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Special Issue: California's Low Carbon Fuel Standard and the Demand for Biofuels

One of the dramatic changes in U.S. and world agriculture during this century has been the increasing diversion of agricultural products from food production into the production of biofuels. The main drivers of biofuel production in the United States have been the countrywide Renewable Fuel Standard (RFS), implemented in 2006, and California's Low Carbon Fuel Standard (LCFS), implemented in 2011. In a typical year 35%–40% of the U.S. corn crop is used to produce biofuels, while over 50% of soybean oil is used to produce renewable diesel fuel.

INSIDE THIS ISSUE:

In this special issue of *ARE Update*, we are pleased to offer three articles that provide insights into the economic impacts of these renewable fuels policies. The first article, produced through the work of a team of UC Davis faculty and grad students, describes the LCFS, including its operation, greenhouse gas emission reduction goals, effectiveness to date, limitations, and the path forward. Andrew Swanson and Aaron Smith examine the new U.S. strategy to produce sustainable aviation fuels and ask whether the policy will provide impetus for further expansion of U.S. corn and soybeans for biofuel production in the second article. The final article by Felipe G. Avileis, Colin A. Carter, and Jens Hilscher examines the boom in renewable diesel fuel spurred by the RFS and LCFS. Currently 65% of diesel fuel in California is from renewable diesel, with much of it produced using soybean oil. The authors examine the worldwide impacts of the policy on vegetable oil production, prices, and land use.

Special Issue Editors
Ellen Bruno and Richard J. Sexton

The California Low Carbon Fuel Standard and Its Consequences

Felipe G. Avileis, Colin A. Carter, Jens Hilscher, Aaron Smith, and Andrew Swanson

Since 2011, California's Low Carbon Fuel Standard (LCFS), intended to reduce greenhouse gas (GHG) emissions from transportation, has heavily influenced California's fuel markets. The LCFS allows refiners to generate credits if they produce a low-carbon fuel, and requires them to buy credits if they produce a high-carbon fuel. The energy mix has changed substantially since the policy's introduction. In addition, refineries have been converted to generate credits, and motor fuel prices have risen.

In 2011 the California Air Resources Board (CARB) started implementing the Low Carbon Fuel Standard (LCFS). According to CARB, the LCFS is "designed to encourage the use of cleaner low-carbon transportation fuels in California, encourage the production of those fuels, and therefore, reduce GHG emissions and decrease petroleum dependence in the transportation sector."

In the following article, we discuss how CARB has implemented the LCFS and whether or not it is achieving its goal of reducing GHG emissions.

The LCFS works as an add-on to the federal Renewable Fuel Standard (RFS), implemented in 2006. It creates strong incentives through a carbon credit trading scheme and has caused large changes in the fuel mix in the state.

The main goal of the LCFS is a 20% GHG emission reduction by 2030 along the path shown by the blue line in Figure 1 (on page 2). The yellow line in Figure 1 shows GHG reductions estimated by CARB over the years. If the yellow line is below the blue line, it means the state has claimed a higher reduction than the standard requires. For example, in 2023, the standard was an 11.25% reduction, but the estimated reduction was 15.34% according to CARB.

Oregon, Washington, and British Columbia have instated similar policies following the LCFS introduction in California. New Mexico also announced its own "Clean Fuel Standard" on February 20, 2024. In this article we consider the workings of the LCFS policy in more detail and discuss its indirect impacts on other outcomes, such as agricultural production and land use.

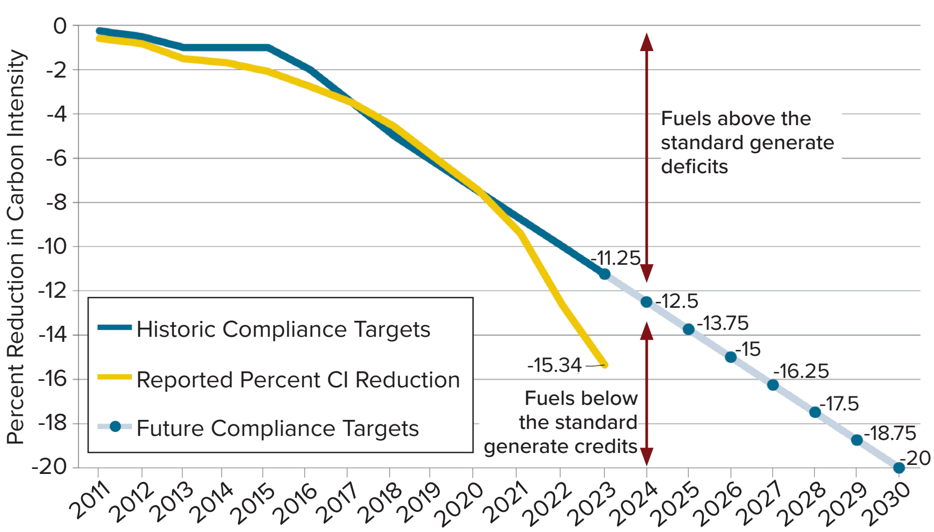
How Does the Policy Work?

The LCFS functions through an accounting mechanism that measures each fuel type against a carbon intensity (CI) target. Carbon intensity equals the number of grams of CO_2 emitted by a fuel per megajoule of energy produced. CARB estimates the CI for each energy source using models that account for emissions throughout a fuel's life cycle.

Life cycle emissions include not only the tailpipe emissions of a fuel, but also the emissions from the fuel's entire supply chain. For example, this method accounts for emissions from transporting the fuel from another state to California, emissions from processing inputs (feedstocks) into fuel, and any emissions from converting land to produce more feedstock.

Dirty fuels have a higher CI than the target and accrue deficits; cleaner fuels have a lower CI than the target and generate credits (see Figure 1). For the state to hit the target, the credits must balance the deficits. Over time, as the target becomes more stringent, the number of deficits accrued by each gallon of high CI fuels such as gasoline and diesel increase.

Figure 1. Performance of the Low Carbon Fuel Standard Over the Years



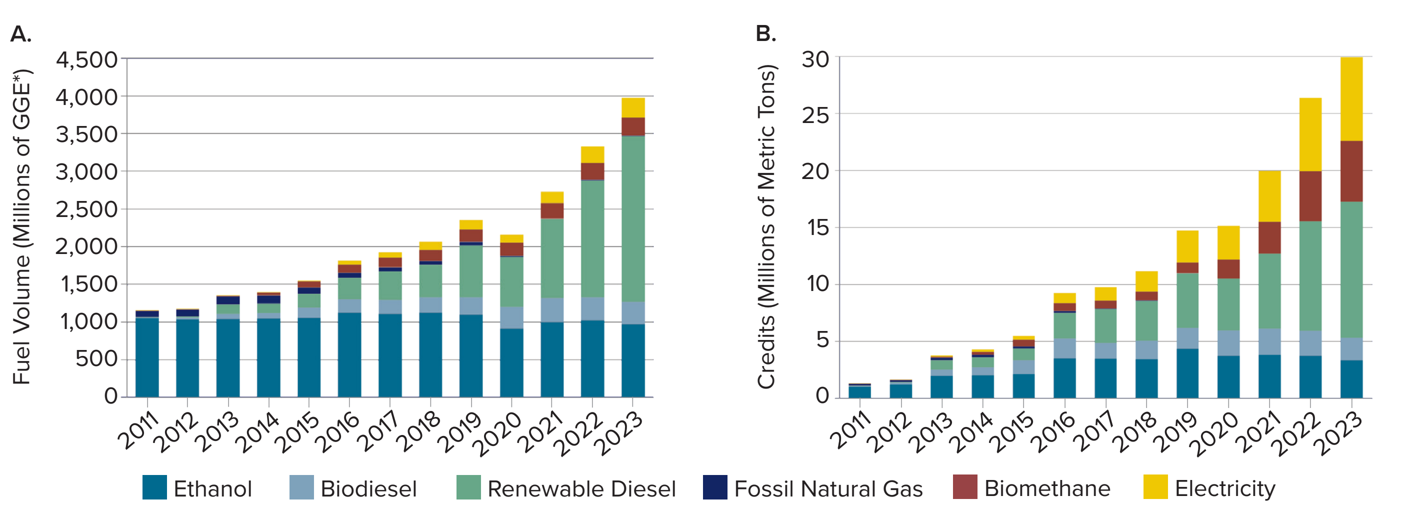
Source: CARB (2024), adjusted by authors.

The LCFS's emissions method also allows for variation in credits generated per gallon across suppliers for the same fuel type, unlike the federal RFS biofuel program. These differences arise from the feedstock used, co-products produced, plant-level efficiency, energy used for processing, and transportation of fuel to California. For example, an ethanol plant powered by renewable natural gas would have a lower CI and generate more credits per gallon than one powered by fossil natural gas.

Who Is Subject to the LCFS?

The LCFS regulates obligated parties, defined as petroleum importers,

Figure 2. Low Carbon Fuel Standard Fuel Volume Consumed and Credits Generated in California



Source: CARB (2024).

Note: *GGE=gasoline-gallon equivalents.

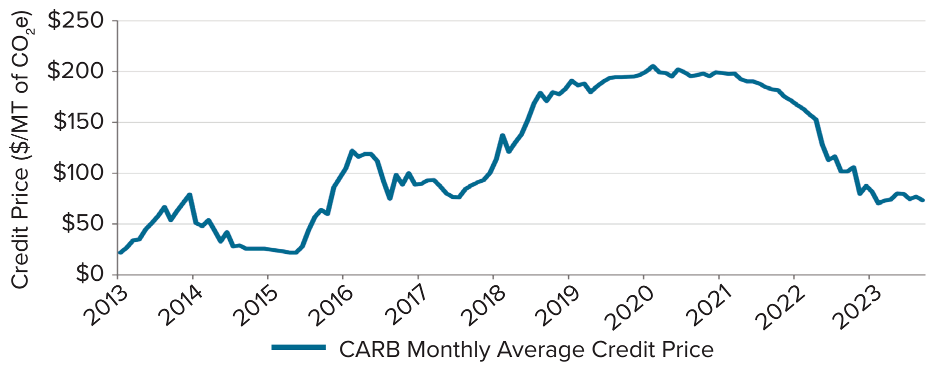
refiners, and wholesalers. Each year, obligated parties must acquire enough credits to offset their deficits. There are two ways of obtaining credits: 1) buying and blending fuels that generate credits and / or 2) buying credits in the open market.

To better understand the mechanism, consider a refiner producing petroleum diesel (CI=100). Suppose the CI target for diesel is 90 in 2024. As an alternative to petroleum diesel, trucks and buses can run on renewable diesel (RD) made from vegetable oils or animal fats. Renewable diesel made from soybean oil has a CI of about 50 and RD made from used cooking oil has a CI of about 20.

Petroleum diesel is 10 CI units above the target, whereas soybean-oil RD is 40 units below the target, and used-cooking-oil RD is 70 units below the target. Our refiner could comply with the standard by selling one gallon of soybean-oil RD for every four gallons of petroleum diesel, or they could sell one gallon of used-cooking-oil RD for every seven gallons of petroleum diesel. Alternatively, the refiner could buy credits from other companies that sell RD.

This mechanism creates an implied subsidy to produce renewable fuels, especially those with a low CI, while also imposing a tax on dirty fuels. Thus, LCFS credit markets function as a tax transfer mechanism from high CI fuel producers to low CI fuel producers. The higher the credit prices, the higher the subsidy for clean fuel production. Compared to no policy, costs of producing dirty fuels are increased because of the need to either produce clean fuels or purchase credits. Because fuel suppliers are compelled to use a different fuel mix than they otherwise would, we end up with a more expensive fuel mix, which implies higher prices for consumers at the pump.

Figure 3. Low Carbon Fuel Standard Credit Prices



Source: CARB (2024).
Note: MT of CO_2e=Metric tons of carbon dioxide equivalents.

What Are the Main Sources of Credits?

The main sources of deficits are fossil diesel and gasoline, but an array of different fuels can qualify as credit-generating fuels in the LCFS. Figure 2 shows the energy mix (Figure 2A) and the credit generation (Figure 2B) from credit-generating fuels. Corresponding to the overall large reduction in CI illustrated in Figure 1, we see a large increase in the production of low CI fuels. In 2023, RD was the most consumed renewable fuel in California (Figure 2A), followed by ethanol, biodiesel, biomethane, and electricity.

RD also generated the most credits, followed by electricity, biomethane, ethanol, and biodiesel (Figure 2B). The amount and sources of credit generation are fundamental in determining the value of LCFS credits and, therefore, implied subsidies.

Biomethane has experienced a surge in credit generation since 2020 while contributing only a small increase in energy supply in the state. Biomethane from dairy farms is driving this result. Dairy farmers wash manure into large lagoons, where microbes eat it and emit methane, a potent GHG. Farmers can install an anaerobic digester, which is like a giant cover on the lagoon, to capture the methane and process it for use in natural gas vehicles. Biomethane typically has a large negative CI because farmers get credit based not only on the emissions from the fuel produced but also because covering the lagoon prevents methane emissions that would otherwise have occurred.

The Rise and Fall of Credit Prices

When credit prices are high and expected to remain high, there is an incentive to invest in clean fuel production capacity and to scale back dirty fuel distribution. When credit prices drop, the incentive to produce low CI fuels is reduced.

Credit prices are determined by the supply and demand for credits, given the CI target. Demand for credits is a function of the consumption of dirty fuels; the more dirty fuels consumed, the higher the demand for credits. The supply of credits is determined by the production of clean fuels, i.e., those with a CI lower than the threshold.

From 2018 until late 2021, credit prices traded at relatively high prices, around $200 per metric ton (MT) of carbon dioxide equivalent (CO_2e), as shown in Figure 3. The high prices were due to the lack of credit supply, while deficits from dirty fuels increased. High credit prices mean high subsidies, leading to a significant growth in the investment in credit-generating fuels. After the surge in investment around 2019–2020, especially in RD and biomethane production, credit prices—currently at their lowest levels since late 2015—started to trend downward, trading around $60/MT of CO_2e.

LCFS Shortcomings

The LCFS has reduced measured GHG emissions by encouraging credit generation through, for example, RD production using waste oils. However, the policy also has drawbacks.

First, the LCFS subsidizes fuels with positive emissions, e.g., fuels with a CI above 0 grams of carbon dioxide equivalents per megajoule of energy. Both biofuels and petroleum fuels have net positive emissions, and the LCFS standard is a positive value that lies between the emissions of these two fuels. Petroleum fuels are taxed under the LCFS, but their tax rate may be less than it would be under a full carbon tax. Biofuels are subsidized instead of taxed because they have a CI below the standard. The standard encourages switching from fuels with higher emissions to fuels with lower emissions, but the program still subsidizes fuels with emissions greater than zero. As a result, the program can encourage overconsumption of fuels with net positive emissions.

Second, it is unclear how much of the estimated reduction in emissions would have happened in the absence of the policy. Because of the RFS, biofuels will be consumed in the United States no matter what CARB does in California. Therefore, it is possible that the LCFS is partly shifting consumption of biofuels from other states like Iowa and Texas to California rather than generating emissions reductions at the national level.

Third, generating credits through RD production has caused a large increase in the use of RD feedstock, mainly soybeans, canola, and tallow. This feedstock is converted in large refineries in Louisiana, Texas, and California and then used as fuel in trucks, buses, and trains in California. This consumption of RD in California generates credits, but it has also increased feedstock demand in the United States.

One way in which the United States has been able to meet this higher demand has been through a reduction in soybean and soybean oil exports. There has been a corresponding increase in soybean oil production, for example in Brazil. (See the third article in this issue of *ARE Update*.) This may have resulted in more deforestation.

In short, despite its effort to reduce emissions intensity, the LCFS mandate falls short when accounting for secondary effects. For example, if the increased demand for agricultural inputs, such as corn or soybeans, causes deforestation, CARB's calculations may not adequately account for this impact. That means that the substitution from fossil fuels to biofuels might not be as clean as the estimated carbon intensities imply.

Where Is the Policy Heading?

Balancing credit prices is the central challenge CARB faces when determining yearly targets. On one hand, high credit prices are good for investment in clean fuels but are generally viewed as burdensome for consumers. Low credit prices, however, are less burdensome but can be insufficient to properly support investment in clean energy. So, what comes next?

CARB has released a new proposition to amend the current LCFS mandate that runs through 2030. The proposal aims to "strengthen the CI reduction benchmarks," which means the proposal would make dirty fuels generate more deficits. Under these new rules, CARB would increase reduction targets to 30% by 2030, compared to 20%, and a 90% reduction by 2045, compared to 85%.

While this proposal is still under discussion, its clear goal is to elevate credit prices to high enough levels to support continuous investment in the sector. Is this where California should be heading? The stated goal of a drastic increase in the level of GHG reduction from the policy, and the corresponding likely rapid increase in credit prices, means that the current adverse consequences of the policy—higher fuel prices, potential for deforestation, and reduction in agricultural land being used for food production—could be made more severe. A local reduction in GHG is not necessarily beneficial for the planet if GHGs are increased elsewhere as a result of California's policy.

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For additional information, the authors recommend:

California Air Resources Board. 2024. "LCFS Data Dashboard." Available at: https://bit.ly/4cmuSn7.

California Air Resources Board. 2024. "Low Carbon Fuel Standard." Available at: https://bit.ly/3VCLYre.

An Eye to the Sky: Will Sustainable Aviation Fuel Take Off in California?

Andrew Swanson and Aaron Smith

New federal tax credits aim to dramatically increase national production of alternative jet fuels from biofuels. The consumption of sustainable aviation fuels remains low in California despite incentives from the Low Carbon Fuel Standard (LCFS). We compare the incentives for producing biofuels from agricultural feedstocks like soybean oil or ethanol for either on-road or in-air use. We find that the overall balance of incentives is greater for using agricultural feedstocks in non-aviation biofuels than as alternative jet fuels.

California airports supplied over 2 billion gallons of jet fuel in 2022. Consumers, regulators, and investors are pressuring airlines to reduce their carbon emissions. Yet, the aviation industry remains difficult to decarbonize because of the high energy demands of long-haul flights. The electrification of commercial flights remains far beyond the reach of current battery technology, so airlines and regulators are now considering alternative liquid jet fuels known as sustainable aviation fuels, or SAFs for short. SAFs require almost no engine modifications, and they can often be produced in the same facilities as other biofuels.

The Inflation Reduction Act of 2021 (IRA) provides additional tax credits for the production of SAFs in the United States. The goal of these tax credits is to produce over 3 billion gallons of SAF in the United States by 2030, which would be around 15% of total aviation fuel. The total SAF consumption at present only amounts to 1% of aviation fuel use in California and less in the rest of the country. Biomass-based diesel, on the other hand, accounts for two-thirds of all diesel consumption in California. So, will the IRA turn the tide for SAF use in California?

This article discusses the incentives for consuming SAFs in California with an emphasis on the interplay of California's fuel policies, federal fuel policies, and the tax credits from the IRA. SAFs are produced from a variety of different inputs (feedstocks). We emphasize SAFs created from corn ethanol and soybean oil because these are currently the most viable feedstocks for SAF. We compare incentives for consuming biofuels from agricultural feedstocks either on-road or in-air. We find that the overall balance of incentives still tips towards non-aviation biofuels like renewable diesel (RD) and ethanol.

Sustainable Aviation Fuel Incentives

The IRA provides special tax provisions for SAFs in the United States. These tax provisions have two forms: 40B, which ends in December 2024, and 45Z, which runs from 2025 to 2027. The 40B SAF tax credit is a modification of a current tax credit for biofuel diesels called the blender's tax credit. The blender's tax credit provides a $1.00 per gallon tax credit for biomass-based diesels such as soybean oil RD. Fuels must have 50% or more carbon dioxide emissions reduction from petroleum diesel fuel to qualify for the credit. A model of life cycle emissions from the fuel determines the emissions reduction percentage.

The 40B credit adds an additional tax credit of between $0.25 and $0.75 per gallon on top of the blender's tax credit. A qualifying SAF producer receives a minimum of $1.25 per gallon if it has a 50% emissions reduction from petroleum jet fuel. For every 1% reduction beyond 50%, it receives an extra cent per gallon. Therefore, the IRA provides a sizeable incentive to convert biofuels to aviation use instead of on-road usage.

Starting in 2025, the blender's tax credit will be replaced by 45Z in the IRS tax code, which provides a tax credit for all biofuels with a carbon intensity (CI) below 47 grams of carbon dioxide equivalents per megajoule of energy (gCO_2e/MJ). Carbon intensity is a means of measuring a fuel's carbon emissions per megajoule of energy. A fuel receives a tax credit

Table 1. Federal Tax Credits for On-Road and Aviation Biofuels in 2024 and 2025 by Fuel Emissions

Biofuel Emissions	2024 Federal Tax Credits		2025 Federal Tax Credits	
(gCO_2e/MJ)	On-Road Credit ($/Gallon)	Aviation Credit ($/Gallon)	On-Road Credit ($/Gallon)	Aviation Credit ($/Gallon)
45	1.00	1.25	0.04	0.07
30	1.00	1.42	0.36	0.63
15	1.00	1.58	0.68	1.19
0	1.00	1.75	1.00	1.75

Source: Authors' calculations and Congressional Research Service (2023). Available at: https://bit.ly/4c2NOqG.

Note: The 2024 On-Road Credit is the blender's tax credit. The 2024 Aviation Credit is the 40B tax credit. The 2025 On-Road Credit is the 45Z tax credit with a base rate of $1.00 per gallon. The 2025 Aviation Credit is the 45Z tax credit with a base rate of $1.75.

based on the percentage decrease in emission below 47 gCO_2e/MJ. The percentage reduction in emissions is then multiplied by $1.00 per gallon for on-road fuels or $1.75 per gallon for aviation fuels.

Table 1 (on page 5) provides a summary of the different federal tax credits for hypothetical fuels with emissions of 45, 30, 15, and 0 gCO_2e/MJ. In 2024, biofuel diesels earn $1.00 per gallon regardless of the fuel's emissions. The 2024 SAF tax credit starts at $1.25 per gallon for feedstocks with emissions of 45 gCO_2e/MJ and increases steadily to $1.75 per gallon as emissions decrease. In 2025, a fuel with 45 gCO_2e/MJ would provide a small percentage decrease in emissions below 47 gCO_2e/MJ, so both on-road and in-air biofuels would earn less than $0.10 per gallon. Thereby, fuels that barely qualify will lose close to $1.00/gallon in tax credits starting in 2025, and all biofuels with emissions greater than 0 gCO_2e/MJ will see a reduction in tax credits per gallon in 2025 compared to 2024. The one exception is on-road ethanol, which does not qualify for the 2024 on-road tax credit.

Table 2. Incentives to Replace Petroleum With Soybean Oil Renewable Diesel (RD) Versus Soybean Oil Sustainable Aviation Fuel (SAF) in California

	SAF ($/Gallon)	RD ($/Gallon)	Difference ($/Gallon)
Offset Petroleum Fuel Costs			
Fuel Price	2.18	2.33	
D4 RIN Obligation	0.78	0.83	
LCFS Deficits	—	0.09	
Cap and Trade	—	0.39	
Total Petroleum Fuel Costs	**2.96**	**3.64**	-0.68
Plus LCFS Credit Value	0.29	0.30	
Subtotal California Incentives	**3.25**	**3.94**	-0.69
Scenario 1: 2024 Status Quo (CI=40)			
Plus 2024 Federal Tax Credit	1.31	1.00	
Total Incentives	**4.56**	**4.94**	-0.38
Scenario 2: 2024 With CSA (CI=35)			
Plus 2024 Federal Tax Credit	1.35	1.00	
Total Incentives	**4.60**	**4.94**	-0.34
Scenario 3: 2025 Status Quo (CI=40)			
Plus 45Z Tax Credit	0.26	0.15	
Total Incentives	**3.51**	**4.09**	-0.58
Scenario 4: 2025 With CSA (CI=35)			
Plus 45Z Tax Credit	0.45	0.26	
Total Incentives	**3.70**	**4.20**	-0.50

Source: Authors' calculations.

Note: Petroleum fuel costs include wholesale petroleum jet fuel for SAF and wholesale petroleum diesel for RD, D4 RINs for both fuels, and petroleum diesel taxes for RD. Petroleum wholesale prices and taxes are weighted by energy density of relevant biofuel divided by energy density of petroleum fuel as reported by CARB. RINs are weighted by energy density of relevant biofuel divided by energy density of ethanol. LCFS credit values are derived from CARB's formulas. The 2024 Federal Tax Credit is 40B for SAF and the blender's tax credit for RD. CSA soybeans are certified soybeans produced using climate-smart practices that give a 5 carbon intensity (CI) reduction. The 2025 45Z is a federal tax credit according to IRS section 45Z. The difference column is calculated by subtracting the value of RD from the value of SAF.

The Treasury Department awards a reduction in emissions for soybean oil and corn ethanol SAFs that use climate-smart agricultural (CSA) practices. For soybeans, the CSA practices include no-till farming and cover crops, while for corn they also include the addition of inhibitors that prevent the volatilization of nitrogen. Corn ethanol receives a 10 gCO_2e/MJ emissions reduction for these practices, while soybean oil receives 5 gCO_2e/MJ for them. Unlike soybean-oil biofuels, corn ethanol producers will only qualify for SAF tax credits if they certify the use of CSA corn. The certification process could prove to be quite burdensome, as the USDA and private organizations are only now creating CSA pilot programs.

While the IRA is an important recent policy for SAFs, the federal Renewable Fuel Standard (RFS) still plays the largest role in determining national biofuels policy. The RFS mandates the minimum number of gallons of biofuel consumption for ethanol and biofuel diesels, and it divides biofuels into categories based on feedstock, production method, and fuel type. Aviation fuels are exempted from the RFS consumption mandates, but consuming SAFs can offset the consumption mandates on biofuel diesels.

Each fuel category has its own set of compliance credits called Renewable Identification Numbers (RINs). Corn ethanol is in its own category for fuels with at least 20% emissions reduction from gasoline. Soybean oil RD and SAF are in a separate category for fuels with at least 50% emissions reductions from petroleum jet fuel or diesel. Each RIN category has its own separate consumption mandate, but prices for corn ethanol and soybean oil RIN credits follow similar trends.

Incentive Comparisons by Fuel Type

Sustainable aviation fuel consumption in California can take off if the incentives for consumption are strong enough. Sustainable aviation fuel costs roughly 2.5 times as much as petroleum jet fuel to produce, and consumption remains at 1% of the total jet fuel in California. Agricultural feedstocks like soybean oil and corn ethanol have the potential to be converted into SAF, but these feedstocks have competing uses as RD and on-road ethanol—for soybeans and corn respectively. If SAF consumption is going to increase in California, then the incentives for using agricultural feedstocks as aviation fuel must outweigh the opportunity cost of using the same feedstock for on-road use.

Producing aviation fuel instead of on-road fuels likely increases the costs and emissions of biofuels. Dramatically increasing the amount of SAF blended with petroleum jet fuel may also require infrastructure investments from airports. To simplify our analysis, we do not account for these costs. While this simplification favors SAF, it has almost no impact on the primary conclusions of our analysis.

The incentives for using agricultural feedstocks for either aviation or on-road use must weigh the value of the petroleum fuel replaced. We use two components for the value of petroleum fuel replaced: the wholesale cost of petroleum fuel and the additional costs from federal and state carbon regulations. Both are weighted by the ratio of the relevant biofuel's energy content to its petroleum substitute. For example, SAF has roughly 90% of the energy content per gallon as petroleum jet fuel. Replacing a gallon of petroleum fuel with any biofuel needs to account for the fact that biofuel provides less energy per gallon.

In California, petroleum gasoline and diesel are taxed under the LCFS and the Cap-and-Trade programs. Displacing a gallon of diesel or gasoline with biofuels also displaces these taxes. Aviation fuel is not a compliance fuel under these programs, so aviation fuel is not taxed. After accounting for the energy of their respective petroleum fuels, replacing petroleum gasoline or diesel with biofuels eliminates $0.45–$0.50 per gallon in taxes that SAF must overcome to offset the opportunity cost of using on-road biofuels.

Table 2 presents the total incentives for using soybean oil for RD versus SAF in California. The table includes scenarios that differ by the use of CSA soybeans and the version of the federal tax incentive. We use a base carbon intensity (CI) of 40 for RD and 40 for SAF for the IRA tax credits and 50 CI for the California LCFS credits. Differences in the costs of petroleum fuel, the value of RINs, and California carbon taxes on petroleum diesel provide $0.68 of additional value for soybean oil RD over soybean oil SAF. The value of LCFS credits between RD and SAF are almost identical. As a result, RD has a $0.69 per gallon advantage over SAF that federal tax credits must overcome to incentivize switching from RD to SAF production.

Table 3. Incentives to Replace Petroleum Fuel With Corn Ethanol Versus Corn Sustainable Aviation Fuel (SAF) in California

	SAF	On-Road Ethanol	Difference
	($/Gallon)	($/SAF Gallon)	($/Gallon)
Offset Petroleum Fuel Costs			
Fuel Price	2.18	2.89	
D6 RIN Obligation	0.74	0.74	
LCFS Deficits	—	0.10	
Cap and Trade	—	0.34	
Total Petroleum Fuel Costs	**2.92**	**4.07**	-1.15
Plus LCFS Credit Value	0.21	0.20	
Subtotal California Incentives	**3.13**	**4.27**	-1.14
Scenario 1: 2024 Status Quo (CI=50)			
Plus 2024 Federal Tax Credit	—	—	
Total Incentives	**3.13**	**4.27**	-1.14
Scenario 2: 2024 With CSA (CI=40)			
Plus 2024 Federal Tax Credit	1.31	—	
Total Incentives	**4.44**	**4.27**	0.17
Scenario 3: 2025 Status Quo (CI=50)			
Plus 45Z Tax Credit	—	—	
Total Incentives	**3.13**	**4.27**	-1.14
Scenario 4: 2025 With CSA (CI=40)			
Plus 45Z Tax Credit	0.26	0.23	
Total Incentives	**3.39**	**4.50**	-1.11

Source: Authors' calculations.
Note: An SAF Gallon multiplies on-road ethanol values by 1.55 to account for the fact that a gallon of SAF made from ethanol requires 1.55 gallons of corn ethanol to produce it. Petroleum fuel costs include wholesale petroleum jet fuel for SAF and wholesale petroleum gasoline for ethanol, D6 RINs for both fuels, and petroleum gasoline taxes for ethanol. Petroleum wholesale prices and taxes are weighted by energy density of relevant biofuel divided by energy density of petroleum fuel as reported by CARB. RINs are weighted by energy density of relevant biofuel divided by energy density of ethanol. LCFS credit values are derived from CARB's formulas. The 2024 Federal Tax Credit is 40B for SAF. CSA corn is certified corn produced using climate-smart practices that gives a 10 carbon intensity (CI) reduction. The 2025 45Z is federal tax credit according to IRS section 45Z. The difference column is calculated as the value of on-road ethanol minus the value of SAF.

The incentives for using soybean oil SAF are lower than for RD in all of the federal tax scenarios. The 2024 version of the SAF tax credit (40B) reduces RD's advantage to $0.38 and $0.34 for generic and CSA soybeans, respectively. The 2025 version of the federal tax credit (45Z) is less lucrative for all soybean-oil biofuels. As a result, SAF could be even farther behind RD in future years. The use of CSA soybeans helps to close the gap between RD and SAF, but the marginal difference is still not enough to incentivize switching from RD to SAF production.

If SAF were less expensive to produce than RD, then there may still be an incentive for refiners to produce it. However, SAF is more expensive to produce than RD, so it faces even more of an uphill battle.

Table 3 (on page 7) compares using corn-ethanol for SAF consumption versus on-road consumption. It compares different versions of the federal tax incentives and the use of CSA corn. Producers of SAF need 1.55 gallons of ethanol to make a gallon of SAF. We multiply all of the per-gallon values of on-road ethanol by 1.55 to create gallons of ethanol equal to a gallon of SAF. The wholesale value of gasoline displaced by 1.55 gallons of ethanol is $0.71 more than the wholesale value of jet fuel replaced by a gallon of SAF. Carbon taxes add $0.44 to the value of petroleum gasoline displaced by on-road ethanol. Therefore, ethanol SAF has around a $1.15 deficit to overcome before considering any federal tax incentives.

The federal tax incentives provide limited help to corn SAF because the fuel barely qualifies. SAF produced with CSA corn is just below the emissions thresholds for both the 40B and 45Z federal tax credits, so it earns near the minimum for each of the tax credits. The 40B tax credit provided a significant boost in 2024 with a $1.31 credit per gallon of SAF, but the 45Z tax credit hardly moves the needle starting in 2025. The federal tax incentives are proportional to emissions reductions in 2025, so the tax incentives for CSA-corn biofuels are quite small. Any additional processing costs and emissions for corn SAF not accounted for in Table 3 compound the issue, and corn SAF's prospects remain limited in California.

Discussion

Federal tax incentives for SAFs have created a buzz in the biofuel industry and media, but these tax incentives are currently not enough to cover the opportunity costs of diverting agricultural biofuels from on-road to aviation use. The policy incentives for on-road use are larger than for aviation use, and sustainable aviation fuel is more expensive to produce than on-road biofuel. Corn and soybean oil SAFs face significant barriers without either large decreases in their emissions or expanded policy incentives.

California places large carbon taxes on petroleum on-road fuels, and all biofuels have additional value in displacing these taxes. Petroleum jet fuel is exempt from these taxes. This exemption could encourage on-road use instead of aviation use for biofuels. Some groups would like to tax petroleum jet fuel for intra-California flights, which would partially eliminate this exemption.

However, taxing intra-California flights may not encourage more SAF use. Fuel suppliers will comply with carbon regulations in the cheapest way possible. Higher processing costs for SAFs will push fuel suppliers towards on-road biofuels if they are allowed to meet compliance with these fuels. This is why the use of alternative jet fuels remains low compared to biomass-based diesel in states without California's carbon taxes.

If policy incentives were to become large enough to encourage more SAF consumption, it would most likely occur at the expense of on-road biofuels. The RFS and its consumption mandates still appear to be the most important policy in determining national biofuel demand. Additional emissions reductions and volumes from SAFs will likely be small unless the EPA significantly increases mandated volumes. Increasing on-road volumes by an equivalent amount, however, may achieve the same emissions reductions at a cheaper cost because of higher processing costs for SAFs.

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For additional information, the authors recommend:

Swanson, Andrew. 2024. "Is Sustainable Aviation Fuel the Future of Ethanol?" *farmdoc daily* (14):39. Available at: https://bit.ly/3Vt0kKA.

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How the California Low Carbon Fuel Standard Resulted in a Renewable Diesel Boom

Felipe G. Avileis, Colin A. Carter, and Jens Hilscher

The United States is in the midst of a renewable diesel (RD) production boom, which has led to an increased demand for vegetable oil. Most of the RD produced in the United States is used as motor fuel in California—in response to the state's Low Carbon Fuel Standard (LCFS) coupled with the national Renewable Fuel Standard (RFS). These policies increase demand for vegetable oils, which serve as inputs (feedstock) for RD production and have resulted in increased U.S. imports of vegetable oils and more global agricultural land allocated to soybeans and palm trees. The increased demand has resulted in higher vegetable oil prices and has contributed to food inflation in the United States.

The combination of the Renewable Fuel Standard (RFS), which is a federal mandate in place since 2006, and California's Low Carbon Fuel Standard (LCFS), introduced by the California Air Resources Board (CARB) in 2011, has resulted in a large increase in renewable diesel (RD) production, which started to really take off in 2020. RD is a perfect substitute for "conventional diesel," which means that it does not need to be blended with conventional diesel, unlike biodiesel (BD) which is chemically different from RD. BD and RD (both renewable fuels) differ in their production processes but use similar inputs (feedstocks).

The RFS is mainly a fuel blending policy, requiring minimum percent blends of renewable fuels in the conventional fuel pool. On the other hand, as discussed in the first article, the LCFS has an annually increasing targeted reduction in transportation-related carbon emissions. The policy aims to limit the carbon intensity (CI) of fuels. The program is set up so that low CI fuel (e.g., RD) producers earn "credits," while high CI (e.g., gasoline) producers must purchase these credits. A few years ago, the price of credits jumped up as the LCFS ratcheted up carbon-reduction targets.

From 2018 to 2020, LCFS credit prices were at all-time highs, trading at around $200 per metric ton (MT) of carbon, compared to $100/MT previously. This translated into high subsidies for renewable fuel producers and, therefore, increased the supply of renewable fuels. One industry that benefited greatly from the high credit prices was the RD industry.

RD production capacity in the United States was 600 million gallons a year in 2018. With the spike in the price of credits, which act as a subsidy to RD production, new investments were made. Old diesel refineries were converted into RD facilities, as was the case for refineries in California and Louisiana. The current RD production capacity in the United States is around 3.85 billion gallons a year, over a 500% increase in five years.

The full impacts of this huge supply increase are still uncertain. For example, the blend rate for retail diesel in California currently is 65% RD and 35% conventional diesel. Before the boom, RD made up less than 5% of the state's diesel blend. Producing RD requires inputs, such as soybean oil. The shift in RD feedstock demand has also resulted in sharply higher vegetable oil imports.

The Increase in the Use of Soybean Oil as Fuel

Soybean oil is used as a feedstock for either fatty acid methyl esters (FAME) BD or RD. Soybean oil accounts for approximately 60% of BD feedstocks. The FAME production process is limited to a narrow range of feedstocks and the resulting fuel is not a perfect substitute for conventional diesel, unless it is blended.

In contrast, RD can be produced out of almost any type of oil or fat. This allows producers to use different inputs and gives a "second life" to products like used cooking oil (UCO), tallow, and non-edible distillers corn oil. These oils are referred to as waste oils and fats; RD produced using them yields some of the lowest CI fuels that fall under the LCFS.

However, refiners also use large amounts of other inputs to produce RD, for example edible vegetable oils, such as soybean, canola, and palm. When RD production was low (before the "boom"), tallow, UCO, and distillers corn oil represented more than 90% of the RD feedstock, and no edible vegetable oils were used. This is because of the lower CI of UCO as compared to soybean oil, and therefore the ability to generate more credits.

After the RD boom, the waste oils and fats share decreased to 65%, with the rest of the RD feedstock mainly being edible vegetable oils (soybean and canola now account for 25% of total U.S. RD inputs). This feedstock change is mainly because there is an insufficient supply of waste oils and fats. In total, around 50% of the U.S. production of soybean oil is used as the main feedstock for BD and RD.

U.S. Demand for Vegetable Oils

The surge in demand for oils and fats, combined with the inelastic supply of waste oil, led to the introduction of vegetable oils as a major feedstock for RD. This has reshaped the domestic market for vegetable oils in the United States and has had a global impact.

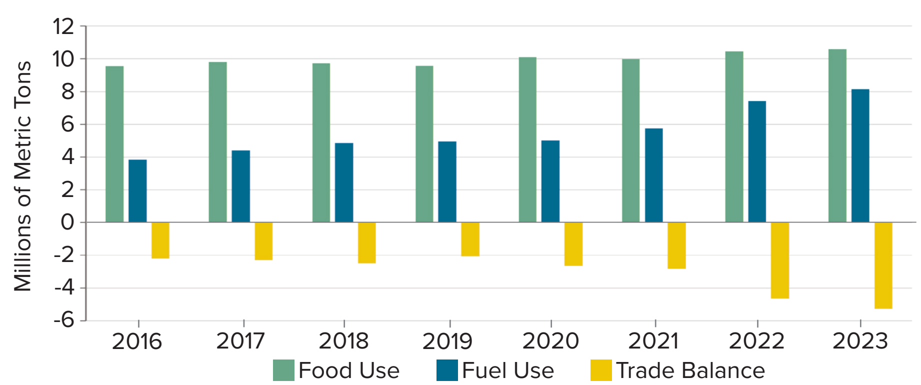
Vegetable oils have two main uses: food and industrial (energy). Food use includes the food processing sector, restaurants, and homes, which mainly use these oils for cooking purposes. Demand for food use has not changed much. From 2018–2023 food use demand increased by less than 8%.

On the other hand, industrial demand, driven by feedstock use, significantly increased. The surge in RD production has led soybean and canola oil demand for industrial use to increase by 63% from 2018–2023, according to the Foreign Agricultural Service of the U.S. Department of Agriculture (FAS-USDA). Figure 1 plots U.S. vegetable oil fuel and food use, along with net imports (trade balance).

Effects on Global Demand for Vegetable Oils

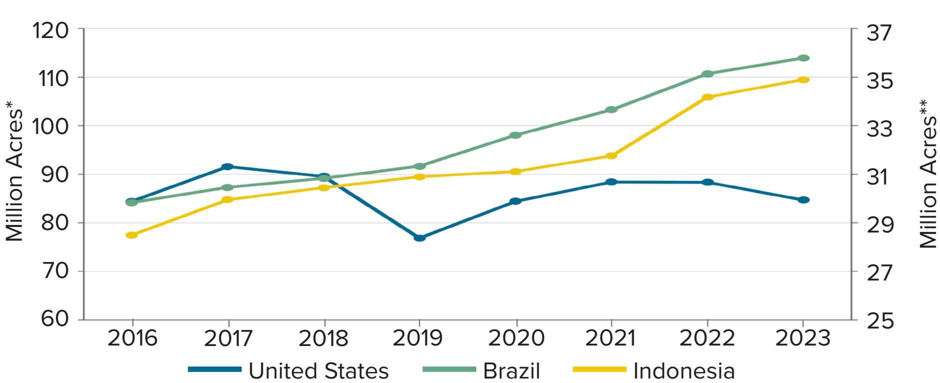
In 2023, the United States accounted for approximately 10% of the global vegetable oil demand. Other significant users were China (20%), India (13%), and Brazil (5%). However, most of this demand in these other countries is not for fuel use. Global demand for food use, which is around 70% of total demand, increased by 9% from 2018 to 2023. Over the same period, demand for industrial use rose by 18%. Demand for RD feedstock in the United States was the key driver of this growth.

Figure 1. Vegetable Oil Use and Trade Balance for the United States



Source: FAS-USDA (2024).

Figure 2. Vegetable Oil Harvested Acreage by Country



Source: FAS-USDA (2024).
Note: Soybean, canola (rapeseed), and palm are the main vegetable oil crops in these countries.
*Left axis is acreage for the United States and Brazil. **Right axis is acreage for Indonesia.

Supply of Vegetable Oils and Land-Use Changes

Global demand for vegetable oils increased by 11% over the RD boom period, while U.S. demand increased by around 27%. Global vegetable oil supply has responded by increasing the area planted by around 15% from 2018–2023. Most of this growth came in the years after the boom, when supply was trying to catch up with demand.

While the demand expansion happened in the United States, supply expansion did not. From 2018–2023, U.S. soybean acreage remained mostly flat at around 86 million acres. Acreage increases were significant in Brazil and Indonesia, two of the top ten vegetable oil producers. Brazil's soybean acreage increased by 28%, from 89 million acres to 114 million acres. Indonesia, the world's largest palm oil producer, increased palm acreage by 15%, from 30 million acres to 35 million acres.

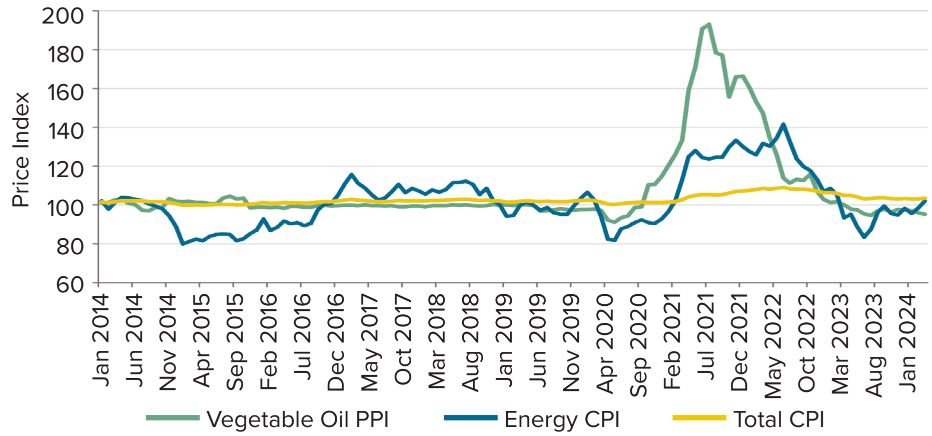
Land expansion into vegetable oils in Brazil and Indonesia was already underway. However, there was a significant increase in the land expansion growth rate after the RD boom, especially in Brazil where the yearly growth rate jumped from 3% to 6%. Figure 2 highlights land-use changes during this period. The left axis is the acreage for Brazil and the United States, while the right axis is acreage for Indonesia.

Trade Flow Changes

The RD boom has affected U.S. vegetable oil trade flows. By 2023, U.S. exports of vegetable oils decreased from 1.2 million MT before the boom to almost zero. Meanwhile, imports increased from 3.5 million MT before the boom to 5.5 million MT in 2023. In short, the United States has almost stopped exporting vegetable oils and significantly increased imports, resulting in the vegetable oil trade deficit doubling (Figure 1).

Because consumption of vegetable oils outside of the United States did not decline, other countries increased exports. Canada, for example, increased canola oil exports to the United States. From 2018–2023, Brazilian soybean oil exports increased by 60%, with a record export number of 1.2 million MT in 2022. When interpreting quantities, one could therefore think of Brazilian exports filling the additional gap in global demand created by the U.S. renewable fuel policies.

Figure 3. Year-Over-Year Energy and Vegetable Oil Price Inflation



Source: Federal Reserve Bank of Saint Louis (2024).
Note: CPI=Consumer Price Index; PPI=Producer Price Index. Energy CPI data accounts for all items a typical household consumes. That includes fuel, electricity, and gas as collected by the Bureau of Labor Statistics. We use PPI for vegetable oils for two reasons: 1) CPI for vegetable oils is skewed toward olive oil, which is not an oil studied here, and is not used as fuel; and 2) the majority of vegetable oils are used in the food industry, thus the inflation is at the food processor level and is passed to consumers through several products.

What Does This Mean for U.S. Consumers?

From cooking oil at home to an input in several processed food products, vegetable oil consumption represents a significant share of the expenditure of U.S. households. The increased demand for vegetable oils for motor fuel has intensified inflationary pressure. Data from the USDA indicates that fats and oils were the food sector with the highest inflation in recent years. Specifically, food at home inflation was equal to 27% from 2018–2024, while fats and oils inflation was equal to 83% over the same period.

While recent inflation was not exclusively caused by biofuels policy, it has certainly played a role in inflation because it drives up the price of both vegetable oils and motor fuel. Figure 3 shows that the correlation between energy and vegetable oil inflation has never been as high as it is now, especially after the RD boom. Note the variability of energy inflation in the 2016 to 2019 period but no corresponding movement in vegetable oil or food inflation. In contrast, the two have been moving together since 2021, which is when the use of vegetable oils for fuel really picked up (Figure 1).

Discussion

Fully understanding the net impacts of the biofuel mandates is complicated. It is important to account for the unintended secondary impacts of the biofuel policies discussed in this article. These policies have increased global demand for vegetable oil as a feedstock, resulting in more land being converted to vegetable oil crops, especially in Brazil and Indonesia. This land-use effect can have significant environmental consequences because some of this land conversion results in deforestation, as is the case for palm oil in Indonesia.

The additional vegetable oil imported by the United States is not necessarily used in the production of RD, but instead goes into food use, backfilling the gap in supply. The state of California (through its agency CARB) measures CI scores for RD. But that measure falls short in capturing all of the environmental effects since CARB only measures the land-use effects of vegetable oil directly used in RD production. Failing to fully capture the environmental effects of increased land conversion leads to overestimating any reduction in greenhouse gas emissions associated with the LCFS policy. CARB seems to be aware of this issue, as discussed in their latest Staff Report, and is making progress in terms of more accurately measuring the CI of biofuels.

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