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Potential biomass-based diesel production in the United States by 2032

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Introduction

The Renewable Fuel Standard (RFS) is a U.S. federal policy that requires a minimum volume of renewable fuels to be blended in transportation fuel. The RFS was created by the Energy Policy Act of 2005, which amended the Clean Air Act, with the intention of improving energy security and reducing greenhouse gas (GHG) emissions. It was further expanded with additional amendments to the Clean Air Act in the Energy Independence and Security Act of 2007 (EISA), thereafter known as RFS2. The U.S. Environmental Protection Agency (EPA) administers the RFS program, evaluating and adjusting the annual volume targets set in the EISA. After 2022, the EPA will have greater discretion for setting volume obligations.

The RFS establishes volume mandates for four fuel categories, each with a GHG reduction threshold: biomass-based diesel (BBD), 50% or more; cellulosic biofuel, 60% or more; advanced biofuel, 50% or more; and total renewable fuel, 20% or more. The four categories are nested within each other in a way that a category of higher GHG reduction threshold could be used to meet the standards for a lower GHG reduction category. In particular, BBD and cellulosic biofuel are subcategories of advanced biofuel, which itself falls under total renewable fuel. In this nesting scheme, fuel in a subcategory such as BBD can be used to meet the volumetric obligations for its parent categories such as advanced biofuel and total renewable fuel in addition to the volume obligation for that subcategory. As a result of this structure, BBD compliance in the past has tended to exceed the volume obligation for this category.

As shown in Figure 1, between 2014 and 2018 the total domestic and imported BBD under the RFS program exceeded the BBD volume obligation. For example, in 2018 there were 2.56 billion biodiesel-equivalent gallons, including 2.15 billion domestically

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produced and 0.41 billion imported, compared with the RFS-mandated 2.1 billion gallons. This is because BBD has been used to a greater extent than other biofuels to meet the advanced fuel obligation. Specifically, the ethanol blend wall, which is the maximum amount of ethanol that can be blended with gasoline, limits the market for advanced ethanol pathways such as sugarcane ethanol. Since BBD is likely to be the most cost-effective means of compliance as the advanced biofuel obligation expands, overcompliance with the BBD obligation is expected to continue (EPA, 2018).

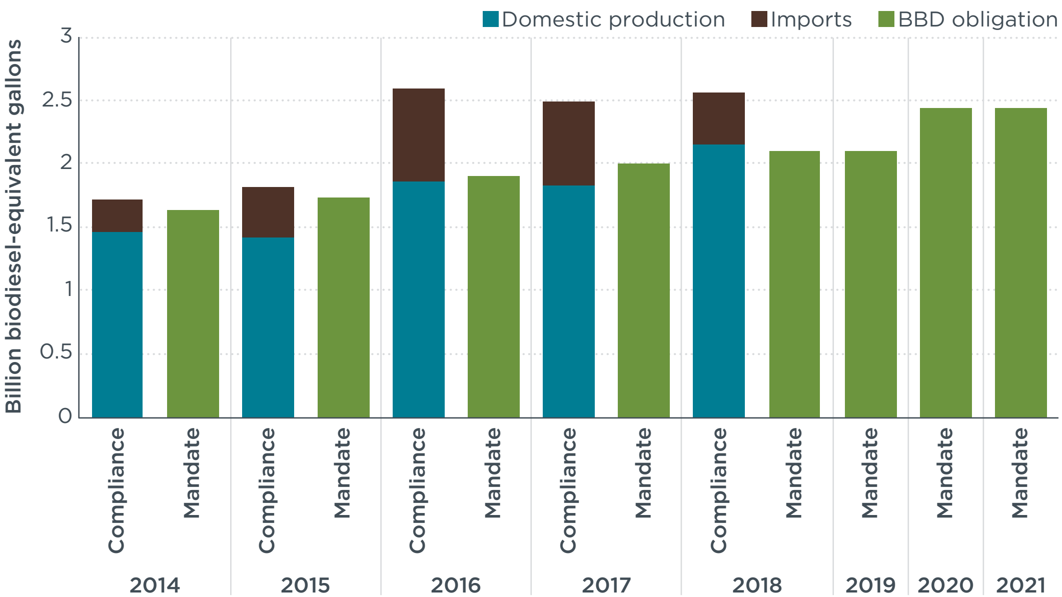

Figure 1. BBD compliance and obligations in the RFS. Source: EPA, 2018; EPA, 2019b.

By statute, the EPA needs to consider the availability of feedstocks for fuel production when determining the volume obligations for each year as this affects the ability of refiners and blenders to meet the obligations (Clean Air Act, 2007). The availability of BBD feedstocks for biofuel production depends on their domestic production, international trade, and their other uses, such as livestock feed and the production of industrial products. The EPA has previously argued that if there are limited quantities of biofuel feedstocks available, increasing the amount used for biofuel will divert these feedstocks from other uses (EPA, 2018). Feedstock switching is bad when low-cost substitute feedstocks such as palm oil, which is associated with high GHG emissions from land use change (EPA, 2012), replace other BBD feedstocks, lowering GHG reduction benefits. In particular, rising U.S. soybean oil prices, which are likely a result of increased demand for soybean oil in BBD production, have been found to drive higher U.S. imports of palm oil (Santeramo & Searle, 2019). Consequently, the amount of BBD that can be produced in the United States without increasing diversion effects on other uses should be one of the crucial factors that the agency considers in future volume rulemakings.

This study provides insights for the EPA in setting future volumetric obligations for BBD as well as advanced biofuel and total renewable fuel categories. Brorsen (2015) and Nelson and Searle (2016) assessed the availability of feedstocks for U.S. domestic BBD production, factoring in the volumes consumed in other existing uses. This study is an update to Nelson and Searle (2016) and expands the outlook for BBD feedstock availability through 2032.

Data and methodology overview

Within the framework of the RFS, BBD includes both biodiesel and renewable diesel made from fats, oils, and greases (FOGs). Though produced differently—transesterification for biodiesel and hydroprocessing for renewable diesel—they typically share the same feedstocks. As renewable diesel processes are typically more expensive than biodiesel production, biodiesel accounts for the majority of BBD in the United States and is approximately seven times that of renewable diesel (EPA, 2018).

The annual volumes of feedstocks used for U.S. biodiesel production from 2010 through 2018 from the U.S. Energy Information Administration (EIA) are shown in Figure 2. Feedstock inputs to biodiesel production in the United States surged almost six-fold from 2.5 billion to 14.3 billion pounds a year from 2010 to 2018. The most common seven feedstocks used for biodiesel production in the U.S. are vegetable oils from soybeans, canola, and corn; rendered products of the animal fats tallow, white grease, and poultry fat; and yellow grease, which is mainly used cooking oil (EIA, 2019). In 2018, soybean oil contributed to more than half of total biodiesel production, followed by corn oil, canola oil, and yellow grease. We are not able to find publicly available data on the feedstock inputs to renewable diesel production, but the types of feedstock are likely to be similar to biodiesel production.

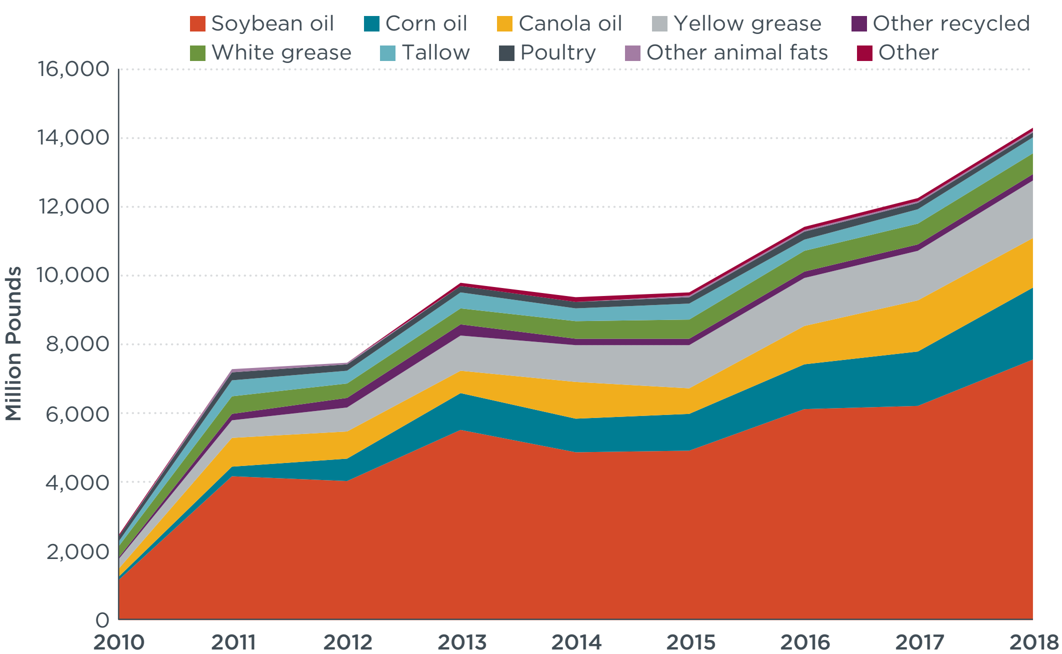

Figure 2. Feedstock inputs to biodiesel production in the United States. Source: EIA, 2019. Note: In case of undisclosed data, the average value of the year before and after was used or was kept the same as the previous year if no data was available for the year after.

In this study, we assess the future availability of the seven major FOGs for use in domestic BBD production through 2032. Feedstock availability for BBD production in the U.S. is estimated by subtracting non-BBD consumption and net exports from domestic feedstock production. Using the historical production, consumption, and trade data of each of the seven FOGs between 2000 and 2018 listed in the appendix, feedstock production, consumption, and trade are projected for the years 2019–2032. To do this, we draw from official projections, assume constant historical rates, or extrapolate historical data linearly or proportionally to future market trends, derived from both qualitative and quantitative data.

Details of data and analysis by feedstock are presented along with our findings in the following section, but we note several caveats. First, missing historical data and future projections are estimated with best available evidence. Second, we assess only the seven major FOGs used for BBD production, so future total BBD feedstock availability might change if other feedstocks become more prevalent. Third, this study mainly uses linear models and does not attempt to capture the complex interlinkages among feedstocks and sectors that are usually represented in economic models.

Production, non-BBD consumption, and availability of Seven FOGs

Overview

The projected domestic production and non-BBD consumption of the seven FOGs between 2018 and 2032 are shown in Figure 3. The shaded area between the upper and bottom lines represents feedstock availability for BBD production in the United States. Soybean oil is on a different scale from the others because it is more than five times the size of the next-largest, corn oil and tallow. We expect the domestic production of most FOGs to increase in the future, with the exception of corn oil. The analysis indicates that the non-BBD consumption of these seven FOGs will grow as well, but to different extents.

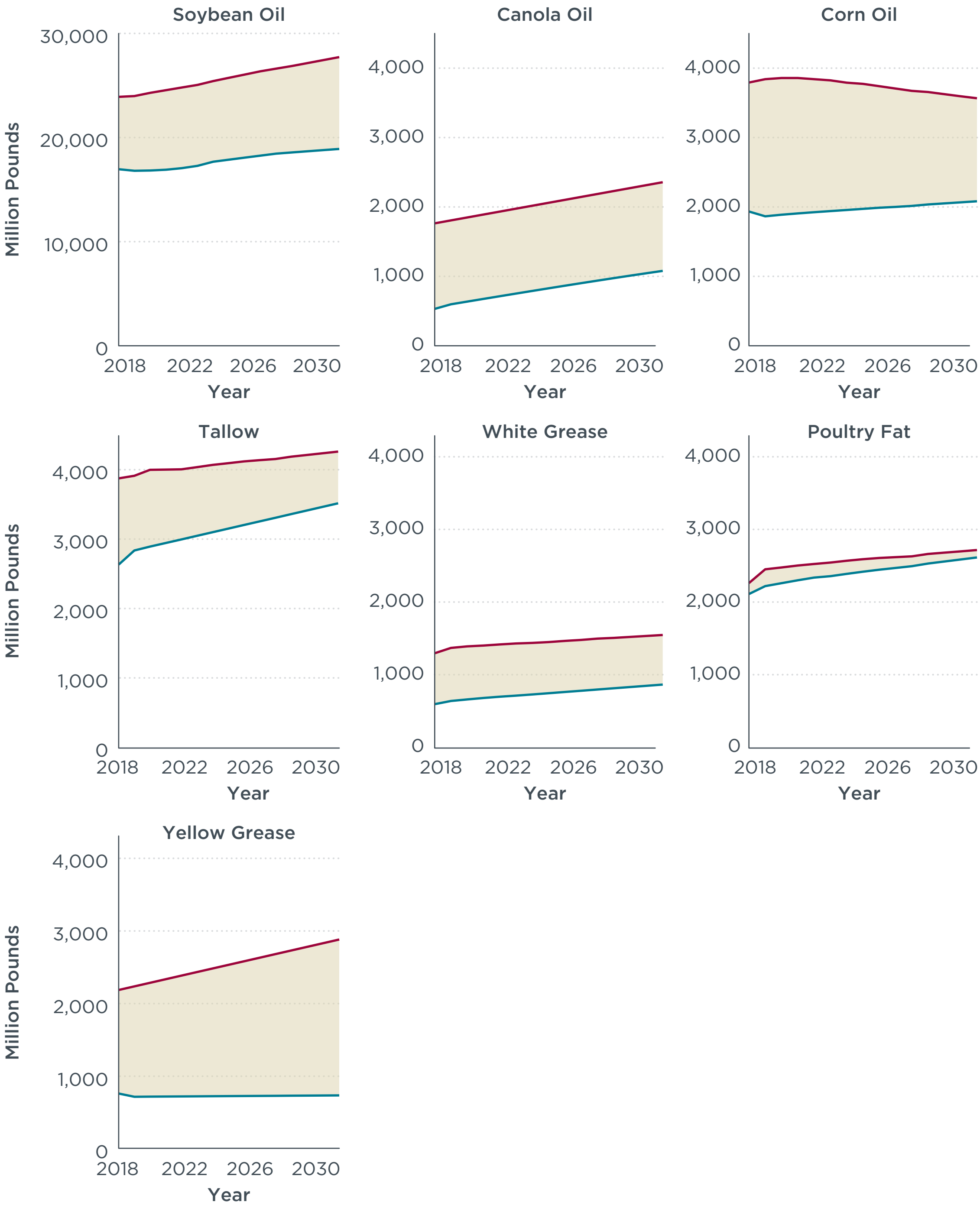

Figure 3. Production (upper line) and non-BBD consumption (bottom line) of seven FOGs. Shaded area represents the availability for BBD production in the U.S.

Table 1 provides an overview of existing uses for potential BBD feedstocks. Industrial products that could be made from FOGs include soap, paint, and lubricants. Some FOGs are used in livestock and pet food. Trading also impacts the availability of some FOGs.

Table 1. End uses of each feedstock analyzed in this study

Feedstock	Edible product	Livestock feed	Industrial products	Pet food	Export/Import
Soybean oil	✓		✓		✓
Canola oil	✓		✓		✓
Distillers corn oil		✓			
Inedible tallow		✓	✓	✓	✓
White grease		✓	✓	✓	✓
Poultry fat		✓		✓	✓
Yellow grease		✓	✓		✓

We make three clarifications regarding Table 1. First, only the inedible parts of corn oil and animal fats are analyzed in this study. Second, soybean and canola oil are valuable in livestock feed, but typically whole oilseeds are used. Since only pressed-out oil is typically used for BBD production, the oil content in the whole oil seeds is not counted in the assessment. Third, though technically different, trade balance is treated as a part of non-BBD consumption during analysis. Positive net exports means less of the feedstock is available for domestic BBD, while negative net exports means there is more of the feedstock available.

Figure 4 displays total non-BBD consumption from the seven FOGs by end use between 2018 and 2032. Non-BBD consumption is generally increasing over time. In most cases, we assume that consumption in edible products and livestock feed increases with growing population and livestock production. Qualitative evidence also indicates that the demand for FOGs in industrial products and pet food is most likely growing. Projections on exports and imports are from published sources or assume historical averages if no information is available.

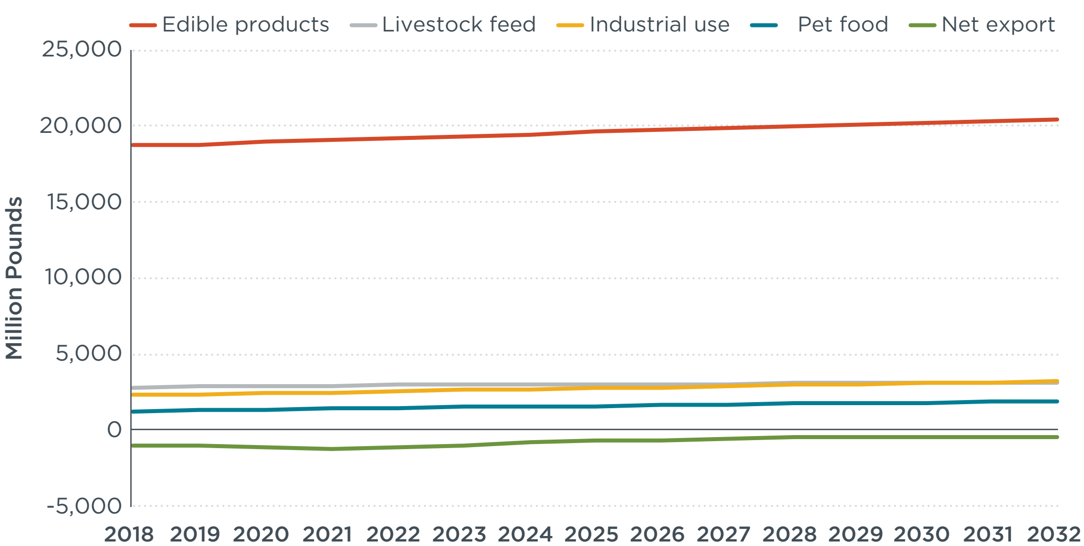

Figure 4. Non-BBD consumption of the seven FOGs by end use (million pounds)

Soybean oil

Key finding: The growth of soybean oil production in the United States has outrun its increasing use for food, industrial products, and net exports, leading to an increase of 1.9 billion pounds, or 27%, of soybean oil available for BBD production cumulatively from 2018 to 2032.

We collect historical U.S. soybean oil production data from the *Oil Crops Yearbook* (USDA, 2019a). The *USDA Agricultural Projections to 2028* (USDA, 2019b) estimates domestic soybean oil production from 2019 to 2028. For years after 2028, we use a linear extrapolation of the 2019–2028 USDA projection. As shown in Figure 3, the production of soybean oil is expected to grow as a result of yield increases (USDA, 2019b).

The end uses of soybean oil include consumption in food and industrial products. The *Production, Supply and Distribution* website (USDA, 2019c) provides historical food and industrial consumption. About 60% of the soybean oil produced in the United States is used in human food, 3% in industrial products, and the rest in biodiesel or for export (USDA, 2019c). We assume that future consumption of soybean oil in food will increase proportionally with national population growth as estimated by the U.S. Census Bureau (U.S. Census, 2017).

Detailed data on each FOG in each industrial use is unavailable. However, we do have two sets of historical data: (a) use of all combined FOGs in each type of industrial use from Census Bureau data and (b) the total industrial use of each FOG, from various sources including the USDA and the Census. We first investigate the growth rate of each industrial product's market, which is used to project how the use of all FOGs in industrial products will change in the future. We then distribute it proportionally to the five FOGs.

The Census Bureau provides six categories of industrial products where FOGs were used from 2000 to 2010: fatty acids, soaps, paint and varnish, resins and plastics, lubricants and similar oils, and other inedible products.

The soap industry is expected to expand at a compound annual growth rate of 2.1% from 2016 to 2024, while the lubricant industry will grow with a compound annual growth rate of 2.9% from 2015 to 2022 (Transparency Market Research, 2018; Global Market Insights, 2016). We estimate the amount of FOGs in these two industrial products using the collected growth rate and apply linear extrapolation for years beyond the projection period. Detailed published projections of the future growth rate of fatty acids and plastics could not be found, but the Census data shows a growing trend in the past, and studies suggest that they are expected to continue to grow in the near future (Tsagaraki, 2016). Therefore, a linear extrapolation of historical data is applied for future projections. As publicly available market information was not found for paint and other inedible FOG categories, and there was no clear trend from the historical data, consumption in future years for these two categories is kept constant as the historical average. The projected values of the six product categories is used to estimate the overall growth of FOGs used in industrial products (Figure 4).

The projected total consumption of FOGs in industrial uses in each future year is then distributed proportionally to the five FOGs, based on the historical consumption of each FOG in industrial products. However, it should be noted that the historical contribution of each feedstock may not hold true in the future as manufacturing processes and consumer preferences change. For instance, some studies have identified a trend of vegetable oils replacing animal fats in oleochemical products (Salimon et al., 2010; Tsagaraki, 2016).

We take historical import and export data on soybean oil from the *Oil Crops Yearbook* (USDA, 2019a) and future trade projections from the *USDA Agricultural Projections to 2028* (USDA, 2019b). According to the U.S. Department of Agriculture (USDA), global soybean oil demand is growing as a result of income and population growth in North Africa, the Middle East, and Latin America. The United States has been and is expected to continue to be one of the major exporters of soybean oil, following Argentina and Brazil (USDA, 2019b). The USDA projects that annual U.S. exports of soybean oil will decrease slightly from 1.9 billion pounds in 2019 to 1.75 billion pounds in 2021, then increase to 2.45 billion pounds by 2028. The USDA projects that annual U.S. imports of soybean oil will remain constant at 0.3 billion pounds from 2018 to 2028 (USDA, 2019b). We assume that net exports beyond 2028 will be the same as the USDA projection for 2028, acknowledging that imports and exports are unlikely to remain constant. However, we do not make our own trade projections due to uncertainties in trade policies. Moreover, soybean oil is the only feedstock for which the USDA projects trade, so historical average net exports are used for the remainder of the feedstocks. As a result, the changes in net exports over time for total FOGs in Figure 4 are solely driven by changes in soybean oil.

Soybean oil is the most commonly used feedstock for biodiesel production in the United States, contributing to more than half of current production (Figure 2). After accounting for non-BBD consumption and net exports, we expect availability of soybean oil for BBD production to increase by 0.13 billion pounds annually on average, reaching 8.8 billion pounds in 2032. This amount is consistent with the projection in the *USDA Agricultural Projections to 2028* (USDA, 2019b).

Canola oil

Key finding: Domestic production of canola oil is expected to increase as is its use in food and industrial products. Canola oil availability for BBD will decrease in 2019 and then increase slowly, by 45 million pounds, or 4%, cumulatively in 2032 compared with 2018.

Historical production of canola oil is retrieved from the *Oil Crops Yearbook* (USDA, 2019a). Although there have been minor fluctuations from year to year, domestic canola oil production is generally increasing, though with slower growth after 2013. We assume future production to follow the same trend, extrapolating the 2013–2018 data linearly.

More than 70% of produced and imported canola oil is used in food, while 2% goes to industrial uses and the rest to biodiesel production and export. Using historical food and industrial consumption (USDA, 2019c), we assume that future consumption of canola oil in food will increase proportionally with national population growth (U.S. Census, 2017) and that its use in industrial products will contribute proportionally to overall market growth, as described in detail in the section on soybean oil.

The United States has been a net importer of canola oil with import volume increasing and exports decreasing. As trade projections for canola oil are not available, we use the average net export from the previous five years (USDA, 2019a) to represent 2019–2032 data.

Canola oil contributes to about 10% of U.S. biodiesel production (Figure 2). Our projection suggests that canola oil availability for U.S. BBD production will increase slightly after 2019, by 5 million pounds annually on average, reaching 1.3 billion pounds in 2032.

Distillers corn oil

Key finding: Domestic production of distillers corn oil (DCO) is projected to peak around 2020. Meanwhile, DCO consumption in livestock feed is likely to increase, leaving less of it available for BBD production in the United States. The 2018–2032 decrease will total 0.37 billion pounds, or 20%.

DCO that is used for making BBD is a by-product of ethanol production. The material is distinct from food-grade corn oil, which is pressed out of corn before the corn is used for any other purpose. The quantity of corn inputs in ethanol plants, the share of ethanol plants that collect DCO, as well as DCO yield determine the production of DCO. We collect historical data of corn inputs to ethanol plants from the *U.S. Bioenergy Statistics* (USDA, 2019e) and the 2019–2028 data from the *USDA Agricultural Projections to 2028* (USDA, 2019b). The USDA projects that corn-based ethanol production is likely to increase slowly until 2020, consuming 5.73 billion bushels of corn, and then decline continuously to consume 5.45 billion bushels of corn in 2028. This will reflect the combined effects of the ethanol blend wall in conjunction with falling gasoline consumption (USDA, 2019b). We linearly extrapolate the 2021–2028 USDA projection to estimate corn inputs to ethanol plants after 2028.

Approximately 0.75 of a pound of DCO is pressed out of each 56-pound bushel of corn input to ethanol mills (Renewable Fuels Association, 2019). We corroborate this number using the estimated corn input data and the 2015–2018 DCO production data (USDA, 2019d). This ratio along with our projection of corn input to ethanol mills is used to estimate future DCO production in the United States. Although this conversion percentage might change in the future because of technology innovations, in this study it is kept constant for all future years.

As shown in Figure 3, DCO production follows the USDA's projected corn inputs in ethanol plants, which decrease after 2020. However, it is possible this projection will not hold true under new policy developments. For example, the Reid Vapor Pressure restriction on summer E15 use has been relaxed (EPA, 2019a). Furthermore, it is possible that fuel efficiency rules might be eased or rolled back, influencing the quantity of nationwide gasoline consumption and the limitations placed by the ethanol blend wall. Therefore, it is possible that DCO production will decline less than this study estimates.

As historical annual data on DCO for non-BBD consumption was not available, these values are estimated based on best available information. In the United States, the only major use of DCO in addition to BBD production is in livestock feed, accounting for about 51%, and other uses are minimal (U.S. Grains Council, 2018a; RFA, 2019). Due to its high metabolizable energy and high content of unsaturated fatty acid, DCO is primarily used in poultry and swine feed (U.S. Grains Council, 2018b). We assume that the historical amount of DCO used in livestock feed will change proportionally with swine and poultry production. Historical swine and poultry production from the *Livestock & Meat Domestic Data* (USDA, 2019f) is used to calculate the average per livestock consumption of DCO. The USDA projects that swine and poultry production will grow reflecting low feed cost and greater global demand (USDA, 2019b), and linear extrapolation of 2019–2028 data is used to estimate production after 2028. The calculated historical per livestock DCO consumption rate is applied to future livestock production to estimate aggregate DCO consumption in feed. Since the imports and exports of DCO are minimal (U.S. Grains Council, 2018) and no trade data is available, we do not factor in net exports of DCO.

DCO currently is the second-largest contributor to U.S. biodiesel production at about 15% (Figure 2). However, its share of overall BBD production is projected to decline, as we estimate that after increasing slightly in 2019, its availability would decrease by 38 million pounds annually on average, dropping to 1.5 billion pounds in 2032.

Inedible tallow

Key finding: Although inedible tallow production is likely to increase, we also expect its non-BBD use in livestock feed, industrial products, and pet food to increase to a greater extent. This is projected to reduce the availability of inedible tallow for BBD production by 0.5 billion pounds from 2018–2032, or 40%.

Tallow is animal fat from cattle, some of which is edible by humans and some is inedible. We expect edible tallow to be used preferentially in food and therefore analyze the availability only of inedible tallow for BBD production in this study. We estimate domestic production of inedible tallow between 2016 and 2018 from the *Fats and Oils: Oilseed Crushings, Production, Consumption and Stocks Annual Summary* (USDA, 2019g) and from the annual U.S. Market Report issue in Render magazine (National Renderers Association, 2019) for the years before 2016. We assume that future inedible tallow production will change in proportion to beef production (USDA, 2019f). USDA 2019–2028 beef production projections (USDA, 2019b) are used and extrapolated linearly through 2032. The USDA expects slow growth of beef production over the next 10 years based on rising slaughter weights, although the number of cattle is expected to drop (USDA, 2019b).

Tallow that is inedible for humans is used in livestock feed, industrial products, and pet food (Table 1). Data from the Census Bureau (2011) indicates that about 10% of inedible tallow is used in livestock feed, 35% in industrial products, and the rest for biodiesel and trade. According Informa Economics (2011), 49% of U.S. inedible tallow for feed goes to cattle, followed by swine (30%) and poultry (21%). The USDA projects that the production of cattle, swine, and poultry would all increase in the future mainly due to low feed costs. We therefore assume that inedible tallow used in livestock feed would grow proportionally (USDA, 2019b). We assume that the quantity of inedible tallow used in industrial products will increase following overall market trends for those products. Detailed methodology behind that assumption can be found in the soybean oil section.

Although we could not find historical data on the amount of inedible tallow used in pet food, Informa Economics (2011) puts it at 9.2%. We apply this percentage to inedible tallow production to estimate the historical inedible tallow consumed in pet food. For future projection, we assume that demand for inedible tallow in pet food will change with the pet food market, which is expected to grow at a compound annual growth rate of 3.36% between 2017 and 2022 (Zion Market Research, 2017), so we assume the same growth rate for inedible tallow use in pet food over this period and apply a linear extrapolation for years after 2022. Historical data on imports and exports of inedible tallow (National Renderers Association, 2019) are also considered in our projections. The United States is a net exporter of inedible tallow, although exports are declining and imports are increasing. We use the average net export from the previous five years for all future years.

Inedible tallow currently contributes to about 3% of U.S. BBD production, while we predict its availability will decline from 2018 by about 36 million pounds annually to 0.75 billion pounds in 2032.

White grease

Key finding: Production of white grease is likely to increase, and use of white grease in livestock feed, industrial products, and pet food will also expand. We project that white grease availability for BBD production will rise slightly in 2019, followed by a decline through 2032. We estimate the availability in 2032 to be 18 million pounds, or 3% lower than the availability in 2018.

White grease is the inedible part of swine fat. As in this study's approach for inedible tallow, we use the historical production of white grease from the USDA for 2016–2018 (USDA, 2019g) and Render magazine for 2013–2015 (National Renderers Association, 2019). Future production of white grease is assumed to increase proportionally with pork production. Historical pork output from the USDA has generally shown an increasing trend, and the USDA projects the growth will continue, reflecting increased slaughter weights and industry commercialization (USDA, 2019f; USDA, 2019b). The historical ratio of white grease to pork production is applied to the USDA projection of pork production to estimate future output of white grease.

While white grease is known to be used in livestock feed, industrial products, and pet food, publicly available data on these uses is lacking. Informa Economics (2011) provides a percentage distribution of white grease in different end uses (Table 2). According to Informa Economics (2011), pet food at 36.5% is the number one use of white grease, followed by livestock feed at 26.4%. Industrial consumption accounts for less than 10% of white grease. To identify the relative shares of nonbiodiesel white grease uses, historical white grease use in biodiesel (EIA, 2019) and import and export data (National Renderers Association, 2019) are subtracted from total historical white grease production (USDA, 2019g). From there, we then estimate the relative shares of livestock feed, industrial products, and pet food, shown in Table 2. With the estimated historical consumption for each end use, the rest of the analysis is the same as for inedible tallow. Unlike tallow, 68% of white grease in feed goes to swine, 28% to poultry, and 3% to cattle (Informa Economics, 2011). In short, we assume white grease use in livestock feed will increase, corresponding to growth in cattle, swine, and poultry production. White grease use in industrial products and pet food will rise to meet higher market demand. The import of white grease tends to be greater than exports; we assume that future net exports of white grease will be consistent with the previous five-year average (National Renderers Association, 2019).

Table 2. Percentage distribution of white grease in each end use from Informa Economics (2011) and calculated relative shares of livestock feed, industrial products, and pet food.

	Livestock feed	Industrial products	Pet food	Biofuel	Export
Percentage distribution for each use	26.4%	6%	36.5%	24%	7.1%
Calculated share	38.3%	8.7%	53%	-	-

White grease currently contributes to roughly 4% of U.S. biodiesel. We project that the availability of white grease will increase slightly in 2019, then decline by about 4 million pounds each year to 0.68 billion pounds in 2032, which would be slightly lower than current availability.

Poultry fat

Key finding: Poultry fat production will increase through 2032, but its consumption in livestock and pet food will also rise, reducing its availability for BBD production by 49 million pounds, or 32%, in total from 2018 to 2032.

As with other animal fats, we assume the production of poultry fat will expand as poultry production climbs (USDA, 2019b). Poultry fat is used in livestock and pet food (Table 1). As in our analysis of white grease, we apply a rescaled percentage distribution from Informa Economics (2011) to the amount of domestic nonbiodiesel poultry fat consumption to estimate historical use of the material in livestock and pet food. We estimate that more than 73% of poultry fat in domestic nonbiodiesel uses is for livestock feed and about 27% for pet food. Poultry feed accounts for almost 90% of poultry fat uses in livestock feed, followed by swine at 6% (Informa Economics, 2011). We assume these two non-BBD uses of poultry fat will increase proportionally with the growth in livestock production (USDA, 2019b) and the pet food market (Zion Market Research, 2017). According to National Renderers Association (2019), the United States is a net exporter of poultry fat, and trading volume has been relatively constant for the past several years, so we take the average of the previous five years' net export data for a projection of future years.

We find that poultry fat is not a significant source of biodiesel production in the U.S., amounting to about 1%. Based on our analysis, its availability is likely to decrease by 10 million pounds a year to 0.1 billion pounds in 2032.

Yellow grease

Key finding: We expect production of yellow grease, or used cooking oil, to increase and its consumption in livestock feed and industrial products to grow as well, but only slightly. We estimate growth in yellow grease availability for BBD production of 0.72 billion pounds, or 51%, collectively from 2018 to 2032. This result suggests that yellow grease has the potential to surpass corn oil and become the second-largest feedstock for BBD production in the U.S.

Yellow grease is the third-largest source of biodiesel output in the U.S., accounting for 12% of production (EIA, 2019). There are many sources of used cooking oil, including home kitchens, but it is not practical to collect the material from smaller, decentralized sources, and for this feedstock, collection is an important consideration. Yellow grease is usually gathered from restaurants; as of 2011, about half of restaurants in the U.S. collected it (Informa Economics, 2011). Available quantities of yellow grease has generally shown an increasing trend since 2003 (2003–2010 data from U.S. Census, 2011; 2016–2018 data from USDA, 2019g[1]). We assume that the rising trend will continue and apply a linear extrapolation to historical production data to estimate future yellow grease production in the United States.

The analysis of yellow grease consumption follows the same methodology as for white grease and poultry fat by applying the relative shares of nonbiodiesel end-uses for yellow grease from Informa Economics (2011) to the nonbiodiesel and trading share of overall production. The Informa Economics study suggests that 1.2% of yellow grease is used in pet food; however, we could not find other sources to corroborate this information. In contrast, other studies mention the use of yellow grease in livestock feed

1 Data for yellow grease production between 2011 and 2015 is missing.

and industrial products (Howell et al., 2010; ECOFYS, 2013). Therefore, we exclude this small fraction of pet food in our study and rescale the percentage distribution between livestock feed, 97%, and industrial use, 3%. About 65% of yellow grease in livestock feed goes to poultry and the remainder is relatively equally distributed between cattle and swine (Informa Economics, 2011). We assume that the non-BBD consumption of yellow grease will increase proportionally with cattle, swine, and poultry production as well as with the size of the industrial products market. The United States is a net exporter of yellow grease. Export volume decreased between 2010 and 2015 and increased afterward, while imports have climbed continuously over time. We assume future net exports to be the average of the previous five years.

Our analysis suggests that the production of yellow grease is outpacing consumption. The availability of yellow grease for BBD production is likely to have declined in 2019 but now is projected to rise by 48 million pounds a year, reaching 2.1 billion pounds yearly in 2032.

Availability of FOGs for domestic BBD production

Figure 5 displays the projected volumetric availability of each of the seven FOGs for domestic BBD production between 2018 and 2032, in order of highest to lowest volumes. As shown, total annual availability of the seven FOGs for BBD production in the United States is projected to increase by about 1.5 billion pounds, or 11%, from 2018 to 2032. Our results indicate that the availability of soybean oil, canola oil, and yellow grease is likely to increase, while availability of DCO and animal fats will most likely decline. Moreover, our results suggest that the share of soybean oil in BBD is likely to rise. Specifically, the growth of soybean oil availability between 2018 and 2032 of 1.8 billion pounds exceeds the overall growth of 1.5 billion pounds for the seven FOGs combined.

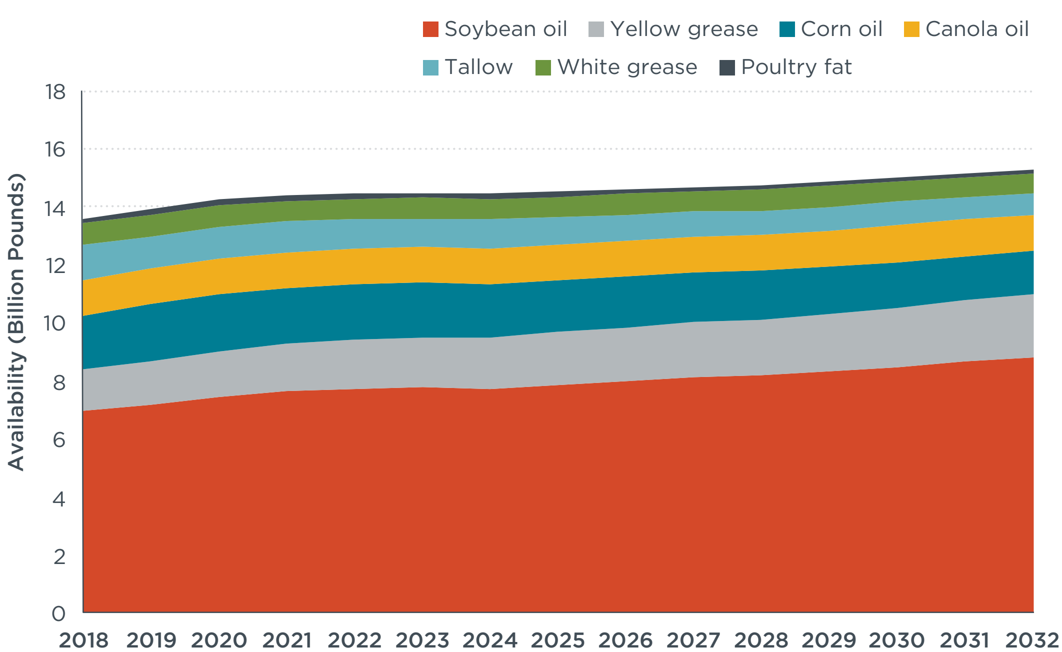

Figure 5. Projected availability of seven FOGs for BBD production in the U.S. (billion pounds)

The converted biodiesel equivalent from volumetric availability of FOGs is shown in Table 3. The conversion factor for soybean and canola oil is 0.13 of a gallon of biodiesel per pound of oil; the other FOGs yield 0.12 of a gallon per pound of oil (Argonne National Laboratory, 2018). The column *Other FOGs* is the sum of other animal fat, other recycled, and other categories from Figure 2 (EIA 2019). We keep this column constant according to 2018 data and add it to the seven FOGs analyzed in the study to get the total available value from all FOGs. The amount of BBD that could be produced from the projected FOGs would increase by an average of 16 million gallons, or 1% annually from 2018 to 2032. We estimate that in 2032 about 1.97 billion gallons of BBD could be produced domestically from available feedstocks. However, this amount is 0.5 billion gallons lower than 2020 and 2021 BBD obligations.

Table 3. Potential BBD production from the estimated feedstock availability of FOGs (million gallons biodiesel equivalent)

Year	Soybean oil	Canola oil	Corn oil	Yellow grease	Tallow	White grease	Poultry fat	Other FOGs	Total
2018	904	160	223	199	149	84	18	41	**1,778**
2019	933	157	237	182	129	88	28	41	**1,795**
2020	970	158	236	188	133	88	26	41	**1,839**
2021	993	158	234	194	127	87	24	41	**1,858**
2022	1,007	159	230	200	121	86	22	41	**1,866**
2023	1,011	159	226	205	119	86	23	41	**1,869**
2024	1,007	160	220	211	116	85	22	41	**1,862**
2025	1,023	160	216	217	113	85	21	41	**1,875**
2026	1,037	161	210	223	110	84	19	41	**1,886**
2027	1,053	162	205	229	106	84	18	41	**1,896**
2028	1,061	162	199	234	102	84	16	41	**1,900**
2029	1,079	163	194	240	99	83	16	41	**1,916**
2030	1,102	164	189	246	96	83	15	41	**1,935**
2031	1,124	165	183	252	93	82	13	41	**1,954**
2032	1,147	166	178	258	89	82	12	41	**1,973**

If the volume requirements for BBD as well as advanced biofuel were to increase in the future, the resulting gap between supply and demand would have to be filled using other feedstocks, which would most likely include palm oil because of its low cost (Searle, 2017). Such feedstock switching could reduce the GHG benefits of the RFS policy, as palm oil is associated with high GHG emissions from land use change (EPA, 2012). Second, it is likely that the United States would have to depend greatly on increased imports of either feedstocks or BBD directly, which could be seen as contradictory to the stated objective of the RFS of improving energy security. The EPA has made a similar argument on feedstock availability and environmental impacts in a past rulemaking:

> *"We expect limited growth in the availability of feedstocks used to produce these fuel types [advanced biodiesel and renewable diesel], absent the diversion of these feedstocks from other uses. In addition, we expect diminishing incremental GHG benefits and higher per gallon costs as the required volumes of advanced biodiesel and renewable diesel increase."* —EPA, 2018

The 2019–2022 projections in this study are different from ICCT's previous estimates (Nelson and Searle, 2016). In general, these two studies use similar sources of data and methods of analysis. In most cases, the discrepancies are mainly caused by the use of updated and more recent historical data. However, there are some methodological differences in this study's treatment of corn oil, animal fats, and yellow grease. Nelson and Searle expected corn ethanol production, and thus output of distillers corn oil, to remain flat. However, the updated USDA projection indicates corn ethanol production will decline after 2020 reflecting a projected decrease in gasoline demand in conjunction with the ethanol blend wall. Nelson and Searle assumed that animal fats in industrial use would remain relatively constant and did not include their use in pet food because of data deficiency, resulting in a finding of rising availability of animal fats. However, we now expect the consumption of animal fats for both of those uses to increase based on recent market studies. Therefore, the non-BBD consumption of animal fats in this study is higher, leading to a finding of reduced availability. Nelson and Searle assumed constant production of yellow grease based on 2010 data, while we now have updated 2016–2018 values and project it to grow linearly in the future.

Conclusions

Building on previous studies, this study expands the outlook for BBD feedstock availability through 2032. The findings provide insights the EPA can use in setting volumetric obligations in future RFS rulemakings.

We assess the availability of the seven most common feedstocks for biomass-based diesel production in the United States without diverting these feedstocks from other existing uses. We project that total potential BBD production from these feedstocks will increase by about 16 million gallons, or 1% a year from 2018 to 2032. We estimate the amount of BBD that could be produced from domestically available FOGs to be 1.84 billion gallons in 2020, increasing to 1.97 billion gallons in 2032, a 13% increase compared with 2018.

The projected volume in 2032 of 1.97 billion gallons of BBD that could be produced from domestically available feedstocks is even smaller than the 2020 and 2021 BBD obligation of 2.43 billion gallons. The gap between BBD availability and the RFS-driven volumes might be even higher as additional BBD could be needed to meet the advanced biofuel obligation, its parent category, reflecting pressure from the ethanol blend wall.

Continued increases in BBD and advanced biofuel volume obligations are likely to add pressure to domestic BBD feedstock markets, leading to price increases and feedstock switching. The overall impact of higher obligations could thus result in significant GHG emissions from the production of low-cost substitute feedstocks. Furthermore, obligated parties in the U.S. would need to increase imports of BBD feedstocks or BBD or both to meet higher obligations. Thus, setting BBD volumes low would enables RFS to meet its stated intention of reducing GHG emissions and improving national energy security.

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Appendix

This section lists the data used in projection of FOGs availability. Nonitalic data are historical data. Data marked with an asterisk are projections from other studies. Italic data are our estimates based on methodologies described in this report.

Table A1. Production, consumption, and trade of soybean oil from 2010 to 2032 in million pounds

Year	Production	Consumption (food)	Consumption (industry)	Consumption (biodiesel)	Import	Export
2010	18,888	13,810	2,738	1,141	159	3,233
2011	19,740	13,636	4,874	4,153	149	1,464
2012	19,820	14,099	4,689	4,042	196	2,163
2013	20,130	13,830	5,077	5,507	165	1,877
2014	21,399	13,920	5,040	4,869	264	2,014
2015	21,950	14,491	5,670	4,908	287	2,243
2016	22,123	13,664	6,199	6,117	319	2,556
2017	23,772	14,242	7,134	6,230	335	2,447
2018	23,910	14,401	8,199	7,542	300	2,200
2019	*23,985	*14,530*	*678*	-	*300	*1,900
2020	*24,295	*14,634*	*699*	-	*300	*1,800
2021	*24,550	*14,738*	*721*	-	*300	*1,750
2022	*24,805	*14,841*	*742*	-	*300	*1,775
2023	*25,055	*14,943*	*763*	-	*300	*1,875
2024	*25,425	*15,044*	*784*	-	*300	*2,150
2025	*25,740	*15,144*	*805*	-	*300	*2,225
2026	*26,050	*15,243*	*827*	-	*300	*2,300
2027	*26,365	*15,340*	*848*	-	*300	*2,375
2028	*26,620	*15,436*	*869*	-	*300	*2,450
2029	*26,873*	*15,530*	*890*	-	*300*	*2,450*
2030	*27,158*	*15,622*	*911*	-	*300*	*2,450*
2031	*27,443*	*15,712*	*932*	-	*300*	*2,450*
2032	*27,727*	*15,800*	*954*	-	*300*	*2,450*

Note: Historical (2010–2018) soybean oil consumption in industry includes the use in industrial products and in biodiesel. We subtract consumption in biodiesel from consumption in industry to derive consumption in industrial products. Estimates after 2018 are consumption in industrial products only.

Sources: USDA, 2019a, for 2010–2018 production and trade data; USDA, 2019b, for 2019–2028 production and trade data; USDA, 2019c, for consumption in Food and Industry; EIA, 2019, for consumption in biodiesel.

Table A2. Production, consumption, and trade of canola oil from 2010 to 2018 in million pounds

Year	Production	Consumption (food)	Consumption (industry)	Consumption (biodiesel)	Import	Export
2010	1,136	3,007	646	246	3,131	511
2011	1,099	2,875	963	847	3,289	664
2012	1,274	3,175	430	790	2,761	475
2013	1,562	3,576	974	646	3,391	262
2014	1,552	4,076	935	1,046	3,692	241
2015	1,588	4,314	1,008	745	3,956	246
2016	1,752	4,561	1,294	1,130	4,406	271
2017	1,654	4,226	1,385	1,452	4,078	232
2018	1,764	4,350	1,301	1,452	4,176	243
2019	*1,806*	*4,290*	*122*	-	*4,062*	*247*
2020	*1,849*	*4,321*	*131*	-	*4,062*	*247*
2021	*1,891*	*4,351*	*139*	-	*4,062*	*247*
2022	*1,933*	*4,382*	*147*	-	*4,062*	*247*
2023	*1,976*	*4,412*	*155*	-	*4,062*	*247*
2024	*2,018*	*4,442*	*163*	-	*4,062*	*247*
2025	*2,060*	*4,471*	*172*	-	*4,062*	*247*
2026	*2,103*	*4,500*	*180*	-	*4,062*	*247*
2027	*2,145*	*4,529*	*188*	-	*4,062*	*247*
2028	*2,187*	*4,557*	*196*	-	*4,062*	*247*
2029	*2,230*	*4,585*	*204*	-	*4,062*	*247*
2030	*2,272*	*4,612*	*213*	-	*4,062*	*247*
2031	*2,314*	*4,639*	*221*	-	*4,062*	*247*
2032	*2,356*	*4,665*	*229*	-	*4,062*	*247*

Note: Historical (2010–2018) canola oil consumption in industry includes the use in industrial products and in biodiesel. We subtract consumption in biodiesel from consumption in industry to derive consumption in industrial products. Estimates after 2018 are consumption in industrial products only.

Sources: USDA, 2019a, for production and trade data; USDA, 2019c, for consumption in Food and Industry; EIA, 2019, for consumption in biodiesel.

Table A3. Corn input to ethanol plants (million bushels), production (million pounds) and consumption (million pounds) of distillers corn oil (DCO) from 2010 to 2028

Year	Corn Input to ethanol plants	DCO production	Consumption (livestock feed)	Consumption (biodiesel)
2010	5,019	-	*548*	112
2011	5,000	-	*723*	304
2012	4,641	-	*897*	646
2013	5,124	-	*1,071*	1,068
2014	5,200	-	*1,245*	977
2015	5,223	2,783	*1,420*	1,057
2016	5,432	3,205	*1,634*	1,306
2017	5,605	3,678	*1,876*	1,579
2018	5,575	3,793	*1,934*	2,085
2019	5,700	*3,841*	*1,865*	-
2020	5,725	*3,858*	*1,888*	-
2021	5,725	*3,858*	*1,907*	-
2022	5,700	*3,841*	*1,924*	-
2023	5,675	*3,824*	*1,940*	-
2024	5,625	*3,791*	*1,956*	-
2025	5,600	*3,774*	*1,972*	-
2026	5,550	*3,740*	*1,989*	-
2027	5,500	*3,706*	*2,001*	-
2028	5,450	*3,673*	*2,015*	-
2029	*5,425*	*3,656*	*2,036*	-
2030	*5,379*	*3,625*	*2,051*	-
2031	*5,334*	*3,595*	*2,066*	-
2032	*5,292*	*3,566*	*2,082*	-

Sources: USDA, 2019e, for 2010–2018 corn input to ethanol plants; USDA, 2019b, for 2019–2028 corn input to ethanol plants; USDA, 2019d, for 2015–2018 DCO production; EIA, 2019, for DCO consumption in biodiesel.

Table A4. Production, consumption, and trade of inedible tallow from 2002 to 2018 in million pounds

Year	Production	Consumption (livestock feed)	Consumption (industrial products)		Consumption (pet food)	Consumption (biodiesel)	Import	Export
			Fatty acids	Other inedible products				
2002	3,690	-	-	-	-	-	-	-
2003	3,704	978	571	46	341	-	-	1,556
2004	3,704	943	606	33	341	-	-	1,610
2005	3,877	1,193	606	-	357	-	-	1,416
2006	3,831	1,099	-	-	352	-	-	1,605
2007	3,809	874	-	-	350	-	-	1,781
2008	3,551	545	702	414	327	-	-	1,548
2009	3,376	397	650	414	311	-	-	1,529
2010	3,299	332	771	414	304	170	-	1,711
2011	3,639	*334*	*1,220*		*335*	431	-	1,319
2012	3,600	*334*	*1,255*		*331*	385	87	1,073
2013	3,596	*334*	*1,290*		*331*	465	82	843
2014	3,391	*324*	*1,324*		*312*	380	86	887
2015	3,313	*330*	*1,359*		*305*	429	96	756
2016	3,500	*343*	*1,394*		*322*	332	112	625
2017	3,668	*353*	*1,429*		*337*	-	155	716
2018	3,875	*362*	*1,463*		*357*	484	272	722
2019	*3,912*	*374*	*1,498*		*367*	-	*144*	*741*
2020	*3,998*	*380*	*1,533*		*382*	-	*144*	*741*
2021	*4,002*	*382*	*1,568*		*397*	-	*144*	*741*
2022	*4,005*	*384*	*1,602*		*411*	-	*144*	*741*
2023	*4,037*	*387*	*1,637*		*426*	-	*144*	*741*
2024	*4,069*	*390*	*1,672*		*440*	-	*144*	*741*
2025	*4,094*	*393*	*1,707*		*455*	-	*144*	*741*
2026	*4,120*	*396*	*1,741*		*469*	-	*144*	*741*
2027	*4,138*	*399*	*1,776*		*484*	-	*144*	*741*
2028	*4,154*	*401*	*1,811*		*498*	-	*144*	*741*
2029	*4,187*	*405*	*1,846*		*513*	-	*144*	*741*
2030	*4,212*	*407*	*1,880*		*527*	-	*144*	*741*
2031	*4,236*	*410*	*1,915*		*541*	-	*144*	*741*
2032	*4,261*	*413*	*1,950*		*556*	-	*144*	*741*

Sources: USDA, 2019g, for 2016–2018 production data; U.S. Census, 2011, for consumption in livestock feed and industrial products; EIA, 2019, for consumption in biodiesel; National Renderers Association, 2019, for production data before 2016 and trade data.

Table A5. Production, consumption, and trade of white grease from 2007 to 2018 in million pounds

Year	Production	Consumption (livestock feed)	Consumption (industrial products)	Consumption (pet food)	Consumption (biodiesel)	Import	Export
2007	1,101				-	-	-
2008	1,172				-	-	1.3
2009	1,154				-	-	2.6
2010	1,127	*297*	*67*	*410*	333	-	4.0
2011	1,260	*266*	*61*	*368*	533	-	5.5
2012	1,255	*331*	*75*	*458*	408	25	3.1
2013	1,251	*301*	*68*	*416*	468	34	1.1
2014	1,233	*282*	*64*	*390*	470	30	1.3
2015	1,322	*273*	*62*	*377*	589	62	0.4
2016	1,368	*293*	*66*	*404*	578	53	0.9
2017	1,306	*254*	*58*	*351*	591	47	1.8
2018	1,295	*252*	*57*	*348*	618	64	0.9
2019	*1,369*	*265*	*60*	*363*	-	*51*	*1*
2020	*1,390*	*269*	*62*	*378*	-	*51*	*1*
2021	*1,401*	*271*	*64*	*393*	-	*51*	*1*
2022	*1,416*	*274*	*67*	*406*	-	*51*	*1*
2023	*1,430*	*276*	*69*	*416*	-	*51*	*1*
2024	*1,437*	*278*	*72*	*428*	-	*51*	*1*
2025	*1,449*	*281*	*74*	*440*	-	*51*	*1*
2026	*1,465*	*283*	*77*	*452*	-	*51*	*1*
2027	*1,478*	*285*	*79*	*464*	-	*51*	*1*
2028	*1,497*	*288*	*81*	*476*	-	*51*	*1*
2029	*1,506*	*291*	*84*	*488*	-	*51*	*1*
2030	*1,520*	*293*	*86*	*500*	-	*51*	*1*
2031	*1,533*	*295*	*89*	*513*	-	*51*	*1*
2032	*1,546*	*298*	*91*	*525*	-	*51*	*1*

Sources: USDA, 2019g, for 2016–2018 production data; EIA, 2019, for consumption in biodiesel; National Renderers Association, 2019, for production data before 2016 and trade data.

Table A6. Production, consumption, and trade of poultry fat from 2010 to 2018 in million pounds

Year	Production	Consumption (livestock feed)	Consumption (pet food)	Consumption (biodiesel)	Import	Export
2010	-	-	-	100	-	-
2011	2,215	*1,428*	*533*	240	-	-
2012	2,260	*1,494*	*557*	176	1.1	32
2013	2,293	*1,523*	*568*	160	0.9	33
2014	2,329	*1,524*	*569*	176	0.9	40
2015	2,400	*1,559*	*582*	197	1.3	36
2016	2,454	*1,583*	*590*	220	1.3	32
2017	2,415	*1,586*	*592*	-	4.2	35
2018	2,261	*1,514*	*565*	133	1.3	33
2019	*2,451*	*1,597*	*588*	-	*2*	*35*
2020	*2,476*	*1,614*	*612*	-	*2*	*35*
2021	*2,503*	*1,630*	*636*	-	*2*	*35*
2022	*2,524*	*1,643*	*660*	-	*2*	*35*
2023	*2,544*	*1,656*	*666*	-	*2*	*35*
2024	*2,569*	*1,671*	*683*	-	*2*	*35*
2025	*2,590*	*1,685*	*699*	-	*2*	*35*
2026	*2,607*	*1,696*	*716*	-	*2*	*35*
2027	*2,618*	*1,703*	*732*	-	*2*	*35*
2028	*2,629*	*1,711*	*749*	-	*2*	*35*
2029	*2,662*	*1,731*	*765*	-	*2*	*35*
2030	*2,680*	*1,743*	*782*	-	*2*	*35*
2031	*2,698*	*1,754*	*798*	-	*2*	*35*
2032	*2,716*	*1,766*	*815*	-	*2*	*35*

Sources: USDA, 2019g, for 2016–2018 production data; EIA, 2019, for consumption in biodiesel; National Renderers Association, 2019, for production data before 2016 and trade data.

Table A7. Production, consumption, and trade of yellow grease from 2003 to 2018 in million pounds

Year	Production	Consumption (livestock feed)	Consumption (industrial products)	Consumption (biodiesel)	Import	Export
2003	1,291	-	-	-	-	-
2004	1,523	-	-	-	-	-
2005	1,472	-	-	-	-	-
2006	1,480	-	-	-	-	-
2007	1,543	-	-	-	-	-
2008	1,696	-	-	-	-	982
2009	1,632	-	-	-	-	968
2010	1,404	-	-	246	-	1211
2011	-	-	-	471	-	1248
2012	-	-	-	670	35	997
2013	-	-	-	1,046	45	796
2014	-	-	-	1,089	38	734
2015	1,920	*153*	*5*	1,254	49	558
2016	2,021	*50*	*2*	1,389	51	631
2017	2,013	*109*	*2*	1,471	85	662
2018	2,187	*111*	*3*	1,668	139	786
2019	*2,237*	*112*	*3*	-	*72*	*674*
2020	*2,287*	*113*	*3*	-	*72*	*674*
2021	*2,336*	*114*	*4*	-	*72*	*674*
2022	*2,386*	*115*	*4*	-	*72*	*674*
2023	*2,436*	*116*	*5*	-	*72*	*674*
2024	*2,485*	*117*	*5*	-	*72*	*674*
2025	*2,535*	*118*	*6*	-	*72*	*674*
2026	*2,585*	*119*	*6*	-	*72*	*674*
2027	*2,634*	*119*	*7*	-	*72*	*674*
2028	*2,684*	*120*	*8*	-	*72*	*674*
2029	*2,733*	*121*	*8*	-	*72*	*674*
2030	*2,783*	*122*	*9*	-	*72*	*674*
2031	*2,833*	*123*	*9*	-	*72*	*674*
2032	*2,882*	*124*	*10*	-	*72*	*674*

Sources: Census, 2011, for 2003–2010 production data; USDA, 2019g, for 2016–2018 production data; EIA, 2019, for consumption in biodiesel; National Renderers Association, 2019, for trade data.