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Renewable Diesel Feedstock Trends over 2011-2022

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The growth in renewable diesel production capacity in the U.S. was dramatic in recent years, with capacity in the last two years expanding by 1.8 billion gallons, or 225 percent (*farmdoc daily*, March 8, 2023). One of the most discussed and debated aspects of the renewable diesel boom is its impact on feedstock markets, such as soybean oil. In a previous *farmdoc daily* article (May 1, 2023), we examined historical feedstock usage trends for the combined total of renewable diesel and biodiesel over 2011 through 2022. Our most recent *farmdoc daily* article (December 11, 2023) article examined feedstock usage trends for biodiesel alone, and found that soybean oil dominated as a feedstock for FAME production. The purpose of today's article is to investigate feedstock usage trends for renewable diesel over 2011 through 2022. This is the 15th in a series of *farmdoc daily* articles on the renewable diesel boom (see the complete list of articles here).

Analysis

The two main types of biomass-based diesel (BBD) fuels used to comply with the U.S. Renewable Fuel (RFS) mandates are "renewable diesel" and "FAME biodiesel." Although renewable diesel and FAME biodiesel are produced with the same organic oils and fats feedstocks, their production process differs substantially, resulting in the creation of two fundamentally different fuels (for details see *farmdoc daily*, February 8, 2023).

Table 1 lists the most common organic oils and fats feedstocks used to produce renewable diesel (this list is the same for FAME biodiesel). The first group consists of vegetable oils that are produced by crushing vegetable seeds, such as soybeans and canola. The second group consists of animal fats that are by-products of slaughtering animals. Yellow grease is a unique type of feedstock because it can be made up of various kinds of fats and oils. A key component of yellow grease is used cooking oil; hence, the category "waste fats and oils." It is not hard to grasp the diversity of fats and oils in yellow grease when one thinks about all the different vegetable oils and animal fats that are used for cooking in retail food businesses. This makes yellow grease something of a catch-all type of feedstock. Lastly, it is important to note that the list of feedstocks in Table 1 is by no means exhaustive.

Table 1. Common Types of Feedstocks Used in the Production of Renewable Diesel

Types	Group
Canola Oil	Vegetable Oil
Corn Oil	Vegetable Oil
Cottonseed Oil	Vegetable Oil
Palm Oil	Vegetable Oil
Soybean Oil	Vegetable Oil
Poultry Fat	Animal Fat
Tallow (Beef)	Animal Fat
White Grease (Pork)	Animal Fat
Yellow Grease	Waste Fats and Oils

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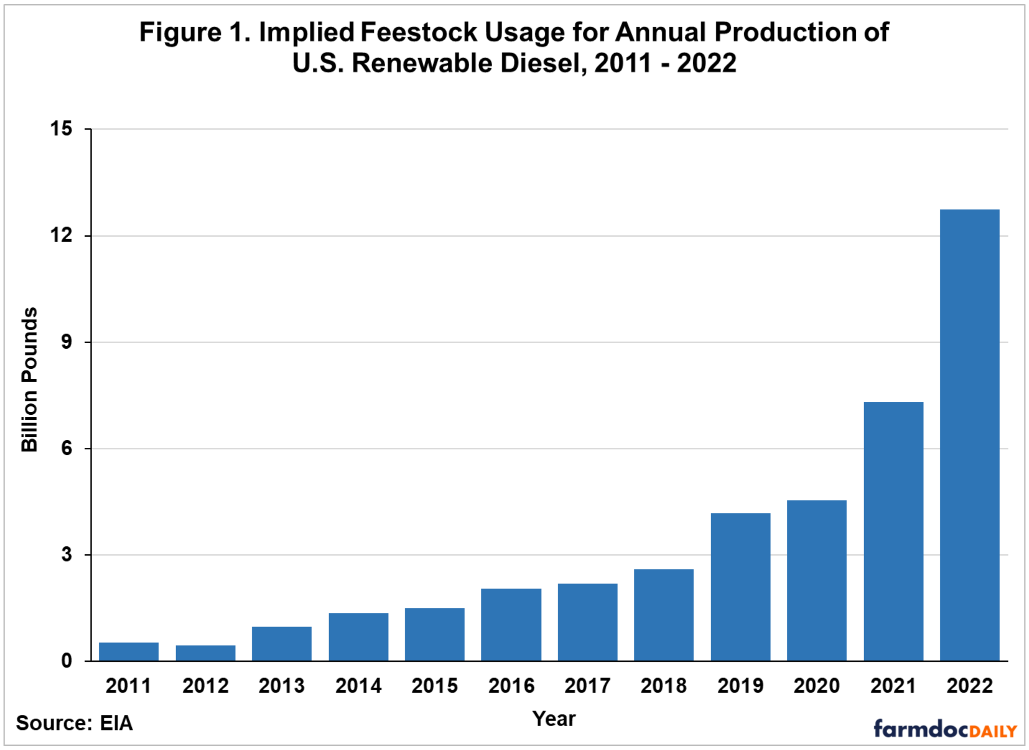
Following our previous *farmdoc daily* articles (May 1, 2023; December 11, 2023), we begin by estimating total feedstock usage for renewable diesel. This is based on benchmark estimates of the pounds of feedstock used per gallon in the production of renewable diesel. Xu, et al. (2022) report that an average of 8.125 pounds of feedstock is used to produce one gallon of renewable diesel, which is the assumption used in our *farmdoc daily* article of May 1st. However, conversations since then with industry sources indicate that 8.5 pounds of feedstock per gallon of renewable diesel is a more widely accepted benchmark. (For example, see the next to last slide in this presentation from Diamond Green Diesel). Therefore, we multiply EIA estimates of monthly renewable diesel production by 8.5 to imply total biodiesel feedstock usage. The monthly production estimates are published by the Economic Information Agency (EIA) of the Department of Energy (DOE) in the Monthly Energy Review over January 2011 through December 2022. We then aggregate to the annual level by summing the monthly feedstock estimates within a calendar year.

Figure 1 presents our annual estimates of implied total feedstock usage over 2011 through 2022 for renewable diesel. The chart highlights the huge increase in feedstock usage that has occurred because of the renewable diesel boom. As recently as 2017 total feedstock usage for renewable diesel was a little over two billion pounds. This surged to nearly 13 billion pounds in 2022, a six-fold increase. Total feedstock usage grew over five billion pounds in 2022 alone. For perspective, the latest USDA WASDE report for December estimates that 61.93 million metric tons, or 136.53 billion pounds, of soybean oil will be produced in the world during the 2023/24 marketing year. Total feedstock used for producing renewable diesel in 2022 represents 9.3 percent of this projection of global production of soybean oil.



The next step of the analysis is to allocate the total feedstock volumes in Figure 1 to the several types of renewable diesel feedstock. This is not a straightforward exercise because, unlike FAME biodiesel, the EIA has never published a full breakdown of renewable diesel feedstock usage. Since there is no EIA data available on renewable diesel feedstock usage prior to 2021, in our earlier article (*farmdoc daily*, May 1, 2023) we estimated renewable diesel shares based on the feedstock shares for biodiesel. Specifically, each year over 2011 through 2020 we computed the percentage of total biodiesel feedstock used for each of the individual feedstock categories found in the Monthly Biodiesel Production Report. We then applied these same percentage shares to the total implied renewable diesel feedstock for that year to estimate volumes of individual feedstock usage for renewable diesel. In particular, we assumed that feedstock shares for renewable diesel and biodiesel were identical over 2011 through 2020. We argued this was the best assumption that could be made. For 2021 and 2022, it was not necessary to make this assumption because the focus of our article was on biomass-based diesel (total of renewable diesel and FAME biodiesel) and the EIA published a full breakdown of feedstock usage for biomass-based diesel in the Monthly Biofuels Capacity and Feedstocks Update.

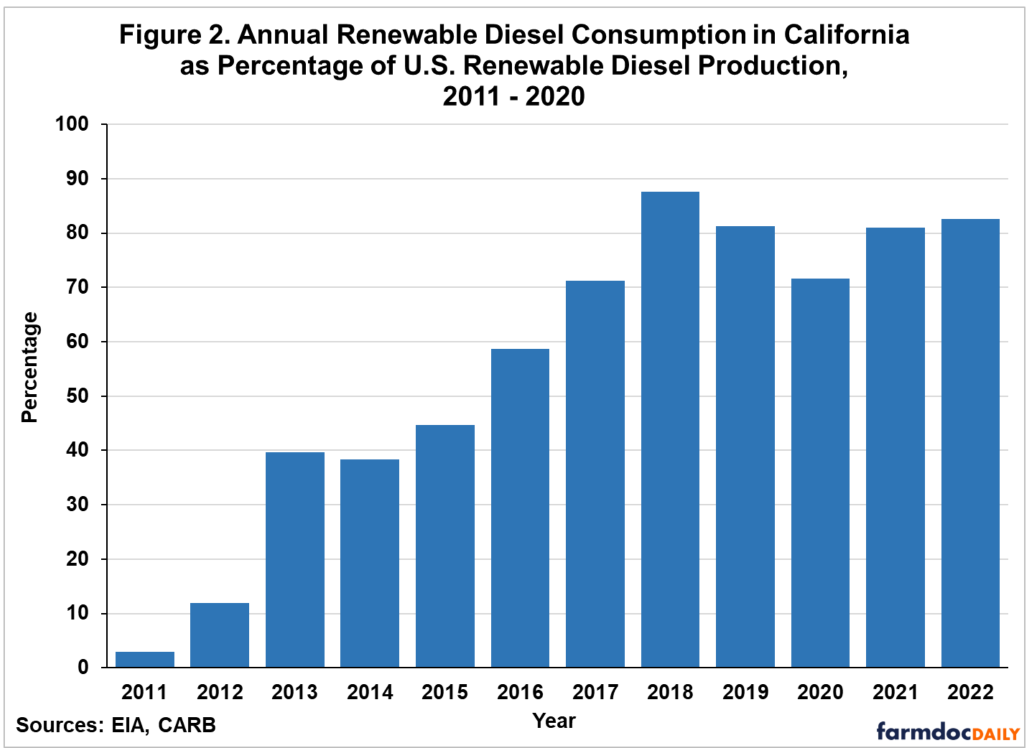
We now believe there is enough data in the public domain and procedures available that can be used to make reasonably accurate estimates of feedstock usage trends for renewable diesel over the entire 2011 through 2022 period. The data and procedures are different for 2011 through 2020 versus 2021 through 2022, so we discuss these two periods separately in the following two sections.

2011-2020 Data and Procedures

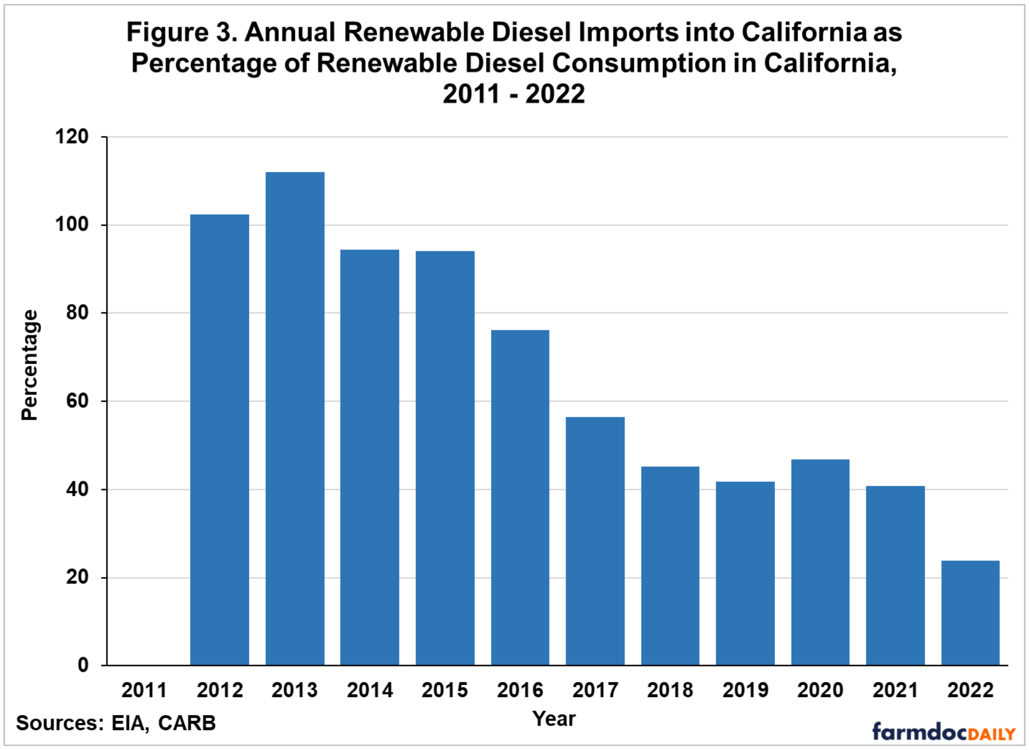
As part of the administration of the Low Carbon Fuel Standard (LCFS) in California, the California Air Resources Board (CARB) tracks the consumption of biofuels by feedstock pathway on a quarterly basis. CARB has reported this data since the LCFS began in 2011. In the case of renewable diesel, the pathways include corn oil, fish oil, soybean oil, tallow, used cooking oil, and other. Tallow was the only feedstock reported from the start of the CARB pathway data in the first quarter of 2011. Fish oil and the other category started in the first quarter of 2013, used cooking oil in fourth quarter of 2014, and corn oil in the first quarter of 2016. The soybean oil feedstock pathway did not start until the third quarter of 2021 when it was broken out of the other pathway. We use the CARB feedstock pathway data to estimate renewable diesel feedstock use over 2011 through 2020.

There are four key issues with using the CARB pathway data to estimate national renewable diesel feedstock use. The first is that the CARB data are reported as gallons of renewable diesel consumed by the type of feedstock used to produce the renewable diesel. This is not a significant problem as we can convert the renewable diesel consumption volumes to pounds of feedstock based on the same conversion factor, 8.5 pounds per gallon, that we employed earlier to imply total national feedstock usage based on U.S. renewable diesel production (see Figure 1).

The second issue is that the CARB data represent consumption of renewable diesel in California, which is obviously not the entire U.S. Fortunately, as Figure 2 demonstrates, California's consumption of renewable diesel is a sizable percentage of total U.S. production in most years over 2011 through 2020. The percentage was small in 2011 and 2012, jumped quickly to around 40 percent in 2013 through 2015, and then continued to rise to more than 70 percent from 2017 onward. The relatively large percentage of U.S. renewable diesel production that is consumed in California means that consumption in California should be representative of the entire country. As a result, a relatively simple procedure can be used to project national feedstock use based on California feedstock use. Each year, total feedstock volume in California can be computed by summing the volumes for individual categories of feedstock use. Percentage feedstock shares can then be computed by dividing individual California feedstock volumes by total California feedstock volumes. The last step is to multiply the California percentage feedstock shares by total implied feedstock usage for the U.S. to obtain U.S feedstock volumes for individual categories over 2011 through 2020. It is important to recognize that this projection method assumes that the composition of feedstock for renewable diesel consumed in California is the same as renewable diesel produced in the entire U.S.



The third issue is that the CARB data are based on renewable diesel consumption not production. Our objective is to estimate feedstock usage for all renewable diesel produced in the U.S. Since renewable diesel consumption can be supplied by domestic production or imports, the CARB consumption data may be problematic given our objective. Figure 3 shows estimates of the percentage of renewable diesel consumption in California represented by imports. Imports were the source for nearly all the renewable diesel consumed in California from 2012 through 2015. (Note that in some years the percentage exceeded 100 because different data sources are used for imports and consumption.) The percentage declined quickly after that as domestic renewable diesel production in the U.S. ramped up. Nonetheless, imports supplied at least 40 percent of renewable diesel consumption in California through 2021.



The specific concern with renewable diesel imports is the possibility that the composition of feedstock usage differs for imports compared to domestic production. EIA company level import data show that only one firm, Neste, supplied all the renewable diesel imports to California from April 2012 through December 2020. We attempted to find data on Neste's feedstock use for imports to California but were unsuccessful. However, the EIA company level import data provide information that is helpful in one specific case. The EIA data show that Neste is the source for all renewable diesel imported into California, and all but an exceedingly small amount is from a single Neste plant in Singapore. Based on this information, we assume that the small amount of renewable diesel reported by CARB in the fish oil pathway is associated with renewable diesel imports by Neste. For the remaining pathway categories, we are forced to assume that the composition of feedstock use for renewable diesel imports into California is the same as renewable diesel production supplied to California by domestic U.S. producers. Fortunately, measurement errors caused by this assumption will be most prevalent in the early years of the sample when imports dominated (see Figure 3) but renewable diesel consumption in California was quite small (see Figure 2).

The fourth issue is that CARB did not start breaking out soybean oil from the other category until the third quarter of 2021. If not addressed, this would mean that we would not have data on soybean oil feedstock use for the entire 2011 through 2020 period, a significant omission given that soybean oil is widely known to be an important feedstock source for renewable diesel. We address this gap using Renewable Identification Number (RIN) generation data collected by the U.S. Environmental Protection Agency (EPA) as part of the administration of the U.S. Renewable Fuels Standard (RFS) program. In the public reporting of RIN generation data, the EPA helpfully provides RIN generation data for some biofuels by feedstock pathway (like the CARB data). One of the RIN breakouts is the annual total of renewable diesel produced using soybean oil. The specific fuel category is non-ester renewable diesel with an RIN equivalence value of 1.7. We collect the annual total of RIN gallons in this feedstock pathway for each year over 2011 through 2020 and convert the annual totals to physical gallons by dividing the RIN gallons by the equivalence value of 1.7. We next convert the physical gallons of renewable diesel to feedstock use by multiplying through by the same assumption we have maintained throughout the analysis of 8.5 pounds of feedstock per gallon of physical renewable diesel. Then, we adjust from the national to the California level by multiplying the U.S. soybean oil feedstock volume by the percentages shown in Figure 2.

The above procedure yields annual estimates of the total pounds of soybean oil feedstock used to produce renewable diesel consumed in California each year over 2011 through 2020. We employ two more steps to break out this total from the other feedstock pathway reported in the quarterly CARB data. The first step is to divide the annual total of soybean oil feedstock estimated above by the annual total of other feedstock reported in the CARB data (after summing the quarterly other category data each year). This provides an estimate of the annual proportion of soybean oil feedstock usage in the other category. The second step is to multiply the annual proportion computed in the first step by the volume of other feedstock reported for each quarter in the same year. The result is a series of quarterly feedstock volumes for soybean oil and a new "other" category over 2011 through 2020 that add up to the volumes for the other category originally reported in the CARB data.

To recap, the following data and procedures are employed to estimate U.S. renewable feedstock usage for 2011 through 2020:

1. Collect quarterly data from CARB on renewable diesel consumption by pathway in gallons. A total of five pathways are reported by CARB: corn oil, fish oil, used cooking oil, tallow, and other. The fish oil pathway is omitted in subsequent steps as it is assumed to be associated solely with imports. The volume of renewable diesel consumption for the remaining four pathways is converted to pounds of feedstock by multiplying volumes by an assumed conversion coefficient of 8.5 pounds of feedstock per gallon of renewable diesel.

2. Collect annual RIN generation data from the EPA for renewable diesel and the soybean oil pathway. Convert the annual RIN totals to physical gallons by dividing the RIN gallons by the equivalence value of 1.7. Convert from physical gallons to pounds of feedstock by multiplying through by the conversion factor of 8.5. Adjust from the national to the California level by multiplying the RIN-derived national soybean oil feedstock volume by the percentage of renewable diesel consumed in California each year. Lastly, break out the soybean oil feedstock usage in California from the other category reported by CARB each year over 2011 through 2020.

3. At this point, quarterly volumes have been derived for the following categories of renewable diesel feedstock in California: corn oil, soybean oil, used cooking oil, tallow, and other. Total volume for each quarter is computed by summing the volumes for these five categories of feedstock use. Percentage feedstock shares are computed by dividing individual California feedstock volumes by total California feedstock volumes.

4. The California percentage feedstock shares are multiplied by total implied feedstock usage for the U.S. to obtain U.S feedstock volumes for the five categories over 2011 through 2020. The used cooking oil percentage share in California is used to project yellow grease feedstock volume nationally. Annual feedstock volumes are computed by summing quarterly volumes.

2021-2022 Data and Procedures

Starting in 2021, the EIA began releasing a new report called the Monthly Biofuels Capacity and Feedstocks Update, and it includes monthly survey estimates of feedstock usage for the combined total of renewable diesel and FAME biodiesel. The EIA also began reporting soybean oil feedstock use for renewable diesel and FAME biodiesel broken out separately starting in January 2022. We used this data in our earlier article on biomass-based diesel feedstock trends (*farmdoc daily*, May 1, 2023). The Monthly Biofuels Capacity and Feedstocks Update also includes feedstock usage for insignificant amounts of other biofuels such as renewable heating oil, renewable jet fuel, renewable naptha, and renewable gasoline. Since the production of these other biofuels is quite small, we treated the feedstock estimates as reflecting only renewable diesel and FAME biodiesel production.

We adopt a straightforward procedure to estimate renewable diesel feedstock usage in 2021, when the EIA does not break usage in any category for renewable diesel and FAME biodiesel separately, and in 2022, when usage is only broken out for soybean oil. The starting point is data on biomass-based diesel feedstock volumes found in the Monthly Biofuels Capacity and Feedstocks Update. This report includes a variety of feedstock categories. We focus on the five largest volume categories—canola oil, corn oil, soybean oil, tallow, and yellow grease—and lump all other volumes into a new aggregate "other" category. We know that the category totals, when not broken out, represent the sum of renewable diesel and FAME biodiesel feedstock use.

In our recent *farmdoc daily* article on December 11th we developed a method to estimate FAME biodiesel feedstock usage over 2021-2022 based on historical feedstock shares from 2011-2020. Since feedstock shares for FAME have been stable historically, we argued that feedstock volumes projected using the historical shares should be reasonably accurate. The procedure adopted here to estimate renewable diesel feedstock usage in 2021 is to simply subtract our earlier estimates of FAME biodiesel feedstock usage from the biomass-based diesel feedstock volumes found in the Monthly Biofuels Capacity and Feedstocks Update. We do the same thing in 2022 for all categories except soybean oil, which is broken out for both renewable diesel and FAME biodiesel in the update. Note that differencing procedure results in a few monthly feedstock volumes for canola oil that are negative. In each of these cases, we substitute an average of the two closest adjacent and positive canola oil feedstock volumes for the negative observations.

The above procedures create a minor adding up issue for 2021 and 2022. Specifically, the sum of the estimated feedstock volumes can differ from the implied total feedstock use for renewable diesel in the U.S. for two reasons. First, the substituted average values for negative canola oil observations causes the sum to differ in those months. Second, substituting actual soybean oil feedstock use for estimated use in 2022 causes the sum to differ as well. Our solution is to allocate the (small) differences proportionally to all categories in 2021 and to the non-soybean oil categories in 2022.

The EIA began releasing the breakout between renewable diesel and FAME biodiesel feedstock usage for canola oil in July 2023. This will be extended to corn oil at some point in the future. The additional data will help improve the accuracy of renewable diesel feedstock usage estimates in the future.

Results

Recall that Figure 1 presents our annual estimates of implied total feedstock usage for renewable diesel in the U.S. over 2011 through 2022. Figure 4 presents our estimates of the allocation of those total implied renewable diesel volumes to individual feedstocks over 2011 through 2022. Note that the height of each bar in Figure 4 is the same as in Figure 1. The only difference is that total feedstock usage is allocated by feedstock type in Figure 2 using the data and procedures discussed in the previous two sections. The estimates show that tallow volume has been quite stable over most of the 2011 through 2022 period. After 2013, the minimum for tallow is 1.1 billion pounds and the maximum is 1.8 billion. Usage for the remaining categories grew rapidly as renewable diesel production boomed. Yellow grease feedstock increased the most, from under 100 million pounds in 2015 to over 4 billion pounds in 2022. Corn oil and soybean oil use also rose rapidly from low levels as recently as 2017 to over 2 and 3 billion pounds, respectively, in 2022. The shifts towards yellow grease and corn oil make sense given the relatively low carbon intensity (CI) scores given to renewable diesel made from these feedstocks in the LCFS program. The lower CI scores translate into higher dollar credit values per gallon.

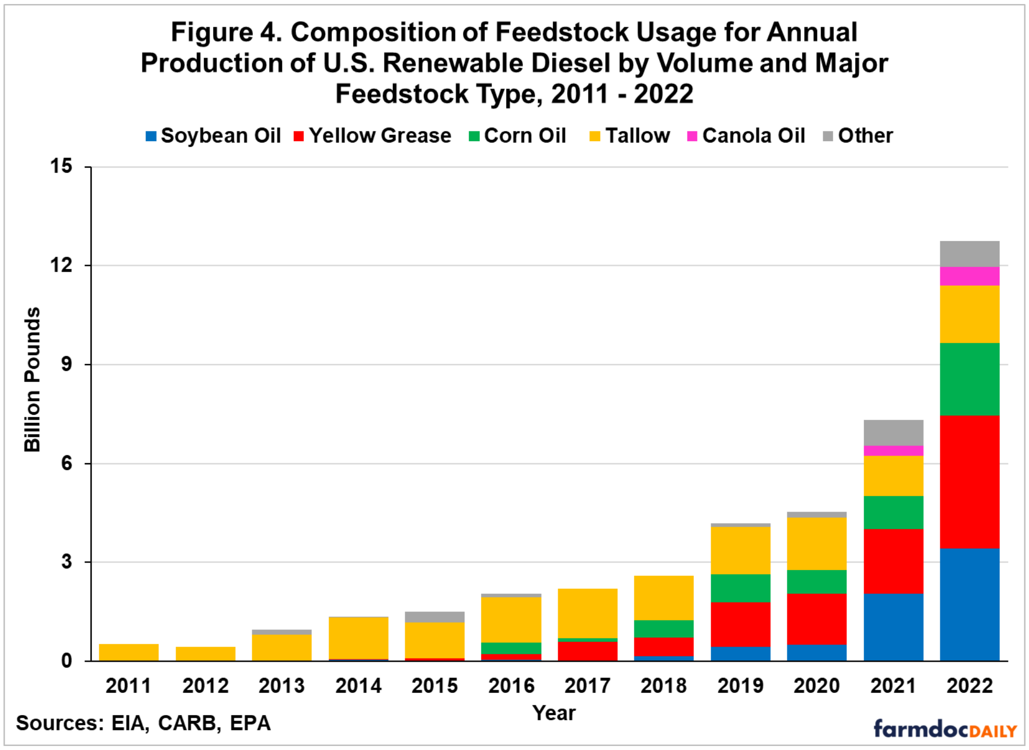


Figure 5 presents the allocation of renewable diesel feedstock usage in percentage terms to provide direct evidence on feedstock market shares. There has clearly been a dramatic change in the composition of renewable diesel feedstock shares since 2011. Shares were dominated by tallow from 2011 through 2018, when the tallow share averaged nearly 80 percent. It should be noted that during these earlier years, the high tallow shares may be influenced by the importance of renewable diesel imports into California. As renewable diesel production and feedstock use increased, yellow grease shares rose in parallel. In 2016, the yellow grease share was only 8.4 percent, but then rose to 31.9 percent by 2019. Soybean oil feedstock shares increased even more rapidly. Almost no soybean oil was used to produce renewable diesel before 2018, yet by 2022 its market share had risen to 26.9 percent. The market share for corn oil was relatively stable after 2016, by comparison. Estimates of canola oil feedstock shares are small and only available for 2021 and 2022 using the data and procedures adopted here. More rapid growth in canola oil market shares is expected in the future given the EPA's approval of this feedstock for RIN generation starting in 2023.

Figure 5. Composition of Feedstock Usage for Annual Production of U.S. Renewable Diesel by Percentage and Major Feedstock Type, 2011 - 2022

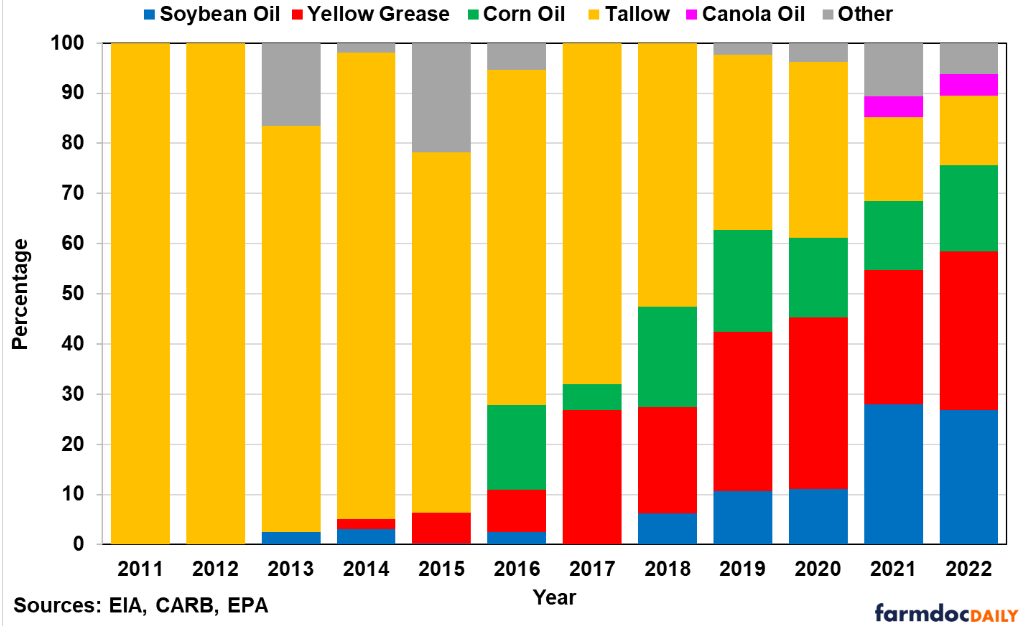


Table 2 provides a summary view of the changes in feedstock shares during the renewable diesel boom. The base for comparison is the average feedstock share during the three years over 2018 through 2020. Earlier years are omitted due to potential measurement error issues discussed previously. The average share over 2021 and 2022 reflects the renewable diesel boom years. Considering the data in this manner highlights the large growth in soybean oil shares during the renewable diesel boom years, mainly at the expense of tallow shares. During 2021 and 2022, the average soybean oil market share increased 18.2 percentage points compared to the average for the previous three years, while the average tallow share decreased by 25.5 percentage points. Yellow grease and corn oil shares changed little during the renewable diesel boom years compared to the immediately preceding years.

Table 2. Average Percentage Shares for Major Categories of Feedstocks Used in the Production of U.S. Renewable Diesel , 2018 - 2022

	Average Market Share (%)					
Period	Soybean Oil	ellow Greas	Corn Oil	Canola Oil	Tallow	All Other
2018-2020	9.3	29.1	18.8	NA	40.8	2.0
2021-2022	27.4	29.1	15.5	4.3	15.3	8.4
Change	18.2	0.0	-3.3	NA	-25.5	6.3

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Finally, it is interesting to contrast the patterns in renewable diesel feedstock usage with those for FAME biodiesel over the same time. In our December 11th *farmdoc daily* article, we showed that biodiesel feedstock shares have been quite stable over time, with soybean oil by far the dominant feedstock type, averaging 55.2 percent of total FAME usage over 2011 through 2022. Neither the dominance of soybean oil nor the stability of feedstock shares was materially impacted by the renewable diesel boom. By comparison, renewable diesel feedstock shares have changed substantially over time, with soybean oil shares rising sharply during the renewable diesel boom and tallow falling substantially.

Implications

This article examines trends in feedstock usage for renewable diesel in the U.S. over 2011 through 2022. There has been a huge increase in feedstock usage because of the renewable diesel boom. As recently as 2017 total feedstock usage for renewable diesel was a little over 2 billion pounds. This surged to nearly 13 billion pounds in 2022, a six-fold increase. Total feedstock usage grew over five billion pounds in 2022 alone. There has also been a dramatic change in the composition of renewable diesel feedstock shares over time. Shares were dominated by tallow during the early years when tallow usage averaged nearly 80 percent. As renewable diesel production and feedstock use increased, yellow grease shares rose. For example, the yellow grease share in 2016 was only 8.4 percent, but rose to 31.9 percent by 2019. The soybean oil share rose even more rapidly, particularly during the boom years of 2021 and 2022. During these two years, the average soybean oil market share increased 18.2 percentage points compared to the average for the previous three years. In terms of individual feedstock market shares, soybean oil has clearly been the biggest winner so far during the renewable diesel boom.

The next article in this series will revisit trends in feedstock usage for biomass-based diesel.

Disclaimer: *The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy. This work was supported in part by the U.S. Department of Agriculture, Economic Research Service.*

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