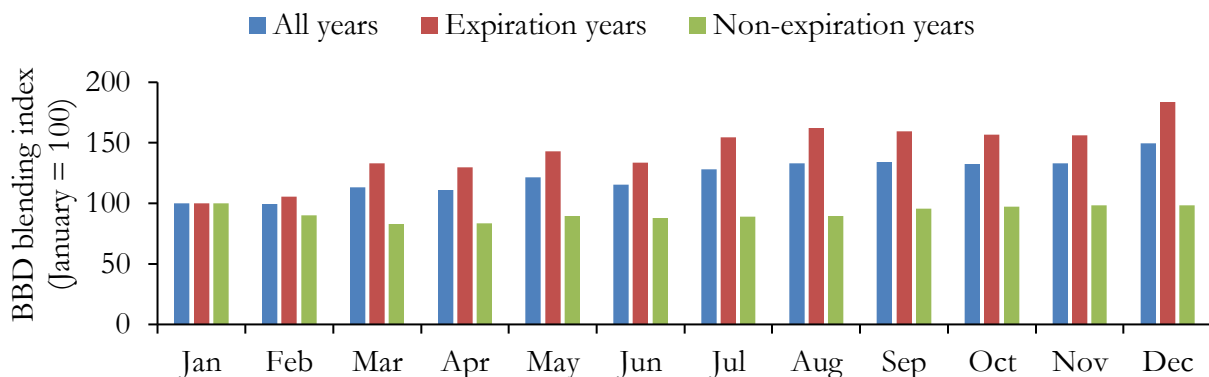


Figure A-39. Index of monthly PADD 1 BBD blending volumes by refiners and bulk terminal operators, 2009-2018. Figures shows average index values for all years, those years in which the BTC expired or almost expired, and those years in which the BTC did not expire.^{99,100}

The rapid increase to RIN prices that occurred in 2013 had a pronounced effect on the PADD 1 region's blending volumes, even relative to other years in which the BTC expired or was on the verge of expiring before being extended by Congress (see Figure A-40). The monthly blending volume in 2013 increased by 146% between January and July compared to an average increase of 36% for all other years in which the BTC expired or almost expired. Volumes remained well above their average values for other expiration years through the rest of 2013, rising sharply again in December. Interestingly, though, 2013 was the only year in which RIN prices had a clear effect on

blending volumes; unlike the trends that occurred at the U.S. level in 2015 and 2018, monthly blending volumes by refiners and bulk terminal operators did not increase and decrease in those respective years relative to the comparable long-term monthly averages.*

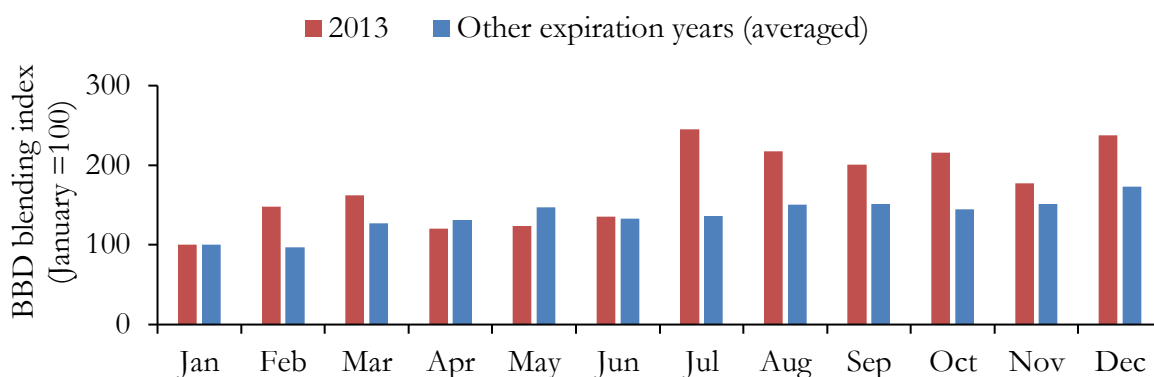


Figure A-40. Index of monthly PADD 1 BBD blending volumes by refiners and bulk terminal operators, 2013 compared to average of other years in which the BTC either expired or almost expired.^{99,100}

Two different studies of RIN price pass-through rates across the PADD regions have determined that the PADD 1 region is the only one of the five to not achieve complete pass-through.^{102,103} This is attributed to the PADD 1 region’s fuel market being “moderately isolated” from the rest of the U.S. market and the region’s refiners being characterized by smaller refining capacities than at the national level.¹⁰³ The effect of this incomplete pass-through on the BBD sector is limited, though, since higher pass-through rates are identified for the PADD 1 ULSD market, meaning that the effect of higher RIN prices in terms of subsidizing BBD relative to petrodiesel (or taxing petrodiesel relative to BBD) is similar to the effect described at the national level.

II.2. Regional demand and blending - PADD 2

The distillate fuel oil profile of the PADD 2 region is characterized by high shares of consumption by the on-road, rail, and farm sectors relative to the U.S. average (see Figure A-41).⁹³ 89% of the region’s consumption in 2017 was by MVNRLM sectors compared to 83% for the U.S. The share of

* This is not to say that overall consumption was not affected in those years, however, as it increased by almost 10% in 2015 and declined by 40% in 2018. As noted above, blending volumes by refiners and bulk terminal operators held relatively steady in both of those years.

combined consumption by the residential, commercial, and industrial sectors was substantially lower at 7% in 2017 than the U.S. average of 12% in the same year, reflecting a lack of heating oil consumption in the region due to the prevalence of natural gas heating. Distillate fuel oil consumption in the region increased by 19% between 2009 and 2017 to 18,932 million gallons. The on-road sector recorded consumption growth of 18% over the same period. The PADD 2 region accounts for approximately 30% of total U.S. distillate fuel oil consumption and 34% of total U.S. MVNRLM diesel fuel consumption.

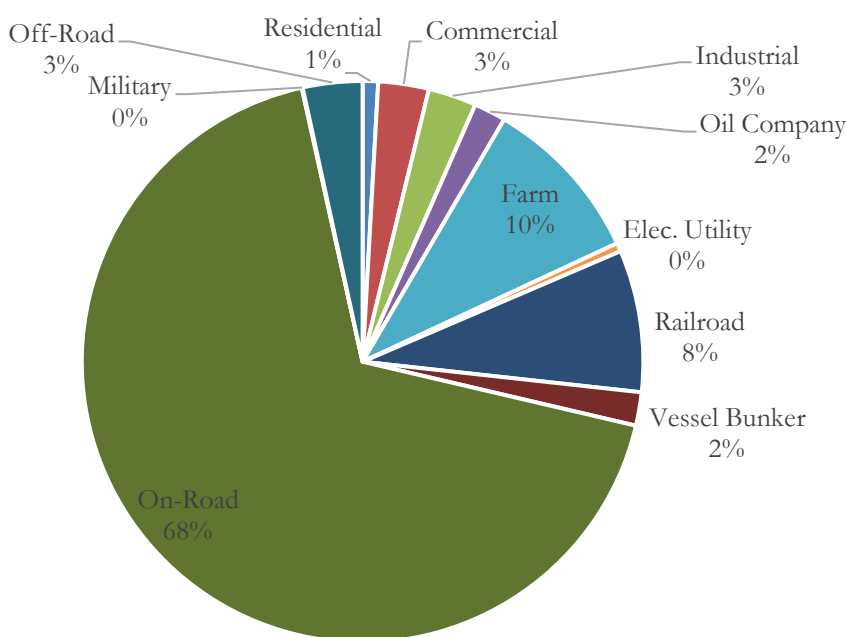


Figure A-41. PADD 2 distillate fuel oil (excluding kerosene) consumption by sector in 2017. Percentages are rounded to nearest whole digit.^{93,94}

The PADD 2 region's average biodiesel blend reached a high of 4.5 vol% in 2016, exceeding the U.S. average of 4 vol% in the same year.^{93,94} The PADD 2 blend rate has increased from 1.7 vol% in 2010 (see Figure A-42). The region consumes very little renewable diesel, on the other hand, due to a lack of supply: that fuel's blend rate reached a high of 0.4 vol% in 2011 and has remained near zero since 2013. The average PADD 2 BBD blend rate relative to the region's total distillate fuel oil consumption was 3.7 vol% in 2017, down from a high of 4.1 vol% the prior year. The lack of renewable diesel consumption has caused the PADD 2 region's average BBD blend rate to remain

below that of the U.S. since 2015. It can be assumed that the on-road sector is responsible for most PADD 2 BBD consumption due to its large share of overall distillate fuel oil consumption and the heavy concentration of retailers and truck stops selling blends of 10 vol% and higher in the region.¹¹⁰

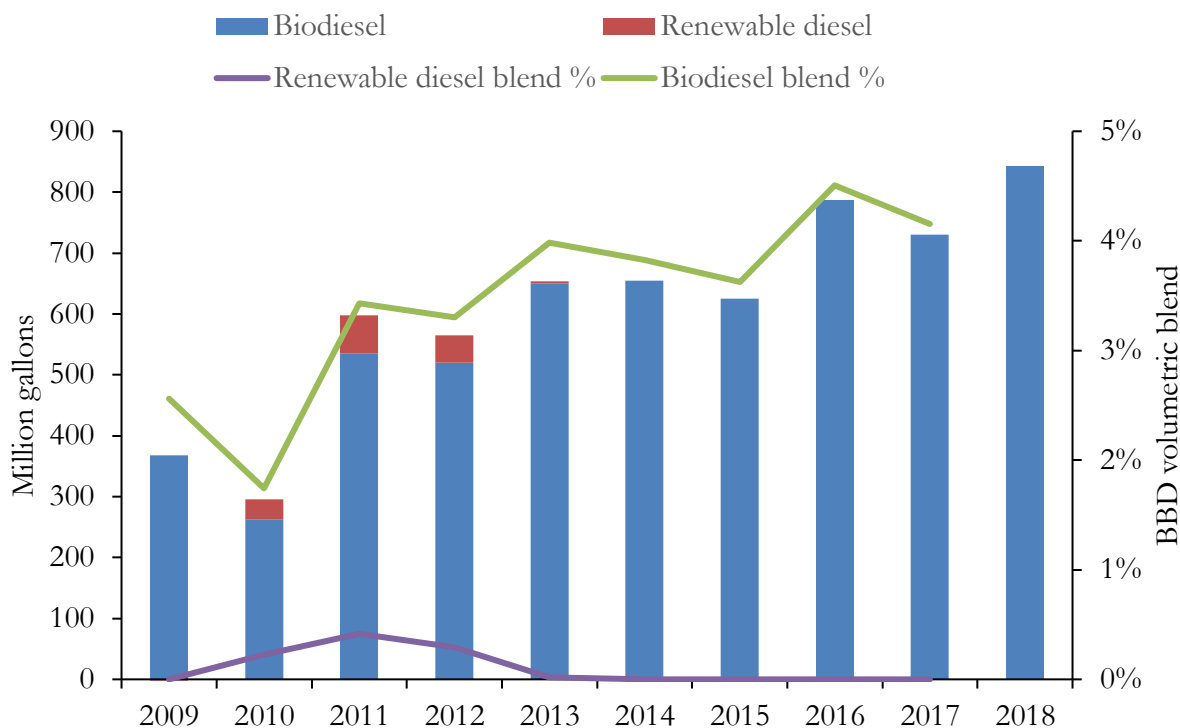


Figure A-42. PADD 2 BBD consumption volumes (2009-2018) and average blend rates as percentage of MVNRLM diesel fuel consumption (2009-2017).^{93,94}

The PADD 2 region has a biodiesel blend potential of 2,872 million gallons assuming a 20 vol% blend limit in the on-road sector and a 5 vol% blend limit in all other sectors that consume distillate fuel oil. This would represent an increase of 2,029 million gallons over 2018's biodiesel (and total BBD) consumption volume of 843.5 million gallons. The potential consumption limit for renewable diesel in the PADD 2 region is 11,941 million gallons for the on-road sector and 18,767 million gallons for all sectors that consume distillate fuel oil.

State-level blending and sales data is limited due to a lack of data publication efforts by state governments and market participants. The Iowa Department of Revenue does publish annual BBD blending and sales data due to the state's graduated blenders' tax credit, though, and its results present a snapshot of how biodiesel is consumed in the state and how retail blends changed between 2015 and 2018 (see Figure A-43).¹⁰⁴ Biodiesel consumption in the state increased from 37.5 million

gallons in 2015 to 58 million gallons in 2018. Most biodiesel was sold as 11-20 vol% retail blends in both years. The share that was sold in blends of less than 20 vol% decreased during those four years, though, while the share that was sold as 20-49 vol% blends more than doubled to 24% of total biodiesel consumption in 2018.* During that time the percentage of diesel gallons that contained at least 1 vol% biodiesel also increased from 41% to 56 vol%. Biodiesel in Iowa is still far from ubiquitous, but the more important fact is that 82% of its biodiesel sales volume was in the form of blends exceeding 10 vol%. While this was likely influenced by the graduated nature of the state's blenders' credit (see Section 1.3), it does indicate that blends above 10 vol% can be widely used even in states such as Iowa that have cold winter temperatures. Also notable is the fact that the state's average blend rate in 2018 was 7 vol% of combined clear and dyed (i.e., MVNRLM) diesel fuel consumption.

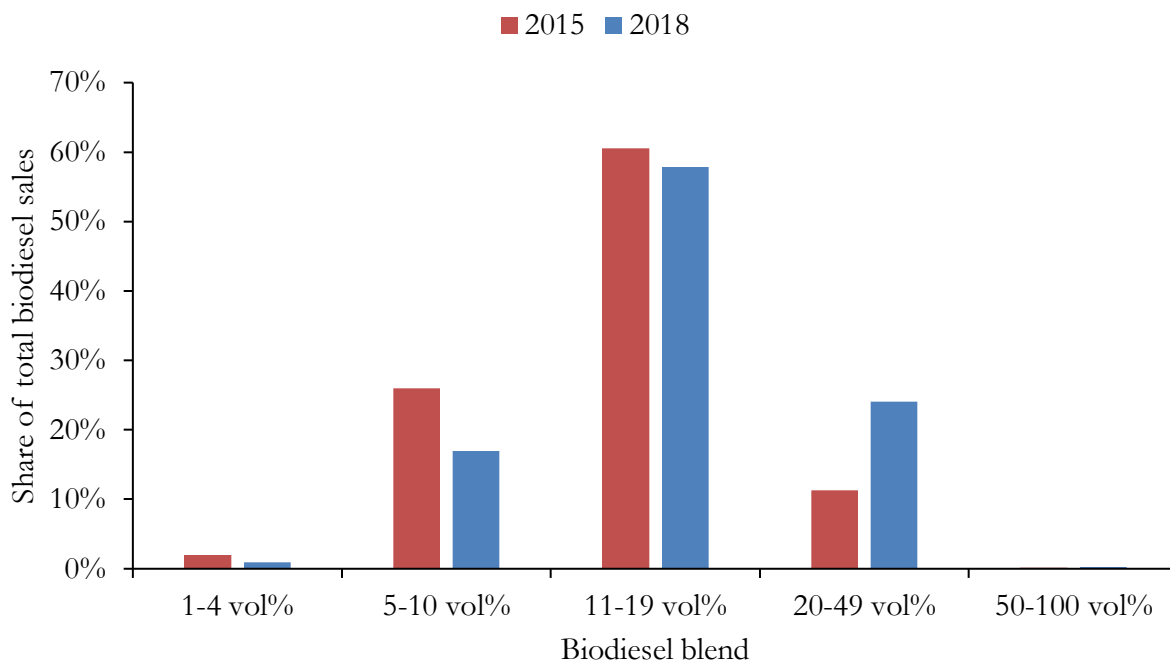


Figure A-43. Biodiesel consumption by blend rates, 2015 and 2018. Includes both clear and dyed biodiesel.¹⁰⁵

Iowa's data also shows that biodiesel is blended with dyed diesel "for use in farm, construction, and other types of equipment that do not travel under their own power on public roads."¹⁰⁴ The average

* The data also shows that biodiesel in the 20-49 vol% blend category was blended at an average 20 vol% rate, meaning that very little was likely consumed at rates of 21 vol% and above.

dyed biodiesel blend rate in 2018 was 1.2 vol%, well below the clear biodiesel blend rate of 8.8 vol%. The volume of dyed biodiesel consumption in Iowa nearly quadrupled between 2011 and 2018, though, and dyed 11-19 vol% biodiesel blends have experienced the largest volumetric growth in recent years. 31% of dyed biodiesel consumption in 2018 was consumed in blends of 11 vol% or higher despite the widespread assumption, including in this report, that only the motor vehicle sector is capable of handling biodiesel blends in excess of 5 vol%. While 56% of the dyed diesel consumed in Iowa in 2018 contained no biodiesel at all, the state's experience shows that biodiesel blending is not uniformly limited to 5 vol% in the off-road diesel fuel-consuming sectors.

The heterogenous nature of biodiesel consumption in Iowa is evident from state data on the consumption of blended biodiesel per county.¹⁰⁴ While the dataset only shows the overall volume of diesel fuel sales that has been blended with biodiesel and not biodiesel consumption or blend rates, it still represents a variety of consumption patterns in the state. On a per capita basis,¹⁰⁵ for example, the volume of blended fuel sales ranges from a low of 2.6 gallons (Des Moines county, population 39,417) to a high of 1,462 gallons (Fremont county, population 6,948). The state per capita average is 146 gallons. County population has little effect on this volume: the average county population in which it is below the statewide average is 32,669 versus 31,327 for those above it. Nor does close proximity to a biodiesel production facility have an impact: of the 11 counties in Iowa that host a facility, only four have a per capita sales figure that is above the statewide average. Finally, while the mode value is within the 41-50 gallon bin range, no fewer than 10 counties are above 429 gallons per person (see Figure A-44). All these counties are rural, and most of them are characterized by agricultural-intensive economies.

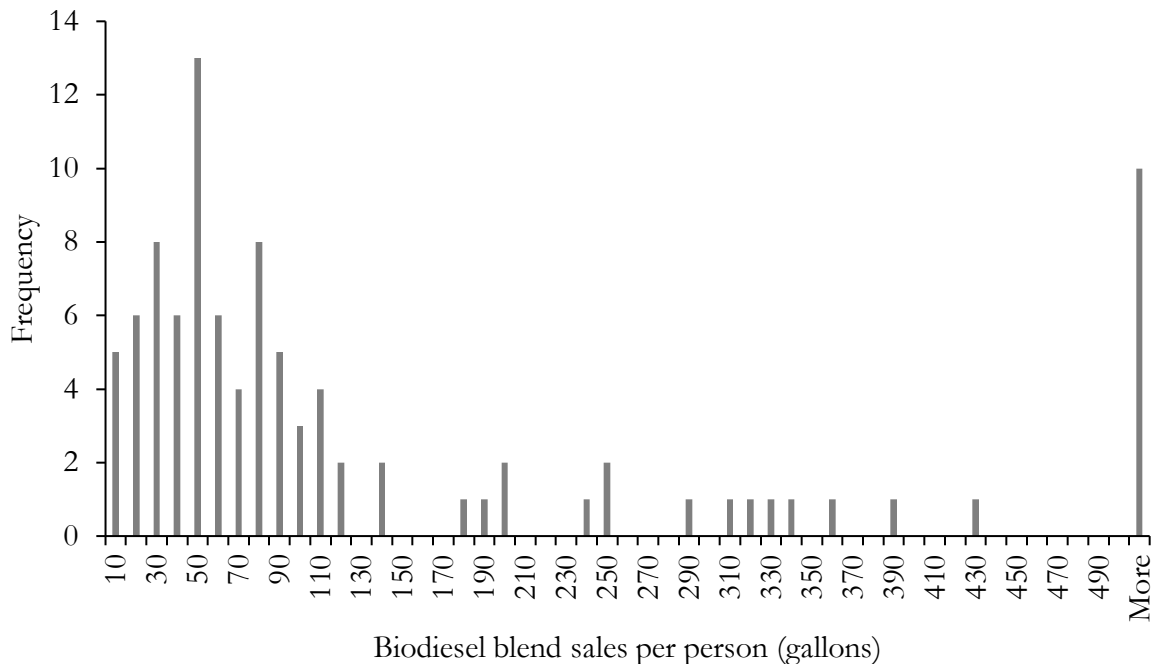


Figure A-44. Histogram of county-level per capita biodiesel blend sales in Iowa, 2018.^{104,105}

Minnesota also publishes biodiesel blending data, albeit at a less granular level than Iowa. Minnesota consumed 77 million gallons of biodiesel in 2016, resulting in an average blend rate in No. 2 diesel fuel sales of almost 8 vol% (on-road and off-road) in that year (the most recent for which data is available).¹⁰⁶ Minnesota's 10 vol% blend mandate was in effect from April through September of that year, reverting to a 5 vol% mandate during the remaining six months. This suggests that blending did occur at those percentages in all the state's covered diesel fuel consumption during that year based on increased diesel fuel demand during the months in which the higher mandated blend rate was in effect.¹⁰⁷

The different approaches taken by Iowa and Minnesota, two agricultural states within the PADD 2 region that are characterized by similar infrastructure and winter weather conditions and average annual blend rates, are worth examining for their impacts on blending patterns. Iowa's primary policy tool most recently has been a graduated blenders' tax credit that provides an additional incentive for blending biodiesel in excess of a 11 vol% rate (see Section 1.3). Not surprisingly Iowa's biodiesel consumption is characterized by the heterogenous presence of higher blend rates, with biodiesel only being blended into just over 50% of the state's clear and dyed diesel fuel supply. This stands in contrast to other renewable fuels such as ethanol that are consumed nationwide at a mostly

uniform 10 vol% blend rate.¹⁰⁸ Iowa's approach to biodiesel blending has been efficient from a downstream logistics perspective in that only 55% of the state's diesel fuel dispensing locations provided biodiesel blends in 2018 and county-level consumption, but 76% of those that did offered blends of 11 vol% or higher.¹⁰⁴ Almost 50% of the state's blended biodiesel sales have been in counties containing fewer than 50,000 people, though, potentially limiting the non-global environmental benefits of biodiesel consumption (see Section 4).

Minnesota's experience has differed from that of Iowa in terms of both approach and outcome. Rather than incentivize biodiesel supply, as Iowa has done, Minnesota has explicitly mandated it. The result has been a similar average annual blend rate as in Iowa but a biodiesel blend supply that is much more homogenous since all diesel fuel sold in Minnesota must meet the minimum biodiesel blend thresholds. Minnesota's approach has imposed a unique set of constraints on biodiesel blending and demand. Its earlier 10 vol% blend mandate was postponed due in part to a lack of sufficient blending infrastructure in southwest Minnesota, for example, and the most recent 20 vol% blend mandate has necessitated reported upgrades of blending infrastructure by downstream refined products companies.¹⁰⁷ While such upgrades would have been incentivized but not mandated in Iowa, Minnesota's approach has ensured that biodiesel's non-global environmental benefits are more widely distributed among the state's population, inasmuch as diesel fuel consumption is correlated with population density.⁹³

The overall PADD 2 region is characterized by limited refiner and bulk terminal operator BBD blending relative to the U.S. average (see Figure A-45). Refiners have accounted for 7% of the total BBD consumed between 2009 and 2018 while bulk terminal operators have accounted for an additional 21% over the same period.^{99,100} The remaining 72% of consumption has been blended or otherwise made available to the market by other entities such as jobbers. This is well above the share that has been accounted for by entities other than refiners and bulk terminal operators at the national level. Moreover, there has been comparatively little change to the share of blending that has been accounted for over the last decade by refiners and bulk terminal operators: this figure rose from 12% in 2009 to a high of 36% in 2015 before subsequently declining to 30% in 2018. There has only been one month (January 2017) in the last decade in which the volume blended by bulk terminal operators was the largest source of biodiesel consumption in the region.

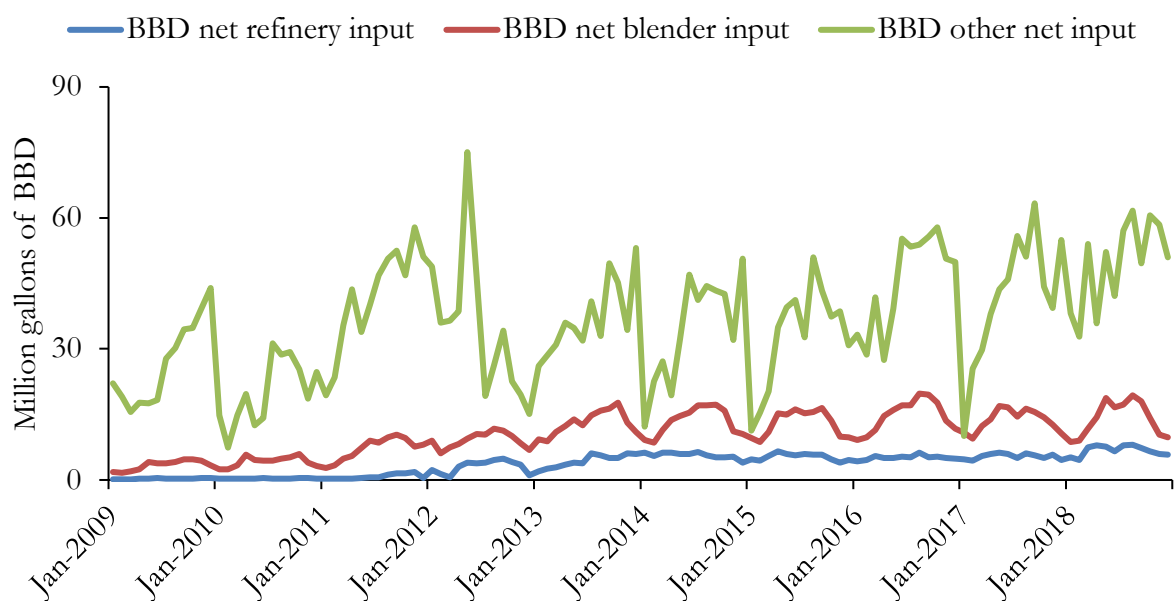


Figure A-45. PADD 2 net BBD inputs by blending category, 2009-2018.^{99,100}

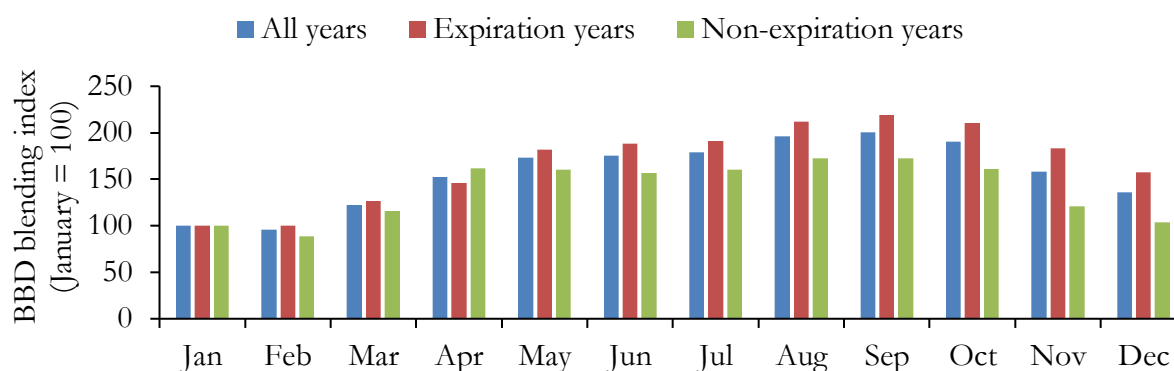


Figure A-46. Index of monthly PADD 2 BBD blending volumes by refiners and bulk terminal operators, 2009-2018. Figures shows average index values for all years, those years in which the BTC expired or almost expired, and those years in which the BTC did not expire.^{99,100}

The PADD 2 experienced higher monthly blending volumes from May onward in years in which the BTC either expired or was allowed to almost expire compared to those years in which it did not. The effect is less pronounced on late year blending in the PADD 2 region than at the national level but still important: December's blending volumes in the region were 58% and 4% higher on average than January's volumes in expiration and non-expiration years, respectively. A possible explanation for the diminished impact of the BTC expiration in the PADD 2 region is the presence of numerous supply mandates and incentives in the region's states (see Section 1.3).

One of the most notable differences between blending patterns in the PADD 2 region compared to the overall U.S. was the lack of higher blend volumes over the course of the year in 2013 relative to other years in which the BTC expired (see Figure A-47). Not only did that year's higher RIN prices not result in much higher blending volumes over the course of the year relative to the usual seasonal progression, but in 2013 the progression was more limited than in the other expiration years on average. Nor was this effect just limited to biodiesel blending by refiners and bulk terminal operators: total PADD 2 biodiesel consumption increased by just 25% between 2012 and 2013 compared to a 54% increase over the same period for the overall U.S.¹ Likewise, the monthly blending volume progressions in 2015 and 2018 were the opposite of what they were for the overall U.S. Taken together, the data suggests that the PADD 2 region's seasonal blending patterns are less sensitive to policy factors such as RIN prices and the BTC than the average U.S. patterns are. A likely explanation for this phenomenon is again the presence in the PADD 2 region of a large number of biodiesel mandates and incentives at the state level that mitigate the comparative impacts of federal policies and their absences, lending support to findings in the empirical literature of indirect linkages between state and federal policy regimes.¹⁰⁹

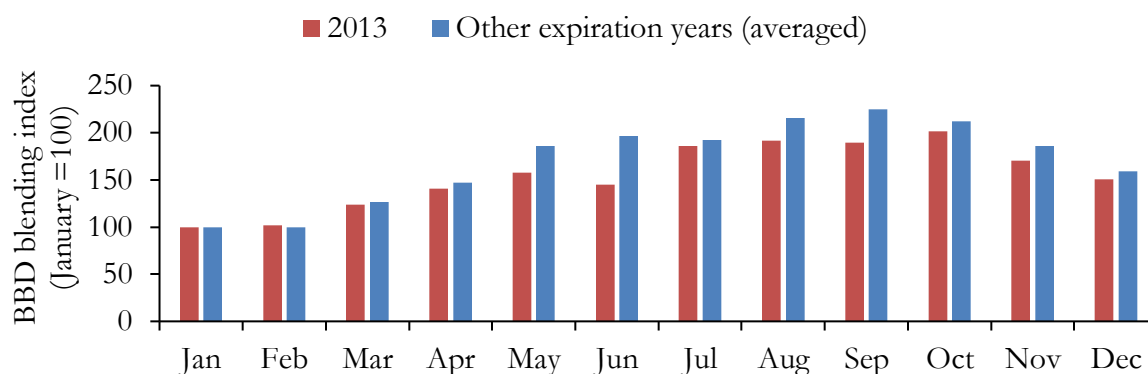


Figure A-47. Index of monthly PADD 2 BBD blending volumes by refiners and bulk terminal operators, 2013 compared to average of other years in which the BTC either expired or almost expired.^{99,100}

II.3. Regional demand and blending - PADD 3

The PADD 3 region's distillate fuel oil consumption profile is characterized by large shares from the oil company, rail, and vessel bunker sectors and a small share from the residential sector relative to the U.S. average (see Figure A-48). Home heating requirements are very limited in the region due to

its warm temperatures throughout the year while the region's heavy oil and gas, rail, and port infrastructure cause those sectors to be important consumers of distillate fuels. Distillate fuel oil consumption in the region increased by roughly 30% between 2009 and 2017 to 13,056 million gallons, equal to 22% of total U.S. consumption.⁹³ The MVNRLM sectors accounted for 18% of U.S. MVNRLM consumption in 2017. The on-road sector's growth rate of 21% between 2009 and 2017 was slower than that of PADD 3 distillate fuel oil consumption but faster than that of the on-road sector in all other PADD regions.

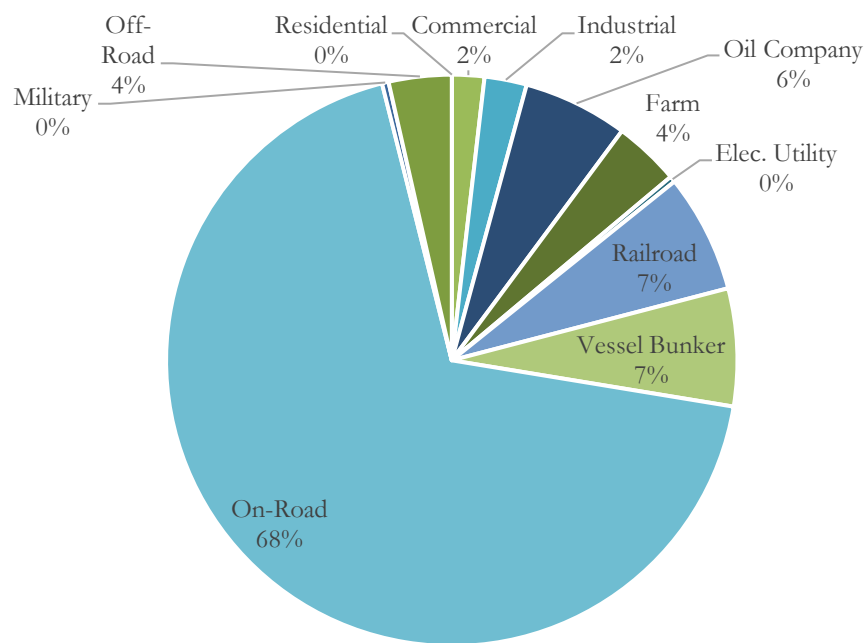


Figure A-48. PADD 3 distillate fuel oil (excluding kerosene) consumption by sector in 2017. Percentages are rounded to nearest whole digit.^{93,94}

The PADD 3 region's average annual BBD blend rate relative to MVNRLM diesel fuel consumption in 2017 was 6.9 vol%, down from 8.3 vol% in 2016 but well above 2009's level of 1.2 vol% (see Figure A-49). The average annual BBD blend rate relative to total PADD 3 distillate fuel oil consumption was 5.8 vol% in 2017. Biodiesel has been the form of most of the region's BBD consumption over the last decade. While PADD 3 renewable diesel production almost doubled between 2014 and 2018, growth in the volume of renewable diesel that has been sent to the PADD 5 region over the same period has caused PADD 3 consumption and the average annual blend rate

of the fuel to remain stable. The region's low renewable diesel annual average blend rate relative to that of the PADD 5 region (see below) is notable given that PADD 3 producers have accounted for more than 90% of total U.S. production over the last decade. The annual average biodiesel blend rate, on the other hand, nearly doubled between 2014 and 2016 on rising production and imports from overseas, and the PADD 3 region has had the highest biodiesel blend rate among all PADD regions since 2015.

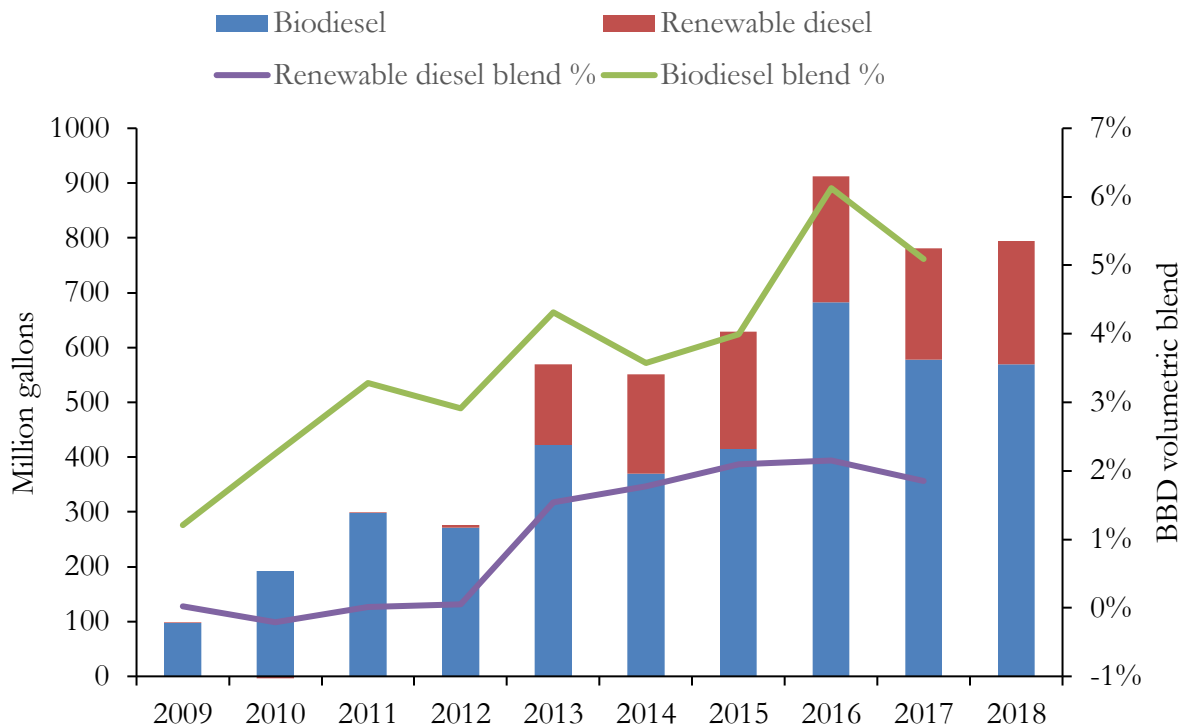


Figure A-49. PADD 3 BBD consumption volumes (2009-2018) and average blend rates as percentage of MVNRLM diesel fuel consumption (2009-2017).^{1,93*}

Regular BBD blending on a monthly basis by refiners and bulk terminal operators did not occur until 2012, and the two entity types were responsible for blending only 4% of the total BBD that was consumed in the PADD 3 region between 2009 and 2011.^{99,100} This percentage rapidly as the RFS was implemented, though, reaching 26% in 2012, 37% in 2013, and peaking at 66% in 2015 (see Figure A-50). This share then declined rapidly and over the last decade PADD 3 refiners and

* PADD 3 renewable diesel production volumes are calculated from the following sources: the quarterly earnings presentations published by Darling Ingredients for Diamond Green Diesel; the quarterly earnings statements published by Alon USA Energy and Delek US Holdings for AltAir Paramount; and quarterly production data provided by Renewable Energy Group. Cetane Energy was assumed to produce 3 million gallons per year between 2010 and 2018. Green Energy Products was assumed to produce 3 million gallons per year in 2015.

bulk terminal operators have blended 36% of the BBD that has been consumed in the region, well below the U.S. average of 49% over the same period. Refiners have played a larger role in the PADD 3 region, however, having accounted for 46% of the BBD that has been blended by refiners and bulk terminal operators over the last decade (compared to 28% at the U.S. level). This outsized contribution is due in part to the fact that the PADD 3 region hosts 53% of the country's atmospheric crude oil distillation capacity.¹⁰¹ This refining capacity, which is concentrated in Texas and Louisiana, in turn has close access to BBD supplies given the large volumes of BBD production in Louisiana and Texas and BBD trade flows through ports in both states (see Section 1). Uniquely among the PADD regions, there have been sustained periods in the PADD 3 region in which refiners blended a larger volume of BBD than did bulk terminal operators.

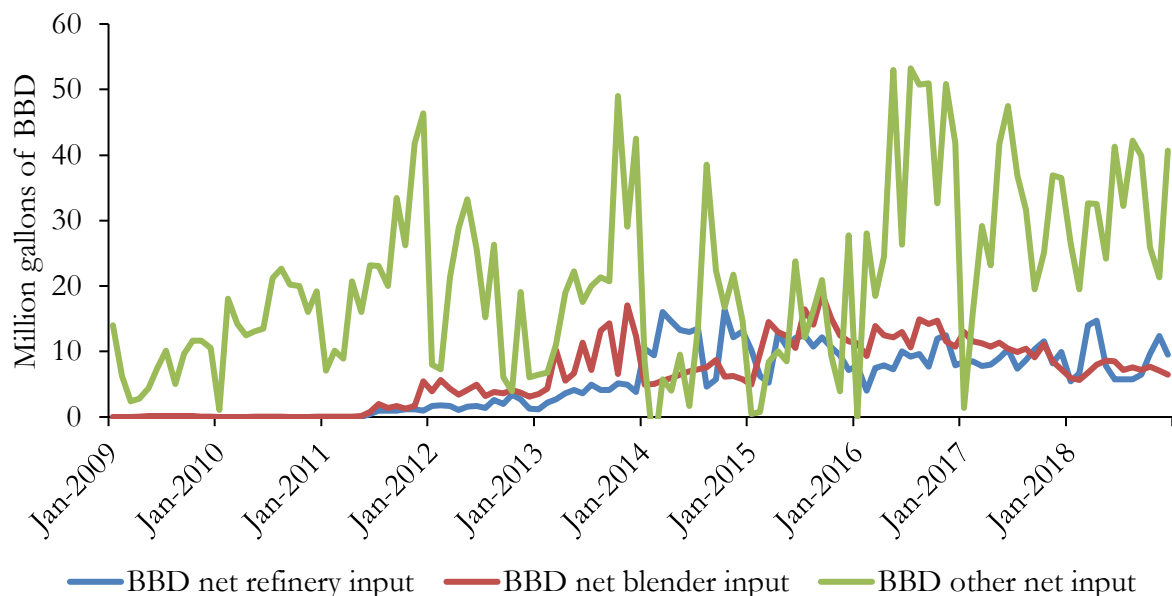


Figure A-50. PADD 3 net BBD inputs by blending category, 2009-2018.^{99,100}

The PADD 3 region's seasonal BBD blending patterns have been quite different from both the U.S. average and those PADD regions that experience colder winter temperatures. Rather than peak in August or September, average PADD 3 blending by refiners and bulk terminal operators has historically not peaked until November with a 75% increase over the prior January (Figure A-51).^{99,100} Unusually, the blending volume in March has historically been higher than in July and comparable to that in August. A possible contributing factor in addition to the region's warm winter temperatures is the presence of a substantial fraction of renewable diesel within the PADD 3 region's overall BBD supply since 2014. PADD 3 BBD consumption does decline sharply from

December in one year to January of the next year, and this decline is primarily absorbed by blenders such as fuel jobbers rather than by refiners or bulk terminal operators.

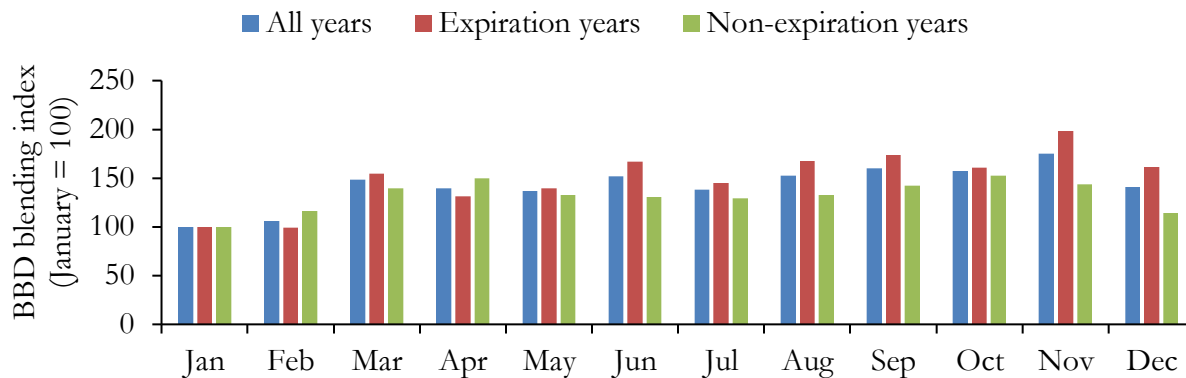


Figure A-51. Index of monthly PADD 3 BBD blending volumes by refiners and bulk terminal operators, 2012-2018. Figures shows average index values for all years, those years in which the BTC expired or almost expired, and those years in which the BTC did not expire.^{99,100}

Refiners' and bulk terminal operators' BBD blending volumes have been affected by the expiration of the BTC, although this effect has been of a smaller magnitude than in the other PADD regions. The effect has also not become especially pronounced until late in the year: blending volume increases from the prior January in November and December have been 99% and 41%, respectively, in expiration years compared to 43% and 14%, respectively, in non-expiration years. The effect of the BTC expiration reverses if the effect of rising RIN prices, which has had a large magnitude in both expiration and non-expiration years, is stripped out. BBD blending by refiners and bulk terminal operators increased by 370% between January and November 2013 compared to an 8% average increase over the same period in all other BTC-expiration years (see Figure A-52). A similar, if more limited, effect was experienced in 2015, which was a non-expiration year that was characterized by a large D4 RIN price increase.

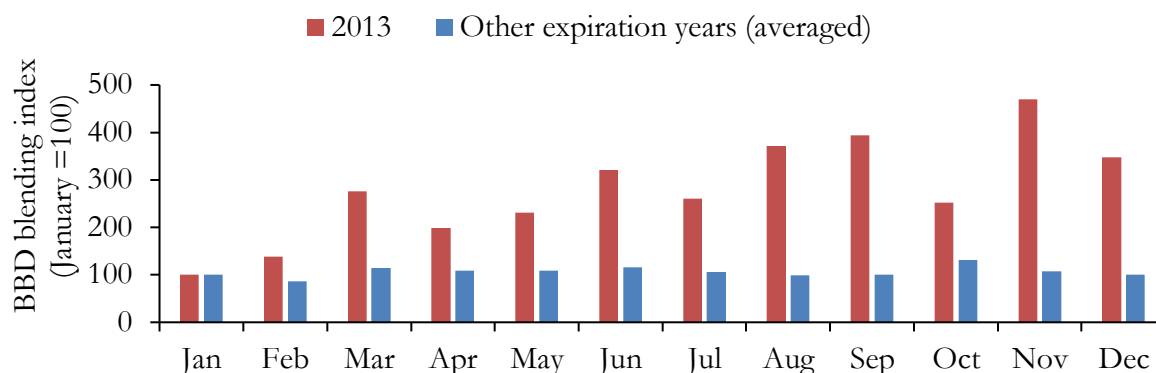


Figure A-52. Index of monthly PADD 3 BBD blending volumes by refiners and bulk terminal operators, 2013 compared to average of other years in which the BTC either expired or almost expired.^{99,100}

II.4. Regional demand and blending - PADD 4

The PADD 4 region's distillate fuel oil consumption is largely comprised of on-road demand, and the sector's share is only slightly lower than the U.S. average (Figure A-53). 84% of distillate fuel oil consumption was attributable to the MVNRLM sectors in 2017. The shares of the industrial and rail sectors are higher than the U.S. average while those of the residential and vessel bunker are substantially lower, the latter due to the region's lack of deep-water ports. Total distillate fuel oil consumption in the region increased by 13% between 2009 and 2017 to 3,042 million gallons,⁹³ and the region was responsible for 5% of total U.S. distillate fuel oil consumption in 2017. The PADD 4 MVNRLM sectors accounted for 4% of total U.S. MVNRLM consumption in 2017. On-road consumption growth was slightly faster than that of overall distillate fuel oil consumption and recorded a 14% increase between 2009 and 2017.

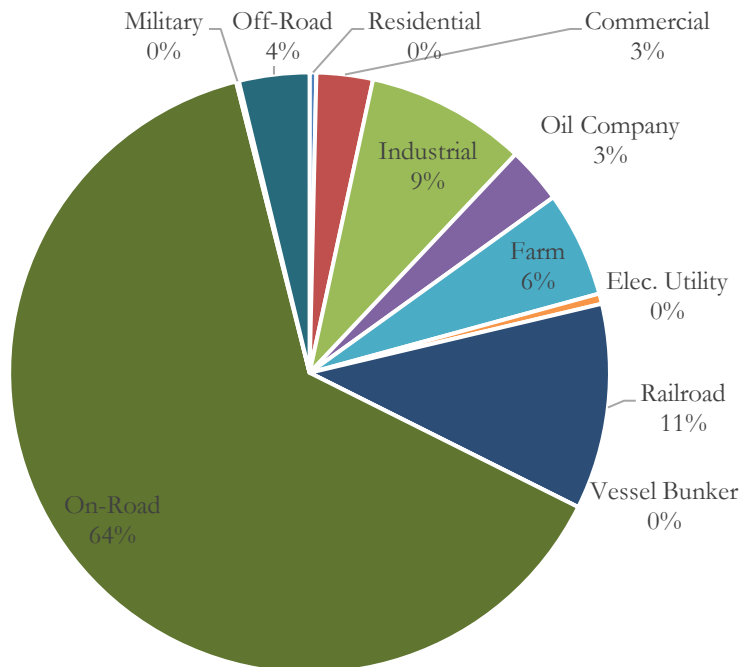


Figure A-53. PADD 4 distillate fuel oil (excluding kerosene) consumption by sector in 2017. Percentages are rounded to nearest whole digit.^{93,94}

PADD 4 biodiesel consumption has increased from zero in 2009 to 17.4 million gallons in 2018 (see Figure A-54); it's highest annual volume was 26.1 million gallons in 2016. Biodiesel has comprised all the BBD that has been consumed in the region over the last decade due to a lack of renewable diesel supply. While a low biodiesel consumption volume is to be expected given the PADD 4 region's limited distillate fuel oil demand, the biodiesel consumption volume is small even on that basis. Its highest average biodiesel blend rate was 1 vol% of MVNRLM diesel fuel consumption and 0.9 vol% of total distillate fuel oil consumption, both in 2016. This low blend rate, which equaled only 0.9 vol% of on-road diesel fuel consumption in 2017, makes it likely that the on-road sector is responsible for most of the region's BBD consumption. A lack of blending infrastructure and the concentration of the region's limited providers of >10 vol% biodiesel blends near urban centers such as Denver and Salt Lake City and interstate routes¹¹⁰ mean that only a comparatively small number of retailers providing such blends are capable of providing sufficient volumes to meet the region's current average blend rate.

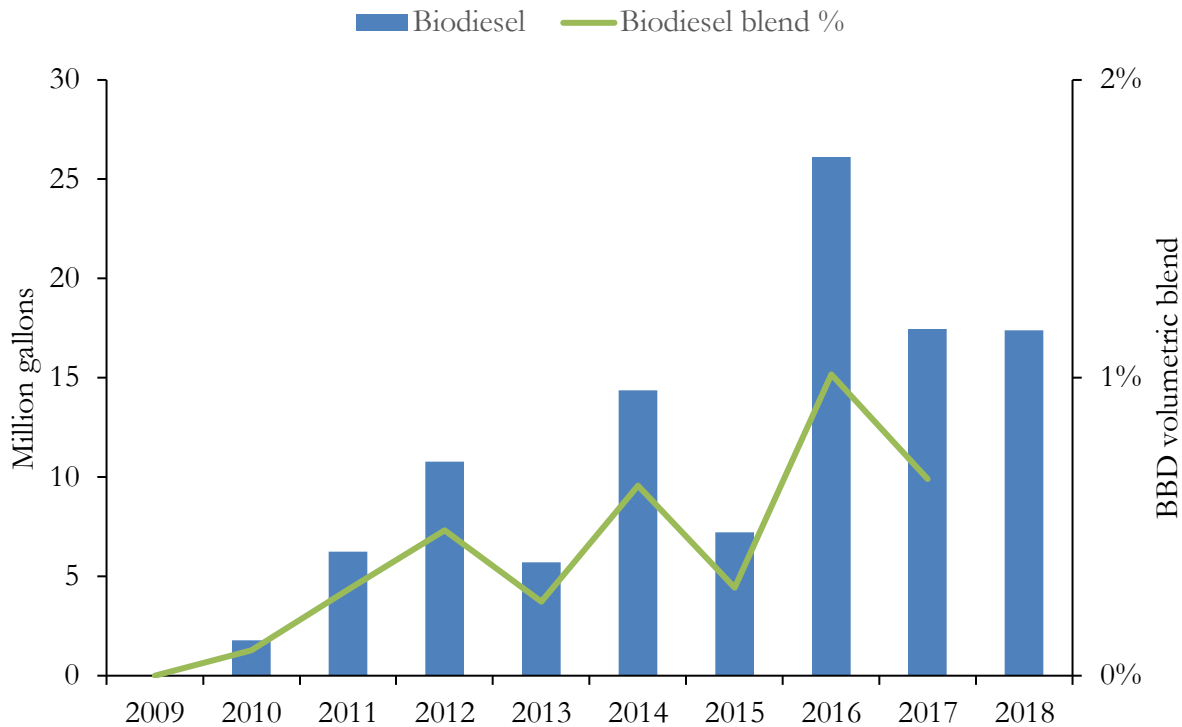


Figure A-54. PADD 4 BBD consumption volumes (2009-2018) and average blend rates as percentage of MVNRLM diesel fuel consumption (2009-2017).^{1,93}

The PADD 4 region's biodiesel blend potential in 2017 was, at 442.7 million gallons, well above its consumption: 25x more could have been consumed than actually was before encountering blending constraints. Renewable diesel's complete lack of a presence in the PADD 4 region means that 3,042 million gallons of it could be blended before downstream infrastructure constraints are encountered. The region's average blend rate is the lowest at the PADD level in the U.S. and biodiesel consumption would need to quadruple before it would equal the average rate of the next-lowest PADD region (PADD 1).

The PADD 4 region is unique in that most of its BBD consumption is blended by refiners, with a smaller volume being blended by bulk terminal operators. Very little BBD is provided to consumers via other entities such as jobbers, and those volumes that do occur are sporadic (see Figure A-55). Regular monthly BBD blending did not occur until late 2011 and refiners did not account for volumes until halfway through 2012. Refiners immediately surpassed the share of blending done by bulk terminal operators and have been responsible for most BBD blending in every subsequent year. This blending is seasonal, increasing beginning in April and decreasing after September. Blending by

bulk terminal operators, by contrast, holds comparatively steady throughout the year despite the region's cold winter temperatures.

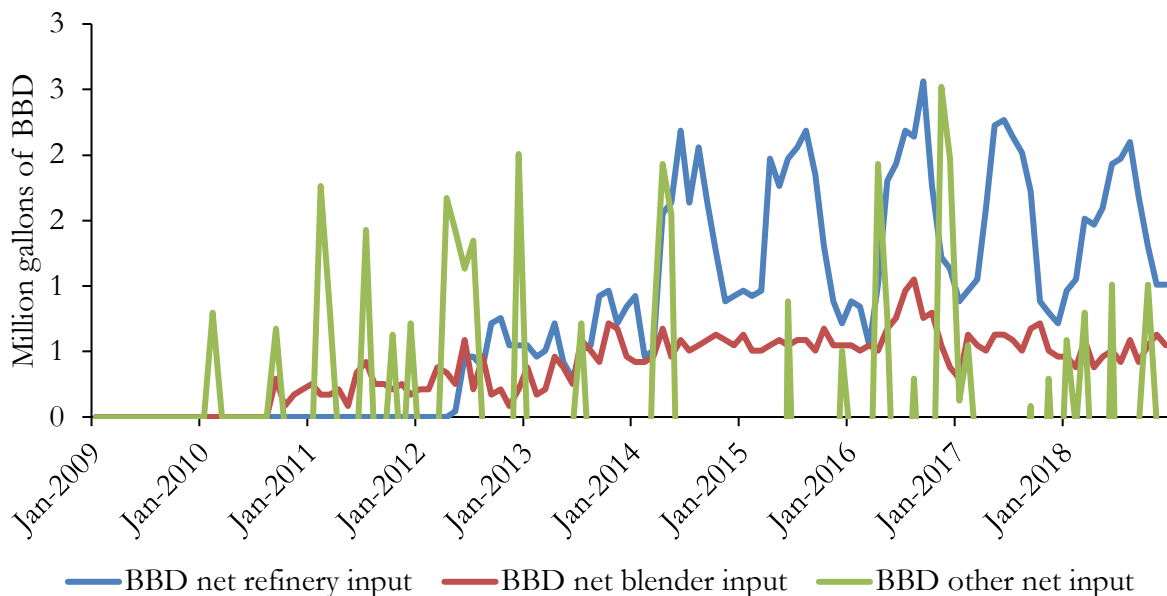


Figure A-55. PADD 4 net BBD inputs by blending category, 2009-2018.^{99,100}

The PADD 4 region's blending profile is also unique in that the combined volume that is blended by refiners and bulk terminal operators regularly exceeds the region's total BBD consumption, in some cases by as much as 200% or more. While this partly reflects the small amount of consumption that occurs within the region, it also suggests that BBD is being blended in PADD 4 states and then shipped to other locations, most likely the PADD 5 region. The volumes involved are ultimately small and the total blending volume over the last decade has exceeded the region's consumption volume by only 36 million gallons (albeit 34%).^{99,100} The PADD 4 region is the only area in which this dynamic occurs.

The expiration of the BTC has historically had no effect on seasonal BBD blending volumes by refiners and bulk terminal operators in the PADD 4 region. Blending normally peaks in June before gradually declining through November (see Figure A-56). Blending volumes in those years in which the BTC either expired or almost expired were on average lower in the second half of the year relative to the prior January when compared to both all years and non-expiry years. Non-expiry years have experienced higher blending volumes in the later months of the year relative to the prior January on average, although this is due to a limited number of datapoints and very high blending volumes in the later months of 2012. There has historically been little difference in the

seasonal blending patterns between expiration and non-expiration years if 2012's volumes are excluded.

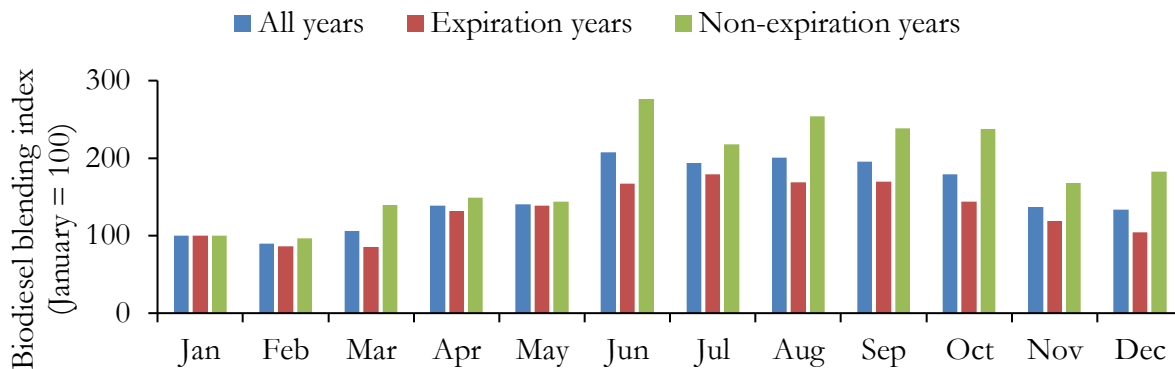


Figure A-56. Index of monthly PADD 4 BBD blending volumes by refiners and bulk terminal operators, 2011-2018. Figures shows average index values for all years, those years in which the BTC expired or almost expired (with and without 2013's values), and those years in which the BTC did not expire.^{99,100}

Seasonal PADD 4 blending volumes have also experienced a much smaller effect from high RIN prices relative to the other PADD regions. The blending volume relative to January in June 2013 was substantially lower than compared to the average of all other years in which the BTC either expired or almost expired (see Figure A-57). 2013's monthly blending volume increases did not exceed those of the other expiration years until the last three months of the year, even though RIN prices were undergoing a large decline from their August 2013 highs by that point. Too much should not be read into the PADD 4 region's results given the region's small overall BBD blending volumes.

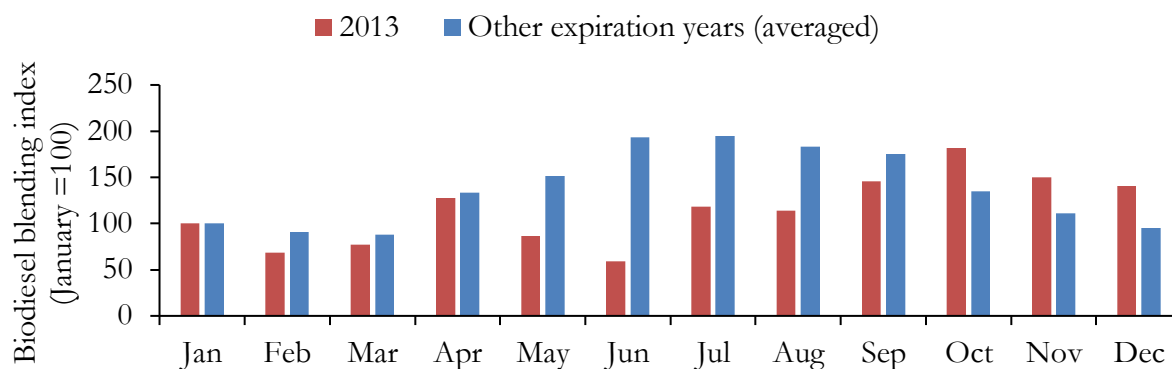


Figure A-57. Index of monthly PADD 4 BBD blending volumes by refiners and bulk terminal operators, 2013 compared to average of other years in which the BTC either expired or almost expired.^{99,100}

II.5. Regional demand and blending - PADD 5

The PADD 5 region's distillate fuel oil consumption profile is similar to that of the overall U.S. (see Figure A-58); residential sector demand is low due to a lack of home heating oil use while the on-road sector demand is slightly higher.⁹³ The MVNRLM sectors accounted for 81% of all PADD 5 distillate fuel oil consumption 2017. The region's total consumption increased by 12% between 2009 and 2017 to 8,558 million gallons, or 14% of total U.S. consumption. PADD 5 MVNRLM consumption accounted for 11% of total U.S. MVNRLM consumption. On-road consumption growth outpaced that of overall distillate fuel oil consumption by recording a 15% increase between 2009 and 2017.

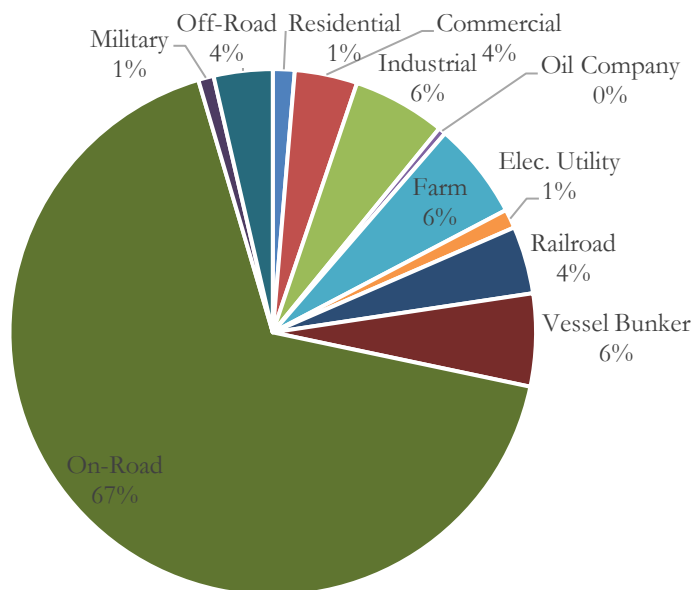


Figure A-58. PADD 5 distillate fuel oil (excluding kerosene) consumption by sector in 2017. Percentages are rounded to nearest whole digit.^{93,94}

BBD consumption as a share of MVNRLM diesel fuel consumption in the PADD 5 region increased from 0.5 vol% in 2009 to 8.9 vol% in 2017 (see Figure A-59, which shows average annual blend rates). The contribution of renewable diesel to California's LCFS is evident in the PADD 2 region's 3.7 vol% average renewable diesel blend rate in 2017; biodiesel's average blend rate in that year was still higher at 4.8 vol%.^{1,93} Renewable diesel and biodiesel blend rates relative to total PADD 5 distillate fuel oil consumption in 2017 were 3 vol% and 4.1 vol%, respectively, or 7.1 vol% for all BBD. Biodiesel retail blends of >10 vol% are available along the region's interstate highways, with the highest concentrations being located near urban centers such as Seattle, San Francisco, and Los Angeles.¹¹⁰

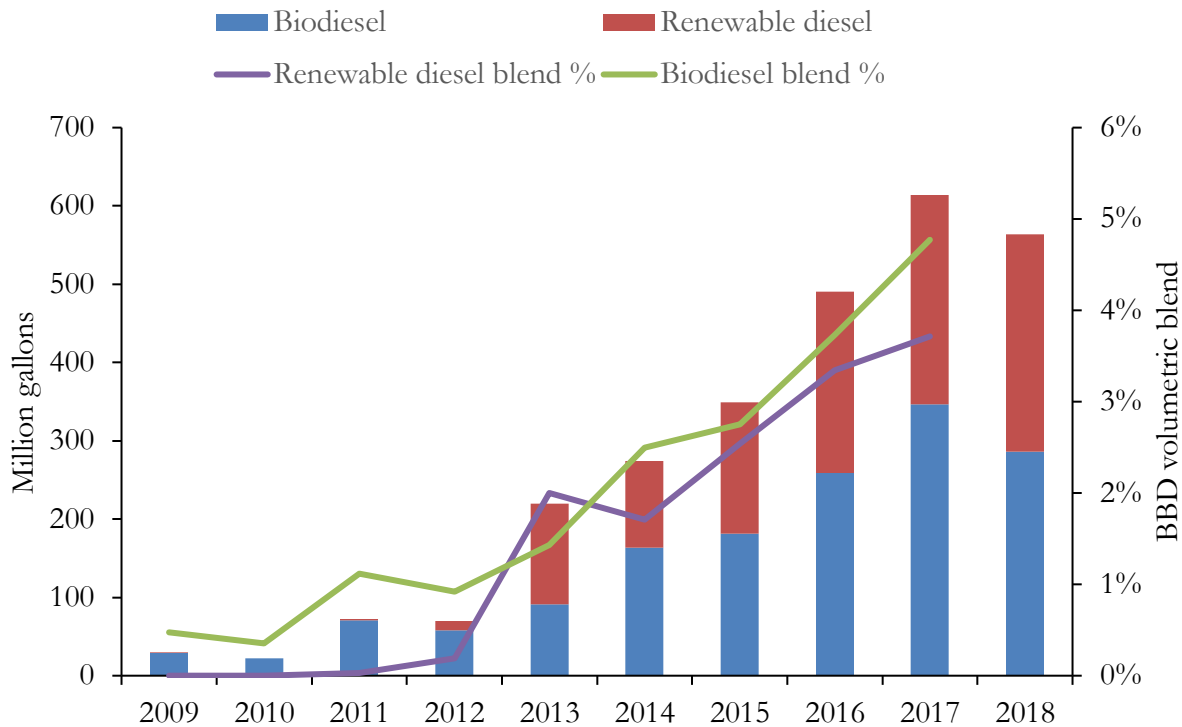


Figure A-59. PADD 5 BBD consumption volumes (2009-2018) and average blend rates as percentage of MVNRLM diesel fuel consumption (2009-2017).^{1,93}

California is the largest source of BBD consumption within the PADD 5 region. The state's LCFS accounted for 507 million gallons of BBD consumption in 2017 out of 614 million gallons of BBD consumption in the PADD 5 region. (see Figure A-60).^{1,21} Approximately half of the region's biodiesel consumption and virtually all of its renewable diesel consumption in that year occurred in California. It can be assumed that the on-road sector is responsible for the large majority of BBD consumption in the PADD 5 region given the scope of the LCFS and the comparatively small sizes of the rail and vessel bunker sectors in terms of PADD 5 distillate fuel oil demand. The concentration of total PADD 5 BBD demand within California has resulted in a high average blend rate relative to the PADD regions in recent years. In 2018 this average blend rate reached 15 vol% of covered diesel fuel in 2018, up from 0.4 vol% in 2011.¹¹¹ In terms of overall distillate fuel oil consumption, California's average blend rate was 11 vol% in 2017.³⁵

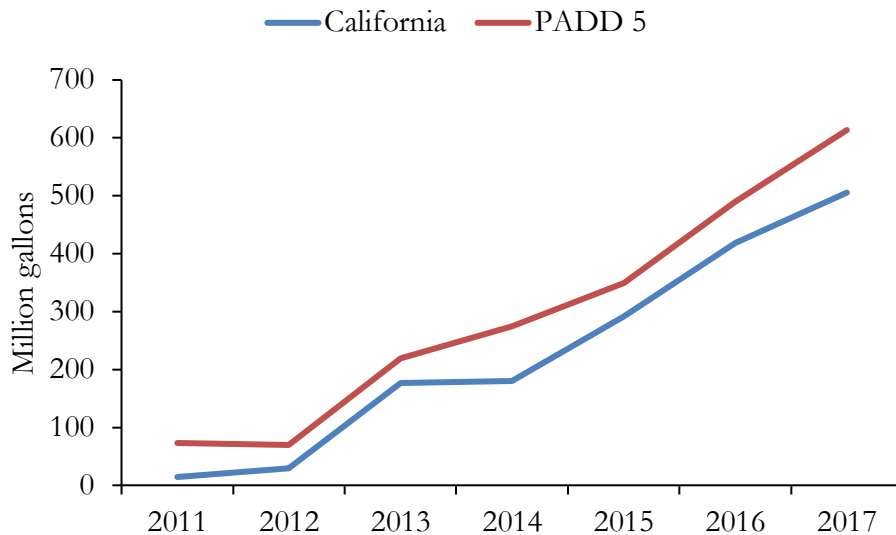


Figure A-60. California BBD consumption relative to total PADD 5 BBD consumption, 2011-2017.^{1,111}

Washington has published limited data on BBD blends that are consumed by the different state agencies. A 2017 presentation by the state’s Department of Agriculture described BBD purchases by these agencies as “leading biodiesel use” in the state.¹¹² The state-owned ferry system is the largest source of agency biodiesel demand in Washington, and it used a uniform 5 vol% blend in 2016. The state vehicle fleets consumed an average biodiesel blend of 14 vol% in that year, although this varied by geography and season: while a uniform blend of 20 vol% was consumed in western Washington throughout the year, fleets in the eastern part of the state, which experiences colder winter temperatures, utilized up to 10 vol%.

The PADD 5 region’s potential biodiesel consumption in 2017 was 1,290 million gallons, assuming a 20 vol% blend limit for the on-road sector and 5 vol% for all other sectors that consume distillate fuel oil, compared to actual biodiesel consumption in that year of 347 million gallons. The region’s potential renewable diesel consumption in 2017 was higher at 8,558 million gallons, compared to actual consumption of 267 million gallons, due to that fuel’s lack of blending constraints. The PADD 5 region still has substantial room to increase its biodiesel consumption, let alone its renewable diesel consumption, before encountering infrastructure blending constraints despite having the country’s highest average PADD-level blend rates.

Only small quantities of BBD were blended in the PADD 5 region prior to 2011 (see Figure A-61). In contrast to the other PADD regions, early PADD 5 blending was primarily performed by refiners

and bulk terminal operators, which have together accounted for 63% of the BBD that has been blended over the last decade. Blending volumes by refiner and bulk terminal operators rose rapidly in early 2013 as RIN prices increased, with bulk terminal operators being the primary source of blended BBD. Blending by other sources such as fuel jobbers began to increase after 2015 and has exceeded the combined blending volume of refiners and bulk terminal operators since 2017.

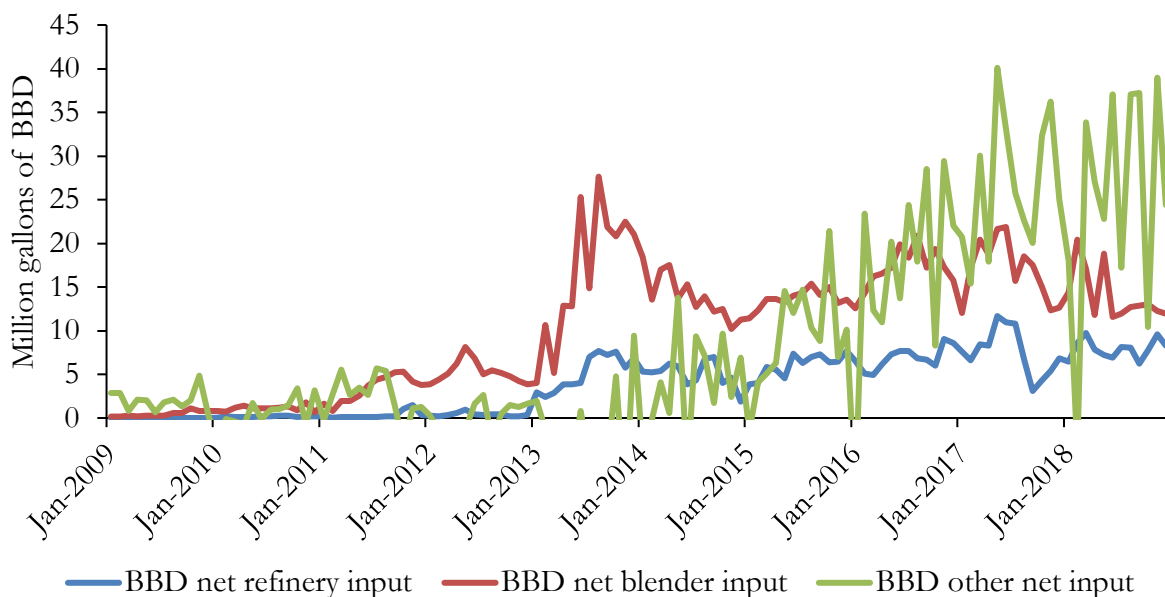


Figure A-61. PADD 5 net BBD inputs by blending category, 2009-2018.^{99,100}

PADD 5 BBD blending exhibits a seasonal pattern this is similar to those of the other PADDs. Blending volumes by refiners and bulk terminal operators are lowest in January and highest in October (see Figure A-62). Like the PADD 3 region, the PADD 5 region's blending activity is also high in November, which could reflect its comparatively warm winter temperatures and a lack of palm oil-derived BBD fuels, which have a relative high cloud point compared to BBD fuels from other feedstocks, under the LCFS. The expiration of the BTC has historically had a very large effect on blending in the second half of each year, with October volumes representing an average increase of 182% over January volumes in those years in which the tax credit either expired or almost expired. By comparison, the average October increase relative to the prior January was an average of 19% in non-expiration years. The historical effect of the expiration remains large even after excluding the 2013 volumes.

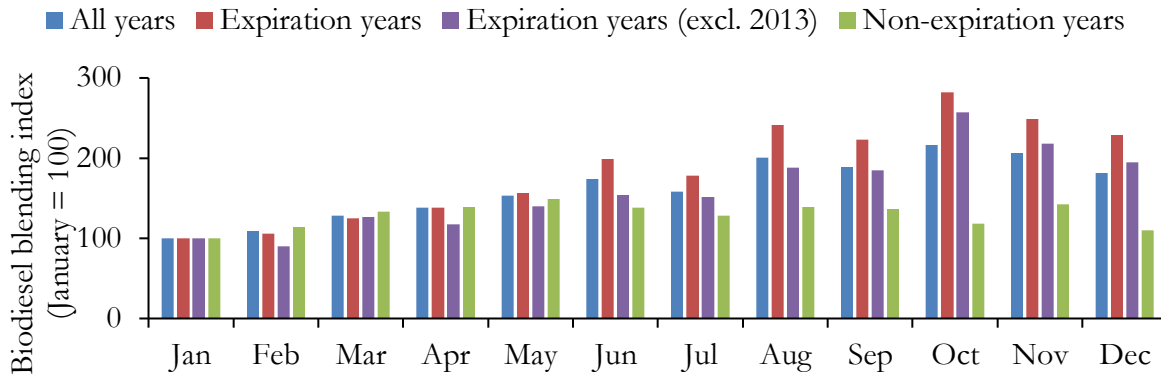


Figure A-62. Index of monthly PADD 5 BBD blending volumes by refiners and bulk terminal operators, 2009-2018. Figures shows average index values for all years, those years in which the BTC expired or almost expired, including and excluding 2013, and those years in which the BTC did not expire.^{99,100}

Monthly PADD 5 blending by refiners and bulk terminal operators increased especially quickly in 2013 as RIN prices moved higher. The blending volume peaked in August of that year rather than in October, coinciding with the D4 RIN price peak (see Figure A-63). A similar sensitivity to RIN prices was exhibited in 2018, a non-expiration year in which the monthly blending volume peaked in March, coinciding with a large RIN price decline over the course of the year. 2018's blending volumes were especially notable in that the monthly blending volumes in all but one month between June and December were lower than in the prior January. Unlike the other PADD regions' 2018 blending volumes, the effect of the imposition of trade restrictions on biodiesel from Argentina and Indonesia did not have much of an effect on the PADD 5 region's blending volumes given that neither country's BBD contributed to the largest driver of regional BBD demand, California's LCFS.

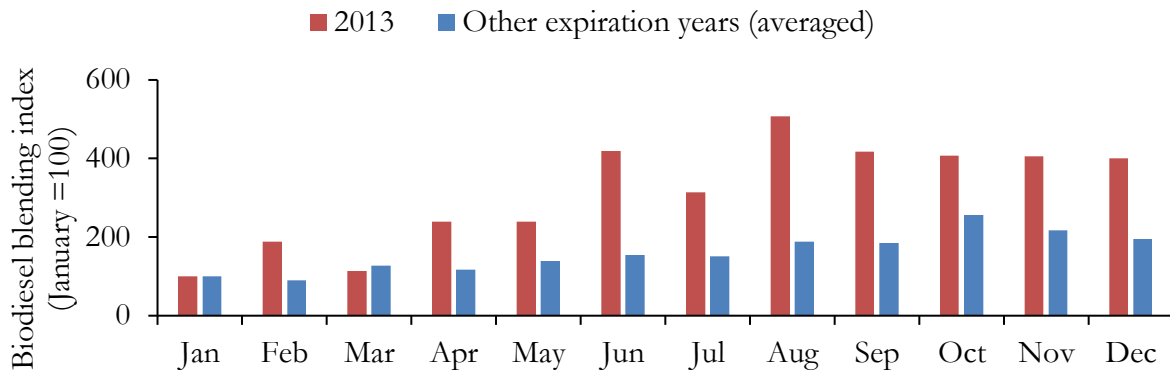


Figure A-63. Index of monthly PADD 5 BBD blending volumes by refiners and bulk terminal operators, 2013 compared to average of other years in which the BTC either expired or almost expired.^{99,100}

II.6. Regional demand incentives - PADD 1

Connecticut requires that all alternative fuel vehicles that the state purchases in order to comply with the EPA Act be able to operate on an alternative fuel, such as BBD, that has been produced within the state.¹¹³ It further requires that all cars and light-duty trucks that are purchased or leased for use in the state fleet be either a hybrid electric vehicle or capable of running on an alternative fuel.

In 2010 Delaware required the development of procedures for “diesel vehicles in the State fleet to use biodiesel of the highest percentage content practicable.”¹¹⁴

All Florida agencies must use biodiesel blends as fuel when available.⁵⁹ All state-administered central fueling operations for state fleet vehicles must also purchase biodiesel for use as fuel “to the greatest extent practicable.”

At least 50% of Maryland’s state diesel vehicles must use a minimum BBD blend of 5 vol% so long as doing so complies with the vehicle warranty.¹¹⁵ Vehicles capable of operating on other BBD blends must use that blend when it is available.

The Massachusetts Department of Transportation must require that contracts for the provision of fuel to the Massachusetts Turnpike offer alternative fuels such as BBD.¹¹⁶ All on-road and off-road diesel vehicles in the state fleet must be fueled by a minimum biodiesel blend of 15 vol% if deemed

appropriate by state agencies. Exceptions can be granted when BBD is not available within a “reasonable distance” or is “cost prohibitive.”

New Hampshire requires that purchases of diesel fuel by the state’s Department of Transportation contain at least 5 vol% biodiesel so long as the biodiesel blend is available and not more expensive than petrodiesel.⁵⁶ The state also encourages the Department of Transportation to purchase biodiesel blends of up to 20 vol% when possible. These blends can be resold by the state to all state entities and eligible non-profits.

New Jersey mandates that all state entities purchase biodiesel blends for use in state-owned diesel vehicles if the blend is not more expensive than petrodiesel and its use is deemed to be “reasonable.”¹¹⁷

All diesel-fueled school buses in North Carolina must be able to operate on biodiesel blends of up to 20 vol%.⁶³ At least 2 vol% of the fuel purchased by school districts in the state must contain a 20 vol% biodiesel blend if available for purchase. Likewise, all acquisitions of new diesel vehicles for the state fleet must have a manufacturer’s warranty that covers the use of 20 vol% biodiesel blends.

South Carolina requires the state’s school buses to be fueled with biodiesel “when feasible.” State agencies must give preference when purchasing vehicles to alternative fuel vehicles, including those that run on biodiesel blends, when the “performance, quality, and anticipated life cycle costs” are comparable to conventional vehicles.⁴²

II.7. *Regional demand incentives – PADD 2*

Any vehicle that is purchased with state funds in Illinois must be certified to run on at a biodiesel blend of at least 5 vol%.⁶⁷ All vehicles owned or operated by state, county, or local entities must obtain biodiesel blends of at least 5 vol% when obtaining fuel from a bulk central fueling facility. Consumption of higher biodiesel blends is required when the vehicle in question is designed or retrofitted for such use. State agencies’ vehicle procurement contracts may give preference to qualified bidders who would fulfill the terms via vehicles fueled by biodiesel produced within Illinois. Finally, state agencies must implement strategies to encourage the consumption of biofuels such as biodiesel in state vehicle fleets.

Indiana state entities and educational institutions must use biodiesel blends of at least 2 vol% in diesel vehicles in which the blend has been approved for use by the vehicle manufacturer.⁶⁸

Iowa mandates that at least 10% of all state fleet vehicle purchases be capable of utilizing alternative fuels such as biodiesel blends.⁷⁰ The Iowa Department of Transportation is allowed to purchase biodiesel for use in its vehicles using funds generated via the sale of EPA credits.

Kansas requires state-owned diesel vehicles and equipment to use biodiesel blends of at least 2 vol% where available when the biodiesel blend price does not exceed that of petrodiesel by \$0.10/gallon or more.⁷¹

Minnesota's biodiesel blending mandate is more stringent than most states' fleet vehicle fuel purchase requirements.⁷⁴ The state therefore requires that all state agencies purchase on-road alternative fuel vehicles, including those that are fueled by biodiesel blends of 20 vol% or higher. State employees are also tasked with ensuring that alternative fuel vehicles utilize the appropriate alternative fuel. State agencies must increase their consumption of renewable fuels such as biodiesel that are derived from agricultural and waste products. These requirements are all part of Minnesota's broader goal of reducing petroleum consumption in state vehicle fleets.

Missouri requires that 75% or more of Missouri Department of Transportation diesel vehicles and heavy equipment utilize biodiesel blends of 20 vol% or higher whenever the blend is available at a price premium of no more than \$0.25/gallon relative to petrodiesel.⁵⁰ Any qualifying biodiesel blend price premium is to be paid via funds generated through the sale of EPA credits.

Ohio requires that all new vehicles that are purchased for the state fleet be compatible with alternative fuels such as biodiesel blends of at least 20 vol%, and that they be fueled by that alternative fuel when "reasonably priced and available."¹¹⁸ The state also maintains a biodiesel revolving trust fund that can be used to pay for a biodiesel blend's price premium relative to petrodiesel when fueling state-owned or state-leased diesel vehicles.

Oklahoma encourages all school and government fleets to utilize alternative fuel vehicles. These vehicles are required to utilize alternative fuels such as biodiesel whenever a fueling station is present within a 5-mile radius and the alternative fuel is "cost competitive" with the petroleum-derived fuel.¹¹⁹

Tennessee requires state fleets to “make every effort” to ensure that all purchases of new vehicles are either energy-efficient or alternative fuel vehicles, with the latter category including vehicles that are fueled by biodiesel blends of 20 vol% or more.⁷⁸ State agencies are encouraged to use biodiesel blends in diesel vehicles “whenever possible” and to support the development of biodiesel fueling infrastructure.

Wisconsin’s Department of Administration encourages all state employees driving state-owned or -leased vehicles to use alternative fuels, including biodiesel, “whenever feasible and cost effective.”⁷⁹ The state further requires that a list of alternative fueling locations be made available in each qualifying vehicle for the driver’s use.

II.8. Regional demand incentives – PADD 3

Arkansas requires all diesel-powered motor vehicles and equipment that is owned or leased by the state government to use a minimum BBD blend of 2 vol% unless certain BBD availability or price (<\$0.15/gallon premium relative to petrodiesel) conditions are met.¹²⁰

Louisiana requires the acquisition of alternative fuel vehicles, including vehicles capable of operating on “non-ethanol advanced biofuels” such as biodiesel and renewable diesel, by its Division of Administration. Exceptions are granted for state agency vehicles that are not based within a 25-mile radius of a fueling station that offers a BBD blend.⁴⁷

All state agency fleets in Texas that have more than 15 vehicles may only purchase or lease alternative fuel vehicles, including those that run on biodiesel blends of at least 20 vol%.⁸² Furthermore, state agency fleets must consist of at least 50% alternative fuel vehicles that use alternative fuels for 80% of their driving. Exceptions are made for fleets operating in areas in which either the necessary fueling infrastructure is unavailable or the cost of the biodiesel blend is greater than the petrodiesel fuel cost.

II.9. Regional demand incentives – PADD 4

Colorado mandates that all state-owned diesel vehicles and equipment utilize a 20 vol% blend of biodiesel that has been produced within the state, subject to supply and price (<\$0.10/gallon premium relative to petrodiesel) requirements.⁹¹ A lack of BBD production capacity in the state makes it unlikely that this mandate has been met.

Utah requires that at least 50% of new or replacement light-duty vehicles in state agency fleets either meet Bin 2 emissions standards or be fueled “to a significant extent” by alternative fuels, including biodiesel.¹²¹

II.10. Regional demand incentives – PADD 5

California requires at least 3% of the state government’s fuel consumption to be of “very low-carbon transportation fuel” that achieves a minimum 60% reduction to carbon intensity (CI) relative to a comparable petroleum-derived fuel.¹²² This acquisition requirement increases by one percentage point per year through 2024. California also requires that the state fleet’s consumption of petroleum products be reduced by 20% relative to a 2003 consumption level by 2020.

Hawaii requires state and county agencies to purchase light-duty vehicles that “reduce petroleum consumption.”⁸⁸ While plug-in electric vehicles and hydrogen/hydrogen fuel cell vehicles are given priority, vehicles that utilized biodiesel blends of 20 vol% or greater can also meet the acquisition requirement. Furthermore, state agencies are further required to “evaluate a purchase preference for biodiesel blends.” Finally, state and county agency contracts for the purchase of diesel fuel must give preference to bids that offer biodiesel or biodiesel blends. A price preference of \$0.05/gallon of pure biodiesel, or the equivalent for biodiesel blends, is mandated.

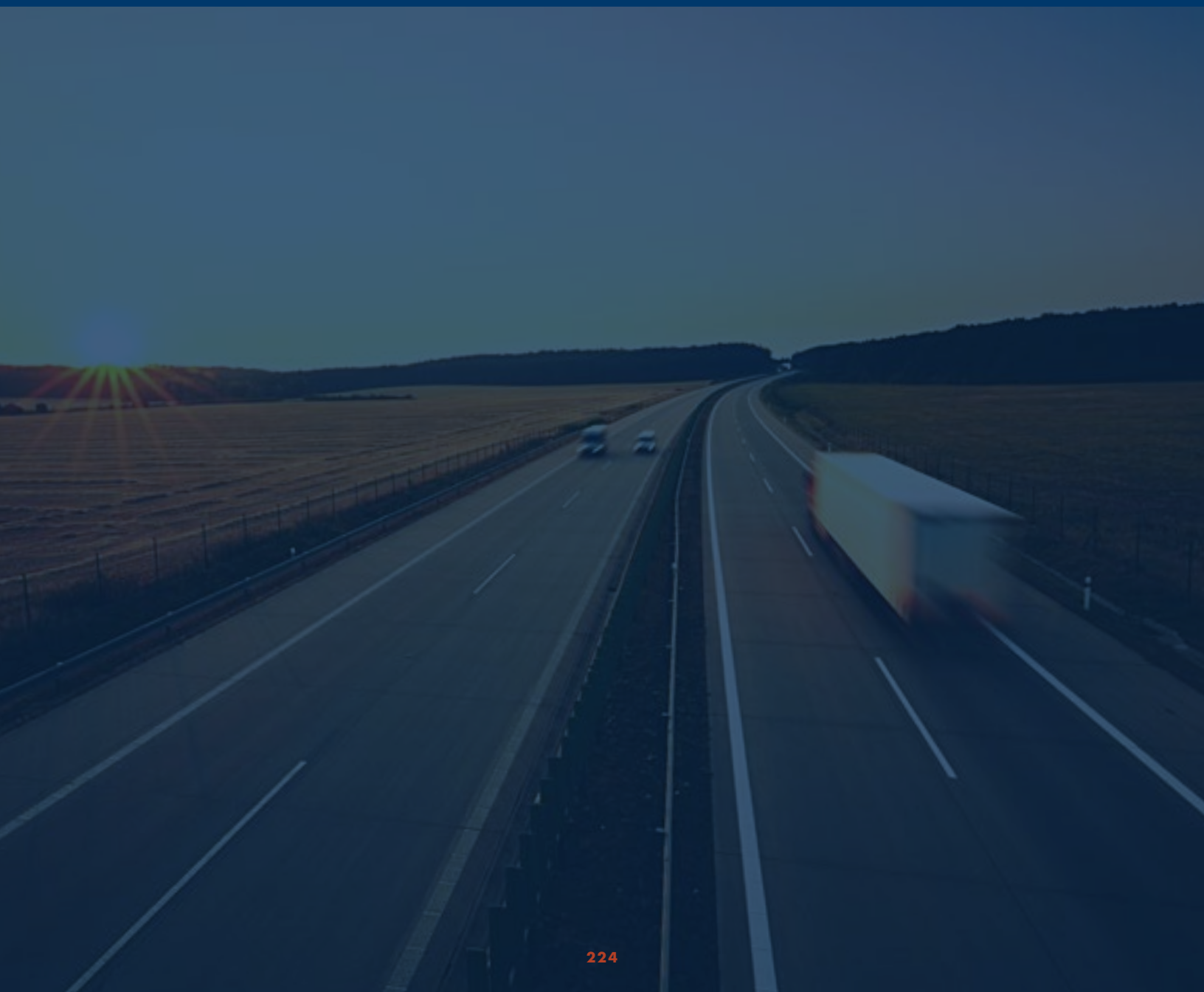
Oregon requires all state agencies and transit districts to purchase alternative fuel vehicles and to fuel them with alternative fuels such as biodiesel whenever it is economically and logistically possible to do so.³⁸

All state agencies in Washington must, where possible, utilize electricity or 100% biofuels, including biodiesel, to operate publicly owned vehicles.⁴⁰ While the state prioritizes the use of electric vehicles, biofuels such as biodiesel may be substituted when the necessary electricity infrastructure is not available. The state government and local entities have the ability to execute contracts with biodiesel

suppliers for the purpose of ensuring that the biodiesel consumed by publicly owned fleets in Washington is sourced from within the state. Furthermore, at least 20 vol% of the diesel fuel that is used by state agency vehicles, vessels, and construction equipment must be biodiesel. USLD that is consumed by state agencies must contain at least 2 vol% biodiesel for lubricity.

Appendix III

DEFINITIONS AND SOURCES



Appendix III – Definitions and Sources

The U.S. Energy Information Administration (EIA) is an important source of data on every aspect of the petroleum and biomass-based diesel supply chains due in large part to surveys that it collects from a variety of market participants. Unfortunately, the nomenclature that the EIA uses at the time of writing* to report the resulting BBD data that it publishes is not uniform. This report reconciled the EIA nomenclature with the standard BBD nomenclature adopted in this report in the following ways, based on discussions with industry partners and cross-referencing with BBD data from other sources (attempts to contact EIA representatives were unsuccessful):

1. The EIA's Short Term Energy Outlook (STEO) report¹²³ appears to use the term “biomass-based diesel fuel” interchangeably to refer to both (1) the broad fuel category that encompasses both biodiesel (FAME) and renewable diesel (hydroprocessed lipids), as well as (2) the more limited category of just biodiesel. The STEO's glossary defines “biomass-based diesel fuel” as “biodiesel and other renewable diesel fuel or diesel fuel blending components derived from biomass, but excluding renewable diesel fuel coprocessed with petroleum.”¹²⁴ While this would seem to include both biodiesel and renewable diesel, the STEO's reported U.S. “biomass-based diesel fuel production” volume (a total of 10,856 million gallons from 2009 to 2018) exactly matches the volume reported separately in the EIA's Petroleum & Other Liquids (P&OL) report¹ under the category “biodiesel”, which is defined in the same glossary as just including ester-based fuel.¹²⁴ The volume also closely matches the U.S. Environmental Protection Agency's (EPA) reported U.S. biodiesel production volume of 11,077 million gallons for the same period, whereas the EPA data shows a U.S. biomass-based diesel (combined biodiesel and renewable diesel) production volume of 12,329 million gallons. The difference between the EPA's two volumes of 1,252 million gallons aligns with the renewable diesel production volume for that period according to producers' earnings reports.

The EIA's P&OL Company Level Imports database reports import volumes for two different types of relevant fuels: “biomass-based diesel fuel” and “other renewable diesel fuel.”⁹ The P&OL's reported “biomass-based diesel fuel” annual volumes are substantially smaller than the STEO's “biomass-based diesel net imports” volumes, which should not be the case if both refer

* In June 2019 the U.S. government proposed to replace its existing BBD fuel categories with the new categories “biodiesel”, “renewable diesel fuel”, and “other renewable fuels and intermediate products.”

to the same fuel(s) given that the former just shows imports while the latter subtracts export volumes from imports (and negative imports are not possible). The P&OL’s “biomass-based diesel fuel” import volumes closely align with the same report’s “biodiesel (renewable)” category in its “U.S. Imports by Country of Origin dataset,¹²⁵ which suggests that the EIA is referring to biodiesel (fatty acid methyl ester, or FAME) when it uses the term “biomass-based diesel fuel”, the glossary’s stated definitions notwithstanding. “Biomass-based diesel fuel” is also given the 203 product code by the EIA, which is the same product code that is listed for “biodiesel” in other relevant EIA surveys.¹²⁶

This interpretation is further supported by the P&OL’s use of the term “other renewable diesel” in both its Company Level Imports and U.S. Imports by Country of Origin datasets. The glossary defines the term to mean coprocessed renewable diesel.¹²⁴ It is unlikely that this definition is correct, however, given that the Company Level Imports database shows that 84% of the last decade’s imports of “other renewable diesel” entered the U.S. through California, presumably to participate in the state’s Low Carbon Fuel Standard (LCFS), yet the LCFS had not certified any lipids coprocessing pathways to participate as of October 2018.¹²⁷ Rather, the EIA’s “other renewable diesel” category most likely refers to non-coprocessed renewable diesel since California both imports¹²⁸ and consumes²¹ large volumes of this fuel. EPA data supports this assumption by showing that the U.S. has not imported any coprocessed renewable diesel over the last decade under the Renewable Fuel Standard.^{129*} EPA data further supports the assumption that “other renewable diesel” refers to renewable diesel in that its reported non-coprocessed renewable diesel import volume over the last decade of 1,139 million gallons closely aligns with the Company Level Imports database’s “other renewable diesel” import volume over the same period of 1,145 million gallons.

2. The EIA’s P&OL Movements between PAD Districts database reports volumes for two relevant fuel categories: “renewable diesel fuel” and, nested within that, “biodiesel.”⁷ Neither fuel category is defined in the definitions that accompany that dataset¹³⁰ and “renewable diesel fuel” is not defined in the STEO glossary either.¹²⁴ The term “biodiesel” refers to FAME in the other P&OL databases and is defined as such in the STEO glossary, as discussed above, and this

* Coprocessed renewable diesel can generate D5 but not D4 RINs under the RFS. Only 142 million gallons of renewable diesel has generated D5 RINs over the last decade, compared to 1,145 million gallons of imported “other renewable diesel” in the Company Level Imports database, and none of the former gallons have been imported.¹²⁹

report assumes it to mean the same in the movements database as a result. Renewable diesel volumes, while not reported separately in the database, are derived from the dataset by subtracting the reported “biodiesel” volumes from the reported “renewable diesel fuel” volumes. This approach is supported by the fact that the resulting movement volume calculations show a rapid increase in non-biodiesel shipments to the PADD 5 region from the PADD 3 region that correlates with data from the California Air Resources Board (CARB) showing similar increases in the volumes of renewable diesel moving into California under the Low Carbon Fuel Standard (LCFS).²⁴

3. The EIA P&OL report’s Refinery and Blender Net Inputs database only reports on a “renewable diesel fuel” category that has the same coprocessing definition¹³¹ as is used for the term “other renewable diesel” in the Company Level Imports database discussed earlier. A strict interpretation of this definition would mean that 6,200 million gallons of coprocessed renewable diesel, and no biodiesel or non-coprocessed renewable diesel, was blended in the U.S. between 2009 and 2018. This interpretation cannot be correct based on the respective fuels’ production volumes over the same period. This also raises the question of which fuel type(s) the term “renewable diesel fuel” refers to. Fortunately, the EIA has released a new survey form for terminal blending activities based on its proposed modifications to the existing nomenclature.¹³² The proposed form uses the new terms “biodiesel” and “renewable diesel” in place of the old terms “biomass-based diesel” and “other renewable diesel”, respectively. This report assumes that the EIA’s original “renewable diesel fuel” category refers to both biodiesel and renewable diesel. This assumption is based on the fact that the corresponding database only reports “renewable diesel fuel” categories, in conjunction with the treatment of that term in the movements database as an overarching category under which the “biodiesel” category is nested.

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³ USDA (2014) “Soybean Transportation Profile.” Available on the Web at: <https://www.ams.usda.gov/sites/default/files/media/Soybean%20Transportation%20Profile.pdf> (accessed May 25, 2019).

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- 9 EIA (2019) “Company Level Imports Archives.” *Petroleum & Other Liquids*. Available on the Web at: https://www.eia.gov/dnav/pet/pet_move_imp_dc_NUS-Z00_mbbblpd_m.htm (accessed May 26, 2019).
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- 11 Walsh, E. and M. Hirtzer (2017) “U.S. sets final anti-subsidy duties on Argentine, Indonesian biodiesel.” *Reuters*, Nov. 9. Available on the Web at: <https://www.reuters.com/article/us-usa-biodiesel/u-s-sets-final-anti-subsidy-duties-on-argentine-indonesian-biodiesel-idUSKBN1D92GV> (accessed May 26, 2019).
- 12 USDA FAS (2018) “Biofuels Annual.” Available on the Web at: [https://www.fas.usda.gov/data/search?f\[0\]=field_commodities:5](https://www.fas.usda.gov/data/search?f[0]=field_commodities:5) (accessed May 26, 2019).
- 13 Iowa RFA (2019) “Iowa produces 365 million gallons of biodiesel in 2018.” *Biodiesel Magazine*, January 2. Available on the Web at: <http://www.biodieselmagazine.com/articles/2516558/iowa-produces-365-million-gallons-of-biodiesel-in-2018> (accessed June 22, 2019).
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END OF APPENDIX



About the Fuels Institute

The Fuels Institute, founded by NACS in 2013, is a 501(c)(4) non-profit research-oriented think tank dedicated to evaluating the market issues related to vehicles and the fuels that power them. By bringing together diverse stakeholders of the transportation and fuels markets, the Institute helps to identify opportunities and challenges associated with new technologies and to facilitate industry coordination to help ensure that consumers derive the greatest benefit.

The Fuels Institute commissions and publishes comprehensive, fact-based research projects that address the interests of the affected stakeholders.

Such publications will help to inform both business owners considering long-term investment decisions and policymakers considering legislation and regulations affecting the market. Research is independent and unbiased, designed to answer questions, not advocate a specific outcome. Participants in the Fuels Institute are dedicated to promoting facts and providing decision makers with the most credible information possible, so that the market can deliver the best in vehicle and fueling options to the consumer.

For more about the Fuels Institute, visit fuelsinstitute.org

NACS

The Fuels Institute was founded in 2013 by NACS, the international association that advances convenience and fuel retailing. Through recurring financial contributions and daily operational support, NACS helps the Fuels Institute to invest in and carry out its work to foster collaboration among the various stakeholders with interests in the transportation energy market and to promote a comprehensive and objective evaluation of issues affecting that market and its customers both today and in the future. NACS was founded August 14, 1961, as the National Association of Convenience Stores, and represents more than 2,100 retail and 1,600 supplier company members.

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FUELS INSTITUTE STAFF

JOHN EICHBERGER Executive Director jeichberger@fuelsinstitute.org	AMANDA APPELBAUM Director, Research aappelbaum@fuelsinstitute.org	DONOVAN WOODS Director, Operations dwoods@fuelsinstitute.org
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(703) 518-7970
FUELSINSTITUTE.ORG
@FUELSINSTITUTE

1600 DUKE STREET
SUITE 700
ALEXANDRIA, VA 22314