



Alternative Land-Use Impacts of the Sustainable Aviation Fuel Grand Challenge: Corn Ethanol vs. Soybean Oil Pathways

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Key Points

- The Biden administration, with bipartisan support, has set a goal of increasing sustainable aviation fuel (SAF) production from 16 million gallons today to three billion gallons by 2030.
- Producing three billion gallons of sustainable aviation fuel would require the use of between eight and 11 million acres of corn or 35 and 50 million acres of soybeans, depending on how rapidly crop yields increase over the next six years.
- Corn ethanol appears to minimize the land-use impacts of meeting the administration's SAF goal using agricultural feedstock, but possible emissions from land-use change create substantial uncertainty about the reductions in greenhouse gas emissions from agricultural-feedstock SAF.

The Biden administration's Sustainable Aviation Fuel Grand Challenge could launch the most important national-level biofuel policy of the next decade. Stakeholders and regulators are pressuring airlines to reduce greenhouse gas emissions. However, commercially viable battery and fuel-cell airplanes do not exist yet because the energy needs of commercial flights far exceed current technology. Hence, airlines and policymakers are turning toward alternative liquid fuels that claim to have lower emissions than petroleum jet fuel.

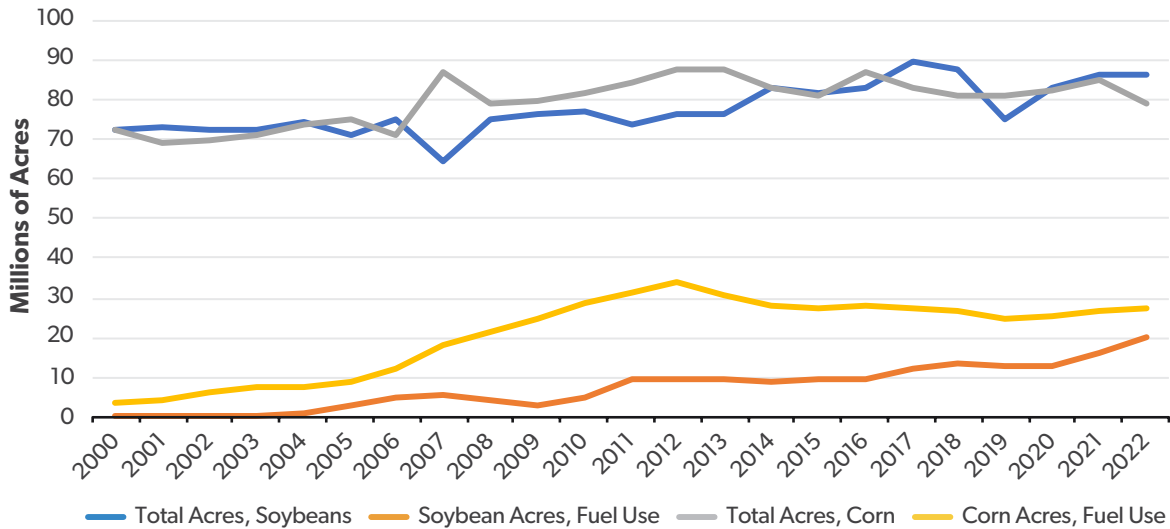
Sustainable aviation fuels (SAFs) are liquid jet fuels produced from feedstock such as plant biomass, waste products, vegetable oils, sugars, and alcohols, including ethanol. The Inflation Reduction Act provides a tax credit of between \$1.25 and \$1.75 for SAF producers, depending on each feedstock's emissions.¹ For a feedstock to qualify, it must have at least a 50 percent emission reduction from petroleum jet fuel. SAFs can be blended up to 50 percent with petroleum jet fuel without

modifying plane engines, and the IRA seeks to enable flights with 100 percent SAF by funding improvements in production methods and logistical infrastructure.² The goal is to boost SAF production from 16 million gallons to three billion gallons by 2030.³

SAFs made from agricultural feedstock appear to be the most viable fuels to scale production dramatically to hit the 2030 target. SAFs can be made from waste products such as beef tallow and used cooking oil, but the potential to scale production using these kinds of feedstock is uncertain given their role as a waste by-product of more valuable commodities.

Also, waste-product feedstock will be in high demand in Europe, as agricultural feedstock is likely to face more political headwinds there. There are already signs that the EU and the US are competing for exports of used cooking oil from China to be converted into biomass-based diesel, an increasing concern for EU policymakers preoccupied with reducing carbon emissions.⁴

Figure 1. Acres of Corn and Soybeans Needed for Fuel Use



Note: Total acres for corn and soybeans come from the US Department of Agriculture’s Foreign Agricultural Service. Soybean acreage for fuel use is calculated using soybean acreage, percentage of total soybean supplies crushed domestically, and percentage of soybean oil used for industrial purposes using historical data from the US Department of Agriculture’s Foreign Agricultural Service. Corn acreage for fuel use is determined using the US Department of Agriculture Economic Research Service’s historical estimates of corn bushels for ethanol and total corn supply and acreage from the Foreign Agricultural Service.

Source: US Department of Agriculture, Foreign Agricultural Service, “Production, Supply, and Distribution Online,” <https://apps.fas.usda.gov/psdonline/app/index.html#/app/home>; and US Department of Agriculture, Economic Research Service, “U.S. Domestic Corn Use,” September 2022, <https://www.ers.usda.gov/topics/crops/corn-and-other-feed-grains/feed-grains-sector-at-a-glance>.

The United States has the industrial capacity and technical knowledge to produce billions of gallons of biofuels, and greater quantities of feedstock can potentially be produced through increasing crop acreage and yield. For these reasons, President Joe Biden claimed during a campaign event in June 2023 that 95 percent of SAFs will be produced using agricultural feedstock.⁵

However, scaling production by increasing acreage is a major concern for many policymakers and environmentalists. The increased demand for corn from the Renewable Fuel Standard (RFS) encouraged farmers to shift millions of acres from the Conservation Reserve Program to corn and soybean production.⁶ The land-use changes driven by the RFS had significant adverse emissions impacts and raised substantive concerns about the emissions benefits of ethanol and other biofuels.⁷ Moreover, increasing demand for biofuels reduces the land available to grow food for human and livestock consumption. For these reasons, ethanol plants may need to lower their emissions to qualify for SAF credits.⁸

Figure 1 illustrates these concerns. Since the creation of the RFS in the mid-2000s, the areas planted to corn

and soybeans have increased by roughly 10 million acres each. This expansion has occurred at the expense of other crops, grassland, and land enrolled in the Conservation Reserve Program.⁹ Before passage of the RFS, the ethanol industry required corn from only four million acres of land to meet its demand for feedstock, but in 2022, ethanol producers needed 27 million acres. The land required to provide corn for fuel use peaked at 34 million acres in 2012. Since then, the required acreage has slowly declined because of stagnating ethanol demand combined with higher corn yields.

The use of soybeans for fuel was close to zero until the passage of the 2005 RFS. Subsequently, biomass-based diesel consumption required about 10 million acres of soybeans and other crops—until 2016, when California revised its implementation of the state’s Low Carbon Fuel Standard. Biomass-based fuels now account for over 50 percent of diesel consumption in California.¹⁰ As a result, soybean acres for fuel use have more than doubled, to about 21 million acres.

A rapid expansion of SAFs could reignite the food-versus-fuel debate and create similar changes in land use for conservation and crop production as

the original RFS policies. To provide context to this debate, policymakers need to know how many corn or soybean acres could be required to meet SAF production goals. Here, therefore, we examine how much corn or soybean acreage would be needed to meet the Biden administration’s goal of producing three billion gallons of SAF with either crop.¹¹

We find that production methods and crop characteristics lead to vastly different results across the two commodities. Producing three billion gallons of SAF using only soybean oil would require around 40 million acres of soybeans. Corn ethanol, on the other hand, requires only around nine million acres to produce the equivalent amount of SAF in 2030. Both pathways require large-scale increases in nonfood uses of agricultural commodities and, by implication, higher crop and food prices. The two crops have different environmental footprints (e.g., corn uses much more nitrogen fertilizer), but the land-use requirements of SAF are substantially lower if met using corn ethanol rather than soybean oil.

Land-Use Scenarios

The Biden administration’s goal of meeting three billion gallons of SAF by 2030 received bipartisan support and funding from Congress in the 2022 Inflation Reduction Act.¹² The amount of agricultural land needed to meet this goal depends on whether the feedstock comes from corn or soybeans. Yields for both crops in 2030 will depend on innovations in crop varieties and the impacts of climate change, which are not currently known with any certainty. Thus, we consider three scenarios for crop yield estimates: low yield, trend yield, and high yield.

The estimated trend yield for both crops assumes that the linear trend in yield growth for each crop from 2004 to 2023 will continue to 2030, with the trend line for each crop estimated using data from the US Department of Agriculture’s Foreign Agricultural Service.¹³ Low- and high-yield scenarios are estimated using the 95 percent confidence intervals around the trend-line forecasts for 2030 for each crop.

Table 1 describes the statistics for estimating the amount of land needed to produce three billion gallons of SAF from soybeans. The 2030 trend-yield forecast for soybeans is close to 54 bushels per acre, with a low-

Table 1. Soybean SAF Statistics for Yield Scenarios

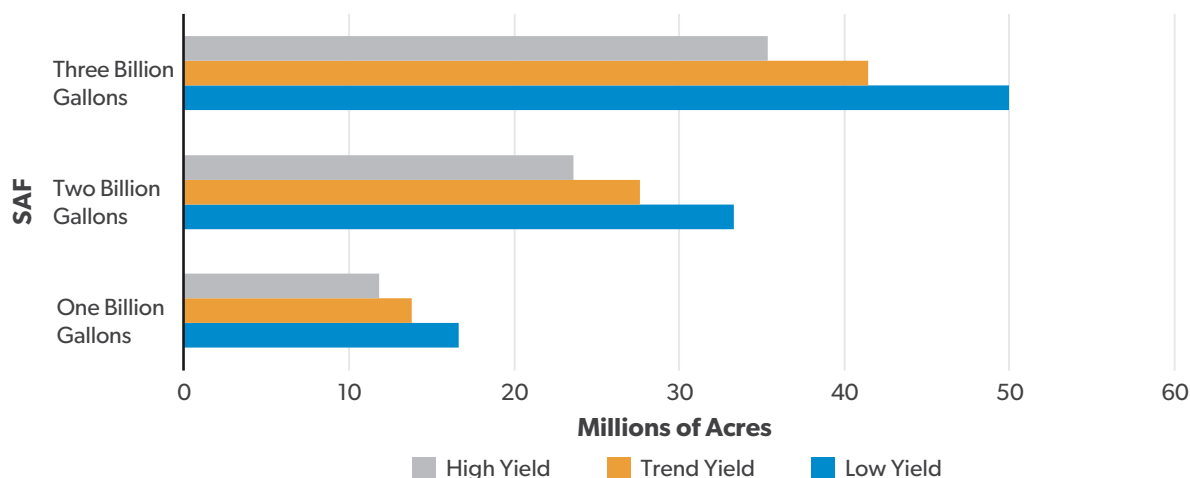
	Low Yield	Trend Yield	High Yield
Yield (Bushels per Acre)	44.86	54.14	63.41
Soybean Oil (Pounds per Acre)	480.01	579.26	678.51
SAF (Gallons per Acre)	60.00	72.41	84.81
Million Acres per Billion Gallons	16.67	13.81	11.79

Note: Trend yield is determined using a linear forecast of the 2004–23 yield trend extended to 2030. The low-yield estimate is the lower bound from the trend-yield forecast’s 95 percent confidence interval, and the high-yield estimate is the upper bound from the same forecast. Authors use 10.7 pounds of soybean oil per bushel and 8 pounds of soybean oil per gallon of SAF for calculations. Source: Authors’ calculations based on yield forecasts and fixed-conversion ratios. Historical yield data from US Department of Agriculture, Foreign Agricultural Service, “Production, Supply, and Distribution Online,” <https://apps.fas.usda.gov/psdonline/app/index.html#/app/home>.

yield forecast of 45 bushels and a high-yield forecast of 63 bushels. A bushel of soybeans produces approximately 10.7 pounds of vegetable oil.¹⁴ SAFs are chemically similar to renewable diesel, which uses 8 pounds of vegetable oil per gallon.¹⁵ Thus, we assume that 8 pounds of vegetable oil are required for each gallon of SAF. In the trend-yield scenario, 72 gallons of SAF can be produced from an acre of soybeans; 60 gallons are produced in the low-yield scenario; and 86 gallons are produced in the high-yield scenario. Therefore, between 12 million and 17 million acres of soybeans are needed to produce one billion gallons of SAF.

Figure 2 shows the amount of land needed to produce one, two, and three billion gallons of SAF using soybean oil. We estimate that 41 million acres of soybeans, almost half the area planted to the crop in 2022, will be needed to produce three billion gallons of SAF if the yield trend from the past 20 years persists. The high-yield scenario would reduce the number of soybean acres to 35 million, while as much as 50 million acres, about 60 percent of the area planted to the crop in 2022, could be required if yields fall below trend.

Figure 2. Millions of Soybean Acres Needed for SAF



Note: Trend yield is determined using a linear forecast of the 2004–23 yield trend extended to 2030. The low-yield estimate is the lower bound from the trend-yield forecast’s 95 percent confidence interval, and the high-yield estimate is the upper bound from the same forecast. Authors use 10.7 pounds of soybean oil per bushel and 8 pounds of soybean oil per gallon of SAF for calculations.

Source: Authors’ calculations based on yield forecasts and fixed-conversion ratios. Historical yield data from US Department of Agriculture, Foreign Agricultural Service, “Production, Supply, and Distribution Online,” <https://apps.fas.usda.gov/psdonline/app/index.html#/app/home>.

The impacts on food consumers from soybean-oil fuel use vary by food type. About 80 percent of crushed soybeans are retained as soybean meal for livestock feed, but almost no soybeans are consumed directly by humans or livestock. As a result, crushing more soybeans for fuel may benefit US meat consumers by providing more domestic livestock feed.

Soybean oil, however, is a primary vegetable oil directly consumed by humans. Humans consume around 50 percent of current US soybean-oil production. In the US, vegetable oils make up 19 percent of calories consumed. Soybean oil used for biofuels directly competes against US food consumers of vegetable oils. Three billion gallons of SAF would require roughly 24 billion pounds of vegetable oil, which was 84 percent of the total US soybean-oil supply in 2022. Thus, the impacts on consumers of vegetable oils would be substantial. Either soybean acreage would have to increase or US food consumers would need to find substitute vegetable oils (for example, canola oil), but prices for those substitutes would also likely increase, incentivizing increases in their production.

Table 2 shows the amounts of land needed to produce ethanol for SAF in the three yield scenarios in which corn is used instead of soybeans. The average corn yield in 2030 obtained using the crop’s estimated

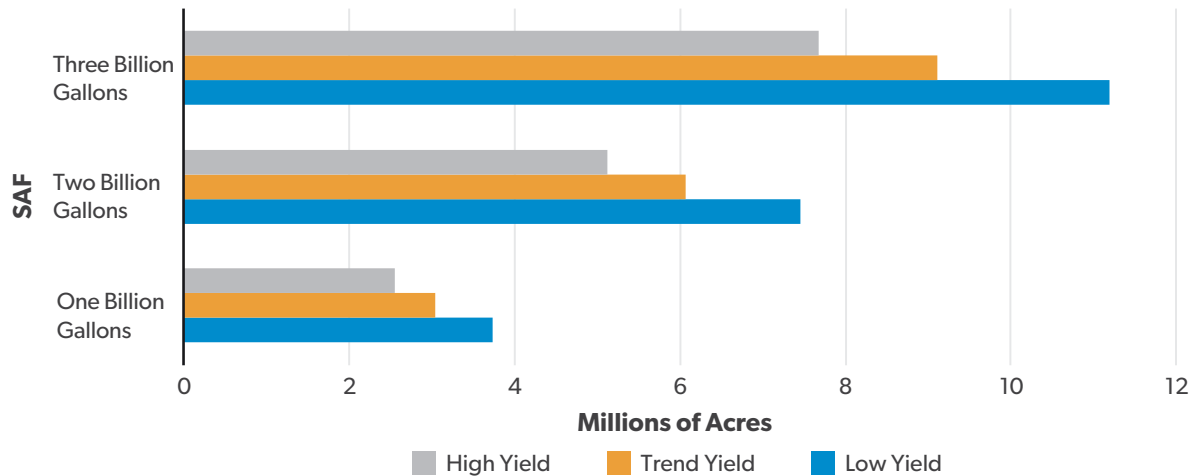
Table 2. Corn SAF Statistics for Different Yield Scenarios

	Low Yield	Trend Yield	High Yield
Yield (Bushels per Acre)	151.99	186.82	221.65
Ethanol (Gallons per Acre)	433.17	532.44	631.70
Corn Oil (Pounds per Acre)	106.39	130.77	155.15
SAF (Gallons per Acre)	268.11	329.54	390.98
Million Acres per Billion Gallons	3.73	3.03	2.56

Note: Trend yield is determined using a linear forecast of the 2004–23 yield trend extended to 2030. The low-yield estimate is the lower bound from the trend-yield forecast’s 95 percent confidence interval, and the high-yield estimate is the upper bound from the same forecast. Authors use 2.85 gallons of ethanol per bushel of corn, 1.7 gallons of ethanol per gallon of SAF, 0.7 pounds corn oil per bushel, and 8 pounds of corn oil per gallon of SAF for calculations.

Source: Authors’ calculations based on yield forecasts and fixed-conversion ratios. Historical yield data from US Department of Agriculture, Foreign Agricultural Service, “Production, Supply, and Distribution Online,” <https://apps.fas.usda.gov/psdonline/app/index.html#/app/home>.

Figure 3. Millions of Corn Acres for SAF



Note: Trend yield is determined using a linear forecast of the 2004–23 yield trend extended to 2030. The low-yield estimate is the lower bound from the trend-yield forecast’s 95 percent confidence interval, and the high-yield estimate is the upper bound from the same forecast. Authors use 2.85 gallons of ethanol per bushel of corn, 1.7 gallons of ethanol per gallon of SAF, 0.7 pounds corn oil per bushel, and 8 pounds of corn oil per gallon of SAF for calculations.

Source: Authors’ calculations based on yield forecasts and fixed-conversion ratios. Historical yield data from US Department of Agriculture, Foreign Agricultural Service, “Production, Supply, and Distribution Online,” <https://apps.fas.usda.gov/psdonline/app/index.html#/app/home>.

trend line is 187 bushels per acre, the high-yield estimate is 222 bushels, and the low-yield estimate is 152 bushels.

A bushel of corn can produce 2.85 gallons of ethanol given today’s production technology, and a gallon of SAF requires around 1.7 gallons of ethanol.¹⁶ In addition, when a bushel of corn is converted into ethanol, the process produces roughly 0.7 pounds of corn oil as a by-product.¹⁷ The oil by-product can also be used to produce SAF under the vegetable-oil pathway. Therefore, a single acre of corn can produce 330 gallons of SAF in the trend-yield scenario.¹⁸

In the low-yield scenario, corn production would generate 268 gallons of SAF per acre. That is more than three times the SAF obtained from an acre of soybeans under the high-yield scenario for that crop. The SAF corn-yield per acre estimates imply that, as shown in Table 2, between 2.56 million and 3.73 million corn acres would be required to produce a billion gallons of SAF using corn. This estimate is roughly 25 percent of the acres needed to produce one billion gallons of SAF using soybean oil.

Figure 3 shows the numbers of corn acres needed to produce one, two, and three billion gallons of SAF in each yield scenario. Using trend corn yields, roughly nine million acres of corn are needed to produce three billion gallons of SAF, which is roughly 11 percent of the area

planted to corn in 2022. This is less than a quarter of the land needed to produce three billion gallons of SAF if soybeans were used and 2030 soybean yields followed their recent linear trend. Furthermore, the range of our estimates in the low-yield and high-yield scenarios for corn is 3.6 million acres, far lower than the equivalent range of 15 million acres for soybeans. This indicates that if SAF is produced using corn, there would probably be less uncertainty about the impacts on land use if yields were to fall below or rise above their recent trends.

Finally, corn is used primarily as livestock feed or for ethanol, with less than 10 percent being used for human consumption in the United States.¹⁹ Using corn for ethanol or other fuel largely competes with its use for livestock feed, especially for cattle. However, one-third of the corn used for ethanol is returned as a high-protein livestock feed called distillers grain. Thus, the net impacts on livestock producers could be a loss of up to six million acres, depending on how much corn acreage increases.

Conclusion

SAFs would certainly represent a new horizon for the industrial use of agricultural commodities in the United States. Soy and corn are types of ready-made biofuel feedstock that could seamlessly transition into

the aviation fuels market at commercial scale. Moreover, current commodity prices make corn and soy biofuels attractive types of feedstock from a cost perspective. Biofuels may represent the easiest and most cost-effective approach to increase SAF production from 16 million gallons to three billion gallons in less than a decade.

Expanding cropland to produce biofuel generates carbon emissions that can offset much or all of their greenhouse gas benefits relative to fossil fuels.²⁰ If current yield trends persist, producing three billion gallons of SAF would require almost 40 million acres of soybeans or nine million acres of corn. Thus, even if corn is used, increasing SAF production to this extent would require at least some expansion of cropland. However, if reducing land-use impacts is a primary goal for policymakers, then corn ethanol is a better option than soybean oil for SAF production.

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