Cerulogy

Animal, vegetable or mineral (oil)?

Exploring the potential impacts of new renewable diesel capacity on oil and fat markets in the United States

Dr Chris Malins and Dr Cato Sandford

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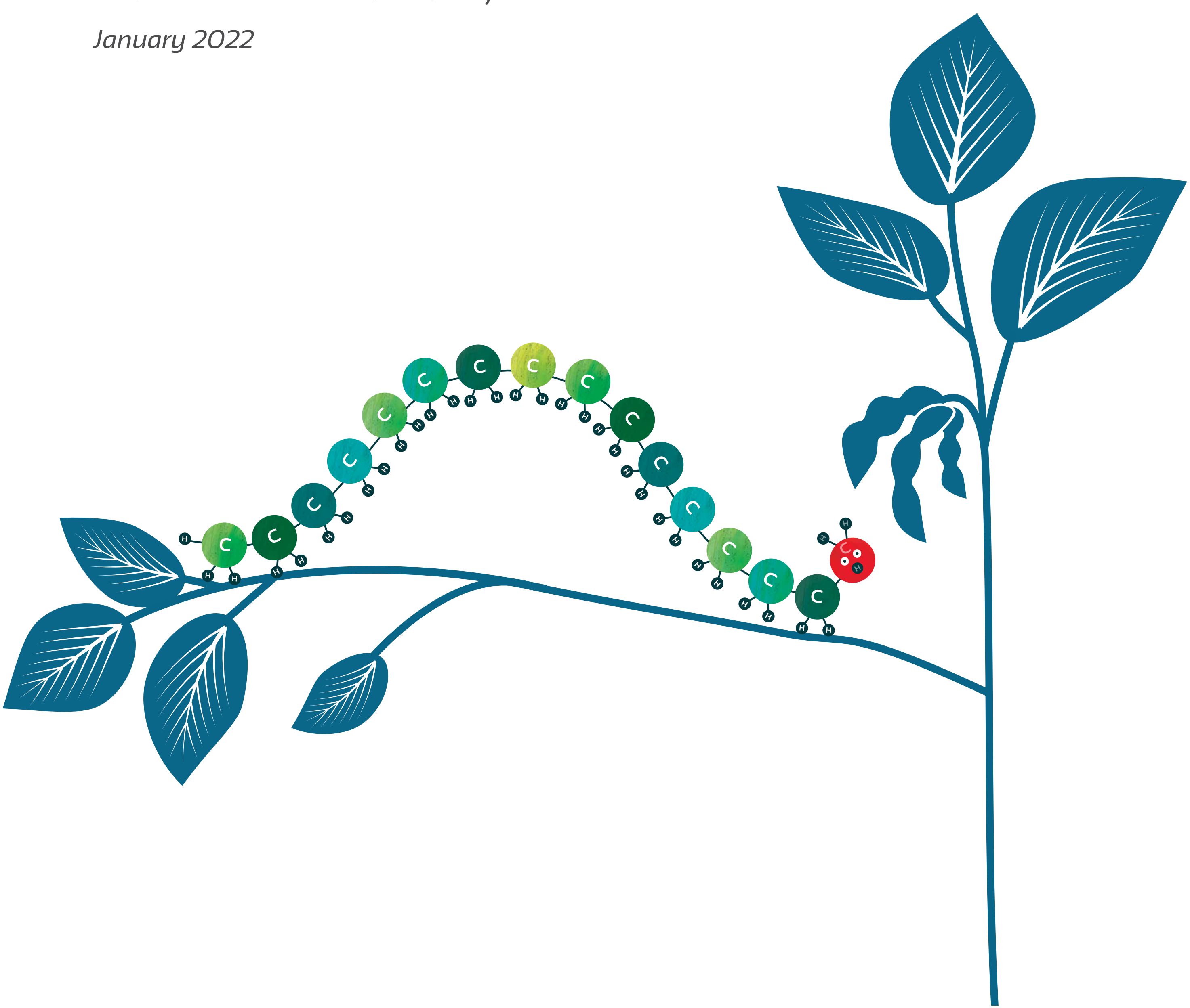

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Summary

The production of renewable diesel by hydrotreating oils and fats has expanded rapidly around the world over the past decade. Unlike conventional biodiesel, renewable diesel is chemically similar enough to fossil diesel that it can be used in existing diesel engines with no blend limit. The process can produce renewable jet fuel as a co-product with minor modifications. The United States currently supports renewable diesel supply through the federal Renewable Fuel Standard, a biomass-based diesel blenders tax credit, and state level policies such as the California Low Carbon Fuel Standard and Oregon Clean Fuels Program. Based on recent credit values under these programs, this stack of policy support could be worth $4 per gallon for waste-oil-based renewable diesel supplied in California. The U.S. currently has about 800 million gallons of renewable diesel production capacity, and in 2020 produced about 500 million gallons.

The generous policy environment for renewable diesel has inspired a cascade of announcements of new projects, including new standalone facilities, conversions of existing refinery units and co-processing with fossil fuels at existing refineries. The Energy Information Administration reports that if all of these announced plans come to fruition renewable diesel production capacity in the U.S. would increase fivefold by 2024, from just under 1 billion gallon a year to more than 5 billion gallons per year (Figure 1). Running all of those potential facilities at full capacity would create 17 million metric tons of additional demand for oils and fats.

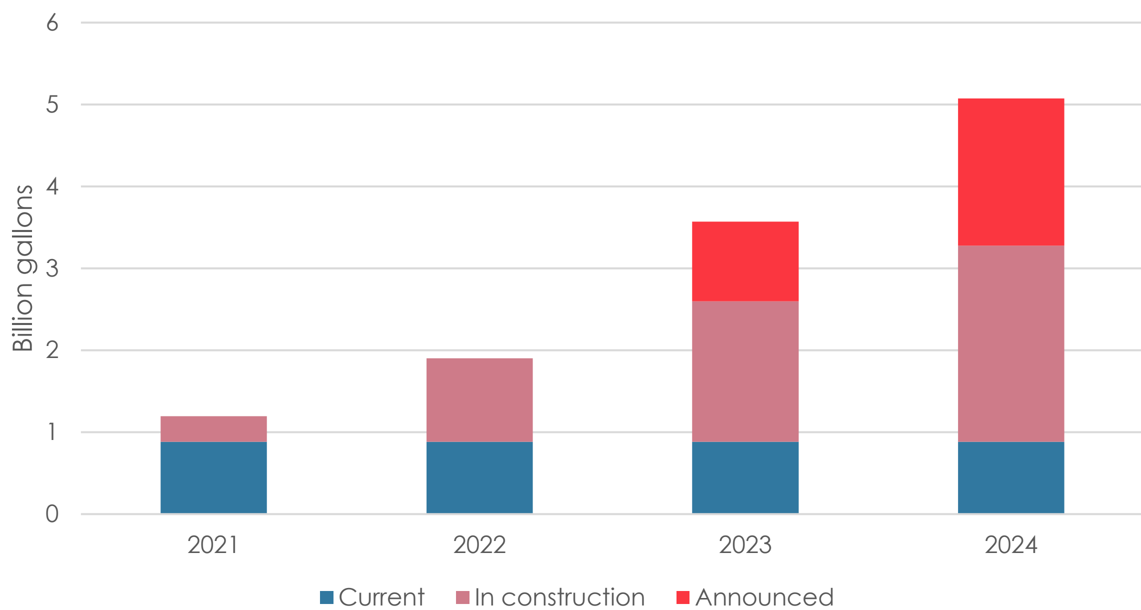

Figure 1. Announced renewable diesel production capacity expansion

Source: U.S. EIA (2021h)

If this capacity expansion could be delivered, it would represent a massive shift in the U.S. biofuel industry. Already the growth of renewable diesel production is impacting feedstock markets, with many analysts identifying growth in renewable diesel as a factor contributing to recent record soy oil prices. It is difficult to see how the millions of metric tons of vegetable oil that would be needed to supply a 5 billion gallons a year industry could be delivered. Predicted increases in domestic soy oil production could support perhaps another 300 million gallons of production, and increased utilization of waste and residual oils another 150 million gallons. Beyond this, increasing production would mean either dramatic unforeseen expansion of domestic soy and canola area, dramatic increases in canola and palm oil imports, or massive displacement of feedstock from other uses (or a combination of the three). Domestic biodiesel production is likely to be strongly impacted, with waste oils and fats in particular diverted to renewable diesel production for supply to the West Coast.

In practice, it seems highly unlikely that the full announced capacity expansion will be delivered. Limits on feedstock availability and limits on the support available for renewable diesel production from the RFS and other policies mean that the market will not support a 5 billion gallons industry as soon as 2024 (if ever). We expect that the next five years will see some projects delayed or cancelled, and some running far below nameplate capacity.

Even if only a half or a third of the announced capacity is delivered it still represents a massive increase in feedstock demand. There is a high risk that increased U.S. renewable diesel production will indirectly drive expansion of palm oil in Southeast Asia, where the palm oil industry is still endemically associated with deforestation and peat destruction. Consuming millions of metric tons of additional vegetable oil could cause tens of thousands of hectares of deforestation.

In setting recent volume mandates for the RFS, the EPA has stated that it is reluctant to mandate excessive growth in advanced biofuel requirements because of the risk that delivering more and more biomass-based diesel could cause market distortions and lead to CO_2 emissions from land use change. The current ramping up of the renewable diesel industry is an attempt to deliver that excessive growth, and there seems to be a very great risk that those undesirable market distortions will be realized. For states with low carbon fuel standards and similar programs, there is a question to be answered about whether unlimited growth in local renewable diesel supply is the best way to deliver on climate goals. If a major outcome of these policies is to suck in resources that would otherwise be supplied as biodiesel elsewhere, and thereby undermine the existing biodiesel business, that has little net climate benefit. Similarly, if the rapidity of vegetable oil demand increases leads to social damage through high food prices and to ILUC emissions as oil palm expands to compensate, that also will have little net climate benefit. It may be appropriate for state programs to consider limiting the contribution from renewable diesel.

More generally, the growth in vegetable oil hydrotreating as a biofuel pathway risks distracting investment from cellulosic biofuel technologies that are still not in wide operation at commercial scale, but that in the long-term could be more scalable, more sustainable, and cheaper.

Contents

1. Introduction

When the Renewable Fuel Standard (RFS) was first introduced in 2010, two types of biofuel dominated the U.S. and global markets – ethanol (used in gasoline engines) and fatty acid methyl ester (FAME) biodiesel (used in diesel engines). Both of these fuels are subject to blend limits, generally up to 10% ethanol by volume in gasoline and up to 5% biodiesel by volume in diesel. More recently a third technological pathway has been commercialized, with global production of 'renewable diesel', also referred to as hydrotreated vegetable oil (HVO), reaching about 7.5 billion liters in 2020 REN 21 (2021). Like biodiesel, renewable diesel substitutes fossil diesel fuel in the transport fuel supply, but unlike biodiesel renewable diesel is chemically similar enough to fossil diesel that there is no limit on the amount that may be blended without damaging vehicles. Renewable diesel relies on the same feedstock base as biodiesel – vegetable oils, including waste oils, and animal fats (henceforth "oils and fats"). It is therefore associated with the same sustainability challenges as biodiesel, such as the risks of driving indirect land use change (Malins et al., 2014) and putting upward pressure on food prices (Malins, 2017a). The main oils and fats used as feedstocks for biomass-based diesel supplied to the U.S. are soy oil, canola oil, distillers' corn oil (DCO)[1], used cooking oil (UCO)[2] and animal fats[3].

Renewable diesel is produced by treating oils and fats with hydrogen to remove oxygen and output hydrocarbon molecules. Renewable diesel may be produced at two types of facility. It can be produced at standalone oil and fat hydrotreating facilities, or it can be co-processed with petroleum at existing oil refineries. In the first case, the output is an entirely renewable fuel. In the second case, only some fraction of the output fuel may be treated as renewable.

To date, the vast majority of oil and fat hydrotreating capacity has been directed towards production of on-road diesel substitutes. In the coming decade, however, there is likely to be an increasing focus on alternative aviation fuel production. The International Civil Aviation Organisation is introducing the CORSIA emission offsetting system, under which alternative fuels use may contribute to airline obligations (ICCT, 2017); the Biden administration in the U.S. has declared a "Sustainable Aviation Fuel Grand Challenge" (The White House, 2021) to support the deployment of increased volumes of alternative aviation fuel; and the European Commission has proposed a mandate for aviation alternative fuel use in its ReFuelEU policy (European Commission, 2021). Hydrotreated oils and fats for aviation applications are often referred to as 'HEFA' (hydroprocessed esters and fatty acids). The process for renewable jet fuel production from oil and fat feedstocks is essentially the same process as for renewable diesel production (in practice, renewable jet fuel production generally requires fractionating and where necessary upgrading the output from hydrotreating facilities so that renewable jet fuel may be produced alongside renewable diesel).

This report provides an overview of the state of the renewable diesel market in the United States. It reviews the support available for renewable diesel under alternative fuel support policies and current and planned renewable diesel production capacity. It considers the

1 Distillers' corn oil is oil recovered from corn after fermentation for ethanol production and is not considered fit for human consumption.

2 Also referred to as yellow grease.

3 Including tallow from cattle, white grease from hogs and poultry oil.

implications of renewable diesel capacity growth for oil and fat markets and for the existing biodiesel industry, and it reviews the potential environmental impacts of increased renewable diesel production.

2. Policy support for renewable diesel

Renewable diesel costs more to produce than conventional fossil diesel, and therefore policy support is necessary to make renewable diesel production commercially viable. The most important U.S. policy instruments for renewable diesel producers are the Renewable Fuel Standard, the biomass-based diesel blenders tax credit, and state level incentives for decarbonizing transportation fuel such as the California Low Carbon Fuel Standard and the Oregon Clean Fuels Program. Even if renewable diesel production capacity grows very rapidly, the actual quantity of renewable diesel or jet fuel that gets supplied will be determined in large part by the level of regulatory support available.

2.1. Renewable Fuel Standard (RFS)

The RFS mandates fuel suppliers in the U.S. to supply minimum quantities of renewable fuels alongside the supply of petroleum fuels. The RFS is divided into several tiers with their own mandated supply levels. The mandates which are relevant to hydrotreated renewable diesel are:

1. The biomass-based diesel mandate, which is a mandate for supplying diesel-substitute fuels that deliver a reportable GHG emission saving of at least 50%. It is met by supplying biodiesel and renewable diesel, and is a sub-category of the advanced fuel mandate.
2. Advanced fuel mandate, which is a mandate for supplying fuels that are not produced from corn and that deliver a reportable GHG emission saving of at least 50%. It is met mainly with biomass-based diesel, renewable natural gas, and non-corn ethanol, and is a sub-category of the renewable fuel mandate.
3. Renewable fuel mandate, which is a mandate for any renewable fuels that can deliver a reportable GHG emission saving of at least 20% or are produced in facilities that had started construction by the end of 2007 ("grandfathering"). It is met by the supply of fuels covered by the advanced mandate plus corn ethanol and any other biofuels (such as biomass-based diesel from palm oil) that do not qualify as advanced but meet the standard to be counted as renewable.

The RFS works through the award of renewable identification numbers (RINs) for the production or import of biofuels, and different types of RIN are awarded to different types of biofuel. The relevant RIN codes for renewable diesel are D4, D5 and D6. D4 biomass-based diesel RINs are awarded to renewable diesel that meets the minimum GHG reduction requirement for advanced biofuels and is not co-processed with fossil petroleum. D5 advanced RINs are awarded to renewable diesel that meets the minimum GHG reduction requirement for advanced biofuels but is co-processed with fossil petroleum. D6 renewable RINs are awarded to renewable diesel that does not meet the minimum GHG requirement for advanced biofuels but that either meets a 20% GHG reduction or can be supplied under the grandfathering provision.

The supply of biomass-based diesel in the U.S. has historically been primarily driven by the advanced biofuel mandate. This is illustrated in Figure 2, where it can be seen that in general the generation of RINs for biomass-based diesel fuels has closely tracked the advanced fuel mandate. The above-mandate generation of biomass-based diesel RINs in 2016 may reflect the fact that the biomass-based diesel blender tax credit was approved in advance for that year, whereas in most other years it has only been activated retrospectively (see next section).

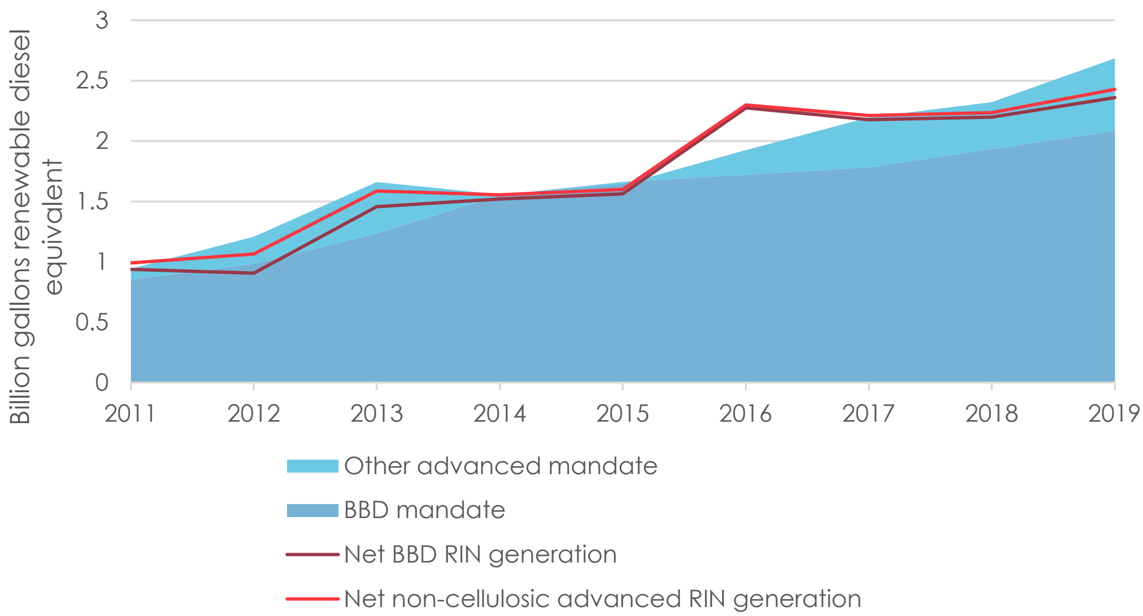

Figure 2. Renewable volume obligations and net* RIN generation for biomass-based diesel and for non-cellulosic non-biomass-based-diesel advanced fuels**

Source: U.S. EPA (2021b), U.S. EIA (2021e)

**Here net RIN generation is the number of D4 and D5 RINs generated by biomass-based diesel and all advanced fuels, minus the number of RINs presumed retired for the volume of biomass-based diesel exported from the U.S. in each year according to U.S. EIA (2021e).*

***The biomass-based diesel and cellulosic fuel mandates are nested within the advanced fuels mandate; here we show the remnant obligation that may be met with other advanced fuels or with additional cellulosic fuel or biomass-based diesel.*

If the advanced biofuel mandate of the RFS remains the main determinant of biomass-based diesel supply in future years, then the prospects for utilization of new renewable diesel capacity will depend on the level of future mandates. A proposed rule setting the 2022 biomass-based diesel standard and the 2020, 2021 and 2022 advanced biofuel standard was released by the EPA in December 2021 (U.S. EPA, 2021a). The proposed mandates are shown in Table 1. The non-cellulosic advanced fuel mandate for 2022 is set at the statutory minimum level of 2.9 billion gallons renewable diesel equivalent (RDE; 5 billion gallons ethanol equivalent), of which at least 2.4 billion gallons RDE must be biomass-based diesel.

Table 1. Proposed RFS volume mandates to 2022, billion gallons RDE

	2020	2021	2022
Non-cellulosic advanced biofuels	2.4	2.7	2.9
Biomass-based diesel*	2.1	2.1	2.4
Other advanced fuel	0.3	0.6	0.5

Source: U.S. EPA (2021a)

**Biomass based diesel mandates for 2020 and 2021 were already set*

Given that biomass-based diesel has historically made a large contribution to the remnant of the advanced fuel obligation and that the U.S. Congress has extended the biomass-based diesel tax credit to 2022, it is reasonable to assume that most or all of the 500-million-gallon RDE increase in mandated advanced fuel volume from 2020 to 2022 will be biomass-based diesel – but how much of this could be supplied as renewable diesel?

As shown in Figure 3, since 2016 increases in the overall biomass-based diesel supply have been delivered by increasing the supply of renewable diesel, with a downward trend in biodiesel supply volumes. Given this existing trend and the ongoing capacity expansions discussed later in this report, it seems likely that most or all growth in advanced biofuel supply to 2022 will be renewable diesel.

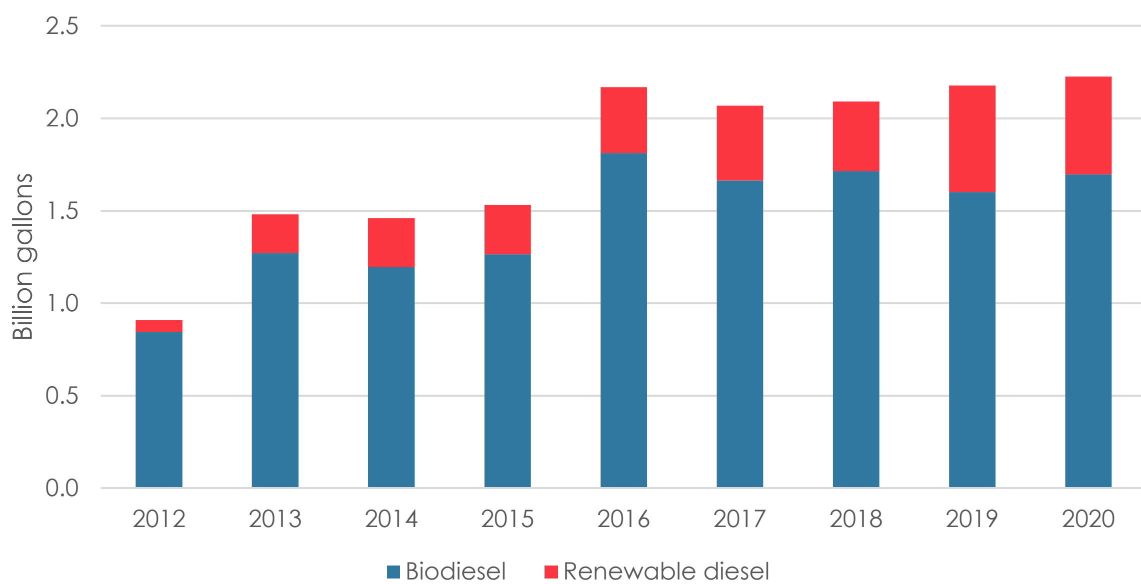

Figure 3. Supply of biodiesel and renewable diesel under the RFS (RDE)

Source: U.S. EPA (2021a)

2.2. The biomass-based diesel tax credit

The U.S. Government provides a tax credit of $1 for every gallon ($0.26 per liter) of biodiesel or renewable diesel blended with petroleum diesel and supplied to the U.S. market (AFDC, 2021a). The tax credit is available to suppliers of both domestically produced and imported fuels. The tax credit is currently in place through 2022. Unlike the RFS, which is discussed in the next section, the tax credit does not identify any specific target for volume of biomass-based diesel supplied, and therefore it may be considered a secondary driver in terms of determining supplied volumes.

The role of the tax credit as a supply driver is further complicated by the fact that it has a history of lapsing and then being retrospectively reinstated (U.S. EIA, 2020b), so that for most of the past decade biomass-based diesel suppliers could not guarantee that they would receive the credit at the time at which fuel was supplied.

2.3. California Low Carbon Fuel Standard

As well as receiving considerable support from federal incentives, renewable diesel supplied in California can generate credits under the Low Carbon Fuel Standard (LCFS). The LCFS is a state-level complement to the RFS, under which suppliers of lower carbon intensity energy to transport receive tradable credits which are used by fossil fuel suppliers to meet carbon intensity reduction targets. When renewable diesel is supplied to California it therefore becomes eligible to generate LCFS credits in addition to receiving RINs and the tax credit. Renewable diesel is particularly appealing as a compliance option under the LCFS due to the lack of a blend limit, as company obligations may be challenging or impossible to meet solely by blending conventional ethanol and biodiesel at current blend limits (cf. Malins, 2018b). Renewable diesel is the only compliance option under the LCFS for which fuel supply can be readily increased without requiring specialist vehicles or changes to blend limits, and increasing the supply of renewable diesel has proved to be one of the simplest ways for fuel suppliers to generate additional LCFS credits. In 2019 the supply of renewable diesel to the California market reached 600 million gallons (Figure 4).

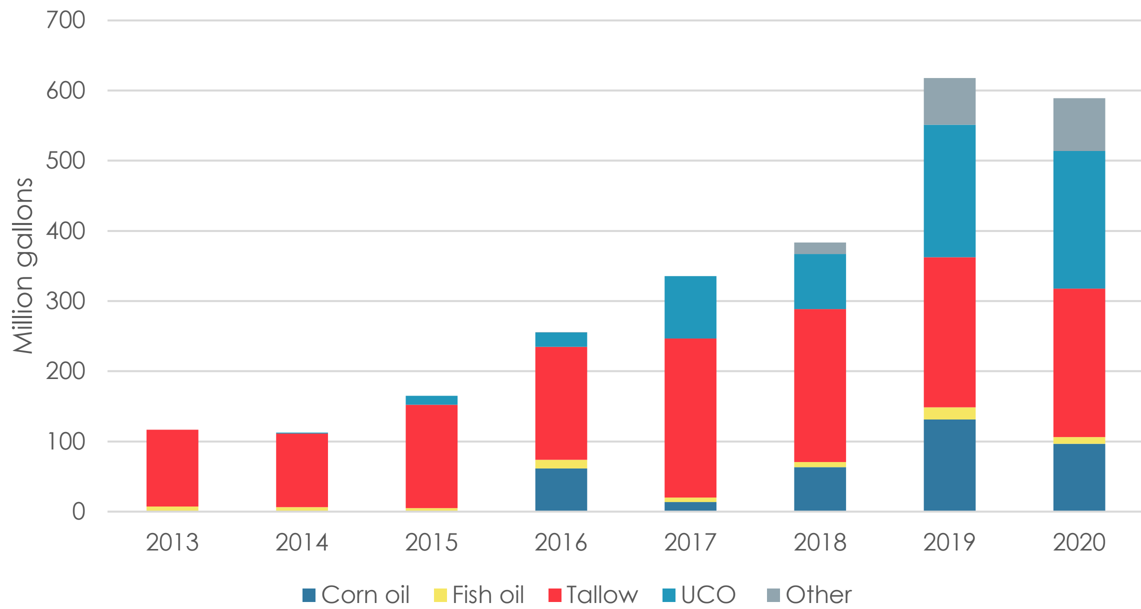

Figure 4. Renewable diesel supply by feedstock under the LCFS

Source: CARB (2021a), volumes inferred from credit generation and assumed carbon intensities.

Since the start of 2020, the average price reported for LCFS credit trades is 194 $/t$CO_2$e (CARB, 2021c). At that credit price, the LCFS could be worth between $0.70 and $1.70 per gallon of renewable diesel supplied, depending on feedstock and carbon intensity. The lower value, $0.70 per gallon, is consistent with a soy oil based renewable diesel with a carbon intensity of 60 gCO_2e/MJ. The higher value, $1.70 per gallon, is consistent with a used cooking oil based renewable diesel with a carbon intensity of 20 gCO_2e/MJ. The extra value available to waste-oil-based renewable diesel under the LCFS system means that the renewable diesel supplied to California overwhelmingly uses waste-oil feedstocks, and no use of soy oil is reported.[4]

This added value for renewable diesel suppliers makes California the most attractive market in the U.S. – for example Fuels Institute (2020) estimates that 80%-85% of renewable diesel consumption in 2017 and 2018 was by the California market, while the Department of Energy's Alternative Fuels Data Center notes that, "Nearly all domestically produced and imported renewable diesel is used in California due to economic benefits under the Low Carbon Fuel Standard" (AFDC, 2020).

The LCFS continues to increase in stringency, with a 20% carbon intensity reduction from the baseline required by 2030. A significant part of this will be delivered by electric vehicles (cf. Malins, 2018a), but there is also a considerable opportunity to further increase renewable diesel supply. For example, California Advanced Biofuel Alliance (2019) present an aggressive vision for diesel substitution in California, suggesting that fossil diesel could be eliminated by the supply of 2.8 billion gallons of renewable diesel (quadrupling the current rate of supply)

4 No soy oil renewable diesel is identified in the California statistics, but some fuel is identified with feedstock 'other'. Feedstocks are further discussed in chapter 5.

plus 700 million gallons of biodiesel. The California Air Resources Board itself is more moderate. In 'illustrative compliance scenarios' published in 2018 (CARB, 2018), CARB considers scenarios with up to 1.8 billion gallons of renewable diesel and jet fuel being supplied.

2.4. Oregon Clean Fuels Program

Oregon has a Clean Fuels Program (CFP) that is similar to the California LCFS, and therefore is another attractive market for renewable diesel supply. Since the start of 2020, the average price for CFP credits has been 127 $/tCO_2e$, which is equivalent to a value of $0.50 per gallon of renewable diesel supplied at a carbon intensity of 65 gCO_2e/MJ and $1.24 per gallon of renewable diesel supplied at a carbon intensity of 20 gCO_2e/MJ.

Oregon data (Oregon DEQ, 2021b) shows that renewable diesel consumption in the state reached 18 million gallons in 2020 (Figure 5). This is still only a fraction of consumption in California, but shows that the CFP is starting to make Oregon a market of interest for renewable diesel supply.

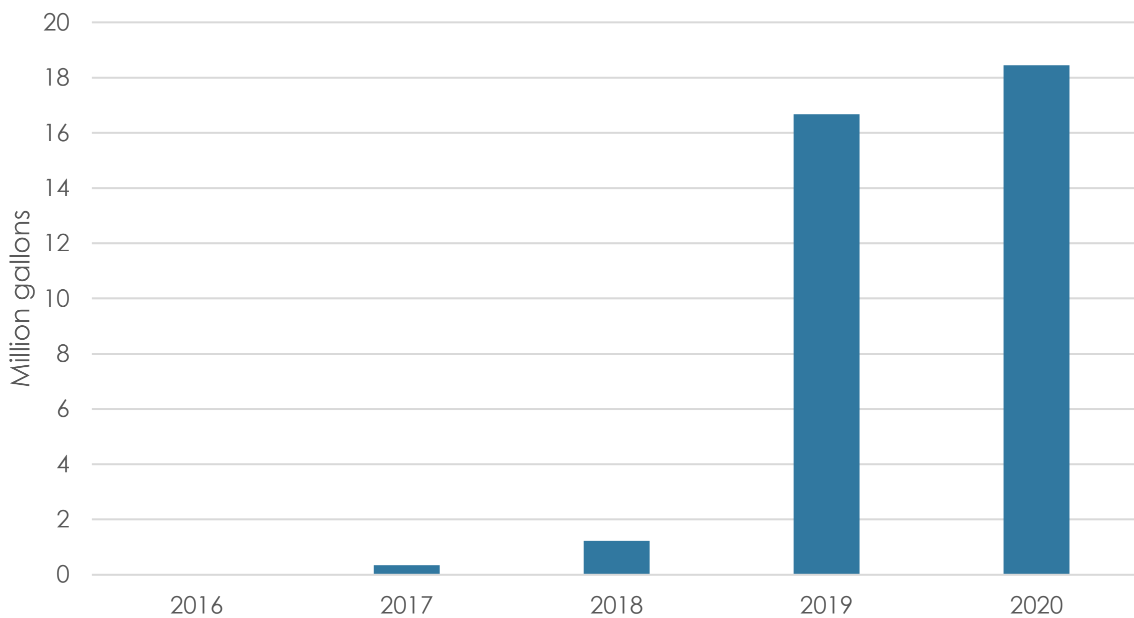

Figure 5. Renewable diesel consumption in Oregon

Source: Oregon DEQ (2021b)

The only renewable diesel producer with pathways registered under the Oregon CFP is REG-Geismar, with pathways for UCO, DCO and animal fats. There are also generic temporary pathways for waste based and virgin vegetable-oil-based fuels. Data released through UC Davis (see Figure 6) shows that the feedstock mix for renewable diesel in Oregon is dominated by tallow.

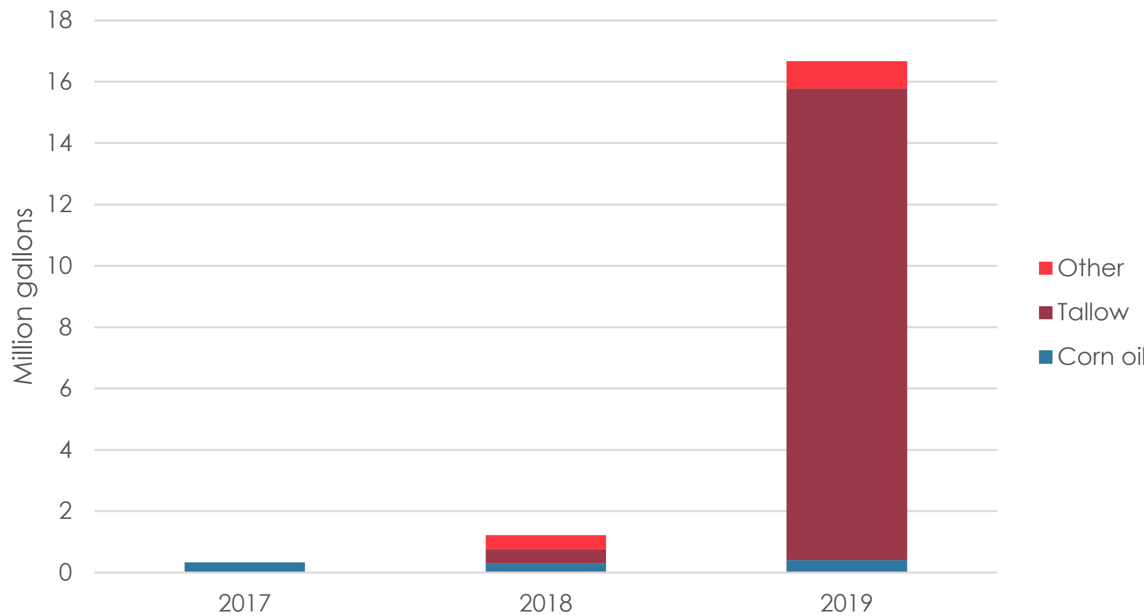

Figure 6. Feedstocks for renewable diesel supplied under the Oregon CFP

Source: Smith (2020)

2.5. Overall value of support

The combination of federal support through the RFS and tax credit with state support through LCFS-like programs represents a compelling value proposition for renewable diesel producers.

Figure 7 compares the cost of renewable diesel production as reported by Brown et al. (2020) to the value proposition for renewable diesel. The cost range reflects variation in feedstock cost and different business models (co-processing, refinery conversion, standalone facility). The value proposition is based on an indication of the 'energy value' of the fuel based on the price of a gallon of fossil diesel fuel (Lane, 2021), the value of the biomass -based diesel blender tax credit, and the potential value of the D4 RIN and of state credits (see note to table for explanation of ranges illustrated). Renewable diesel production is potentially profitable when the value proposition including regulatory incentives is greater than the production costs.

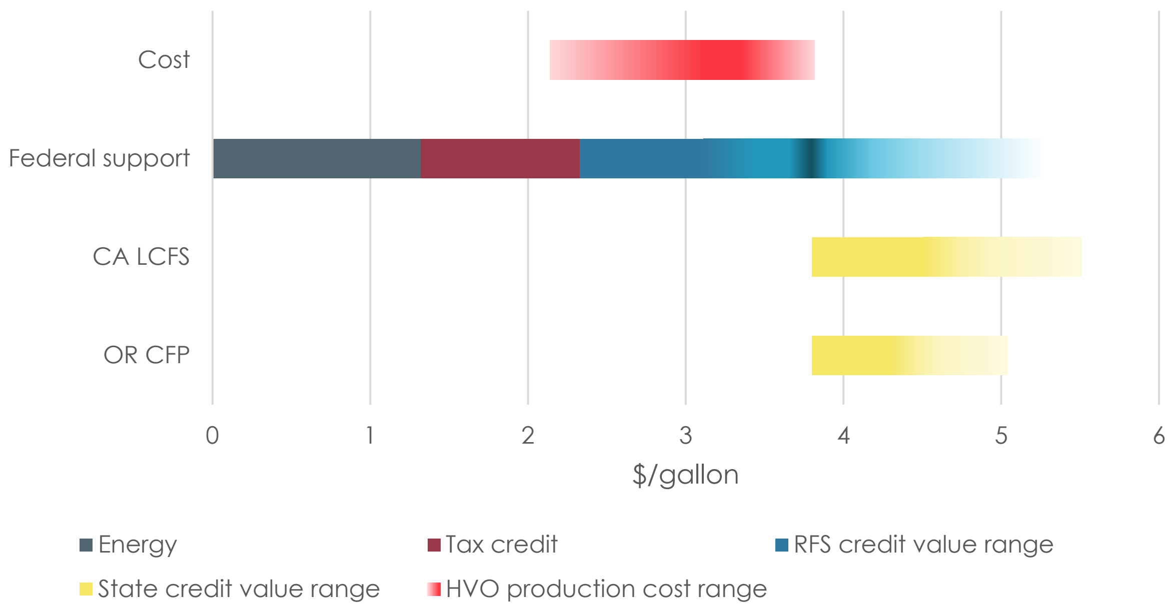

Figure 7. Indicative cost and value for renewable diesel sold into the California market

Source: Brown et al. (2020), Lane (2021), CARB (2021c), Oregon DEQ (2021a), U.S. EPA (2021d)

Production cost range as reported by Brown et al. (2020), energy value as reported by Lane (2021). RFS credit value ranges show value given minimum reported price since start of 2020 (solid part of bar) and then range to highest reported price since start of 2020 (shown as gradient, with average price since 2020 indicated by darker color). Range for state credits is based on average reported credit price since start of 2020 and ranges for renewable diesel carbon intensity from 20 to 60 gCO2e/MJ for California and from 20 to 65 gCO2e/MJ for Oregon (see sections 3.3 & 3.4). State credit value is shown as if added on top of average D4 RIN value since the start of 2020.

It is apparent from Figure 7 that the combination of the tax credit and the value of the RIN is currently likely to be enough to make renewable diesel supply profitable even without the value of state incentives. The state incentives represent a significant boost to the profit margin, however, and thus it is hardly surprising that California and Oregon account for a significant fraction of the national renewable diesel supply (see section 4.3). The Energy Information Administration (EIA) anticipates that the majority of the renewable diesel produced in the U.S. will continue to be supplied to the West Coast for the foreseeable future (U.S. EIA, 2021h). This potentially includes supply to Washington State with the introduction of its own Clean Fuel Standard, scheduled to enter into force no later than 2023 (Washington State Department of Ecology, 2021).

3. Renewable diesel production and capacity

Capacity to hydrotreat oils and fats and produce renewable diesel has increased rapidly over the past decade, supported by the policies mentioned in the previous chapter. This chapter first reviews the production, imports and supply of renewable diesel, and then reviews existing and planned hydrotreated renewable diesel capacity in the United States. It is thereby shown that planned capacity may be outpacing the rate of increase of renewable diesel demand under the RFS and state policies. The following chapter discusses the market implications of this rapid capacity growth.

3.1. Renewable diesel (and renewable jet) production

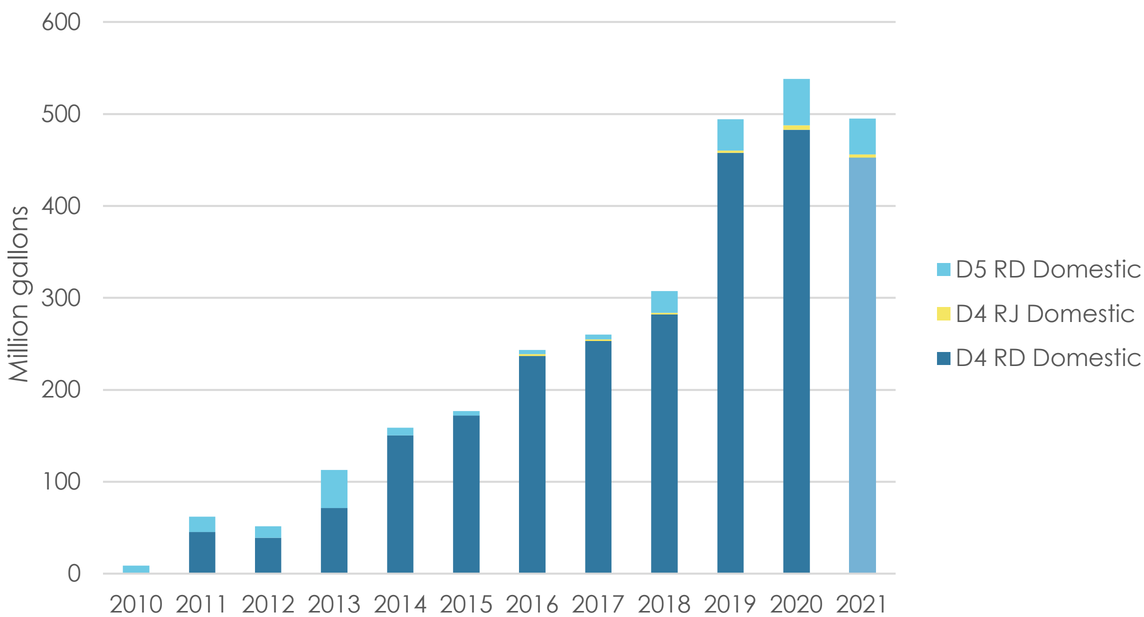

Figure 8. RIN generation by different classes of U.S. produced renewable diesel and jet fuel, 2010 to 2021*

Source: U.S. EPA (2021b)

**Data for 2021 covers January to August only.*

The EIA does not directly publish data on U.S. renewable diesel production, although it does publish estimates of capacity as detailed below in section 4.5. U.S. renewable diesel production can be inferred, however, from reporting by the EPA of the number of RINs generated. Given the considerable value to renewable diesel suppliers from RINs (cf. section 3.5), any renewable diesel producer not receiving support from the RFS would be at a very significant competitive disadvantage, and therefore we assume here that there is no significant volume being produced without generating RINs. It is possible that some volumes of fuel are being produced using feedstocks that do not yet have EPA approved renewable diesel pathways (e.g., canola renewable diesel) and therefore not receiving RINs, but if so we would expect the associated volumes to be small.

Figure 8 shows that in 2020 RINs were generated on 540 million gallons of domestically produced hydrotreated renewable fuels[5], of which 5 million gallons was jet fuel and the rest renewable diesel. Most of this fuel generated D4 RINs – this is domestically produced separately-processed renewable diesel. The fuel generating D5 RINs is co-processed renewable diesel, accounting for a relatively modest 50 million gallons in 2020.

3.2. Renewable diesel imports

In addition to domestic renewable diesel production, the U.S. market is supplied with renewable diesel imports (Figure 9). In 2020 the only country from which the U.S. was identified as importing renewable diesel is Singapore. EIA company-level import data (U.S. EIA, 2021a) shows that all of these imports are reported by Neste Oil, and we therefore assume that all of this imported renewable diesel is produced at the 1.3 million metric ton per year Neste renewable diesel facility there (Neste, 2021).

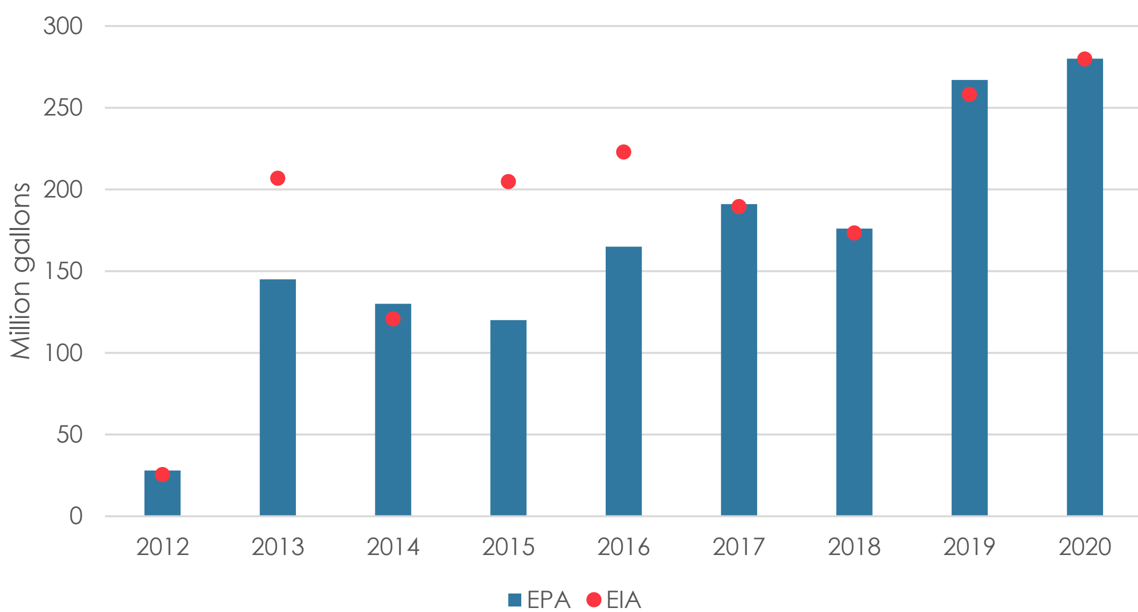

Figure 9. U.S. renewable diesel imports

Source: U.S. EIA (2019b); U.S. EPA (2021a). Note that the EIA and EPA values are not exactly aligned, especially in earlier years. It is not clear to us what the reason for this discrepancy is.

5 Note that not all fuel for which RINs are generated ends up being supplied to the U.S. transportation fuel market. RINs on biofuel supplied to non-RFS markets must be retired, and there is therefore a discrepancy between volumes of fuel on which RINs are generated as shown in Figure 8 and volumes of fuel reported by EPA as supplied to transportation.

Almost all of this material is imported by Neste through California, with the other 15 million liters coming to Oregon (U.S. EIA, 2021a, 2021f). Given that the value signal for renewable diesel is stronger under the California LCFS market than elsewhere in the country (as discussed in more detail in section 3.3), it can be assumed that this imported material is also supplied to the California market. On this basis the current renewable diesel supply to California is about half imports from Neste and half from other sources.

3.3. Renewable diesel exports

U.S. EPA (2021a) identifies a significant increase since 2017 in the volume of renewable diesel being exported from the United States (Figure 10). To the best of our knowledge EIA does not report on renewable diesel exports, and the lack of trade codes to clearly distinguish renewable diesel from other fuels/products makes it difficult to identify the destination for these exports. The only likely markets for renewable diesel exports are Europe and Canada (Bradford & Hayes, 2019), but it is unclear what volumes of renewable diesel has been exported to each.

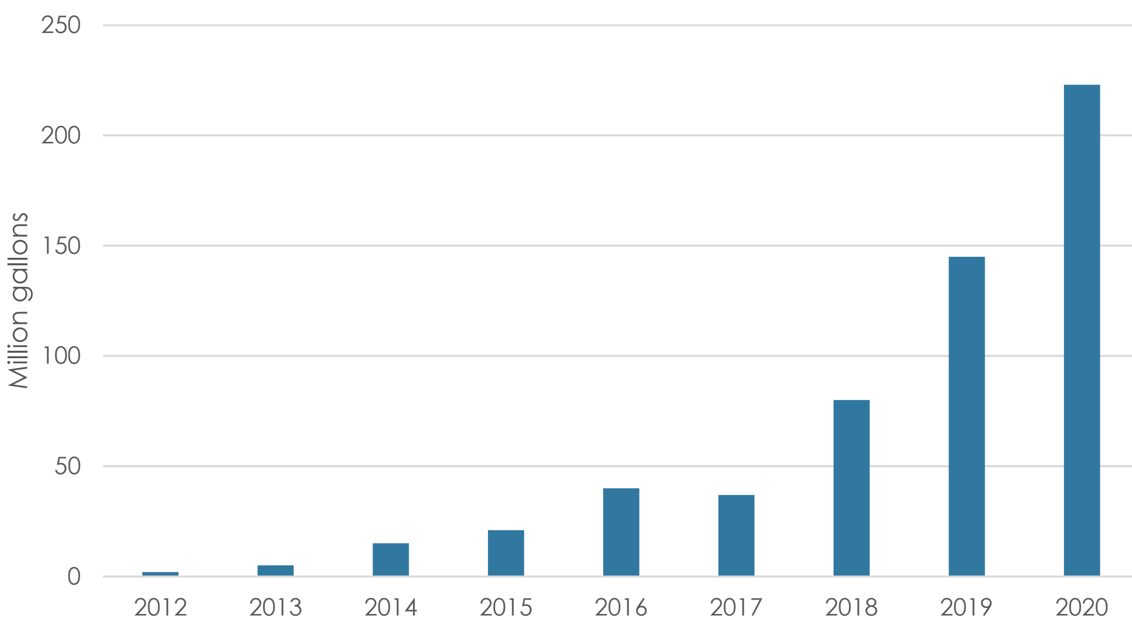

Figure 10. U.S. exports of renewable diesel

Source: U.S. EPA (2021a)

In 2019, for example, Canada is reported to have consumed about 100 million gallons of renewable diesel (ICF Canada, 2020). This is less than the 145 million gallons reported as exported from the U.S. and is likely to include some renewable diesel imported from Singapore and Europe (Bradford & Hayes, 2019). On this basis one could conclude that the U.S. must also be exporting a significant quantity of renewable diesel to Europe – however the USDA Foreign Agricultural Service do not identify the U.S. as a source of exports to Europe (Flach et al., 2021), and we have not found other independent evidence of a significant export flow to the EU. We are therefore unable to draw a firm conclusion about the destination of U.S. renewable diesel exports without access to additional data.

3.4. Renewable diesel supply by region

Data from EPA provides a basis to identify the level of renewable diesel production in the U.S., but there is no national dataset identifying where renewable is being supplied. The volumes of this fuel that are supplied in California and Oregon are reported under the LCFS and CFP respectively, and since 2018 the data suggests that these markets have accounted for 100% of U.S. renewable diesel supply, as shown in Figure 11.

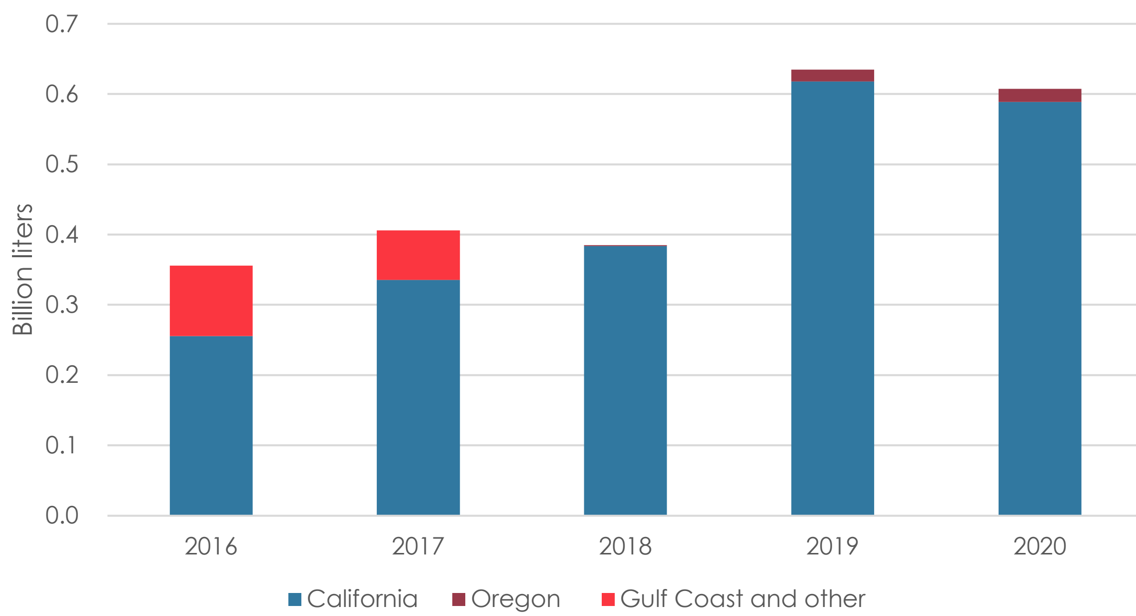

Figure 11. U.S. renewable diesel supply by region

Source: Own estimation based on consideration of CARB (2021a); Fuels Institute (2020); Oregon DEQ (2021b); U.S. EPA (2021a).

It is not trivial to reconcile the various sources of official data on renewable diesel supply, which has resulted in some confusion in the literature about total volumes supplied and whether there is still a significant volume supplied outside of California and Oregon. For example, Fuels Institute (2020) provides detailed estimates of renewable diesel supply by refining region ("PADD", standing for Petroleum Administration for Defense Districts) based on cross referencing data on renewable diesel production and imports and renewable diesel transfers between PADDs which are reported by EIA. In that analysis, the Gulf Coast region (PADD 3) is identified as still consuming a significant amount (over 200 million gallons) of renewable diesel in 2018. This is contradicted, however, by CARB and EPA reporting. Since 2018 CARB has actually been reporting a slightly larger volume of renewable diesel supplied for transportation in California than U.S. EPA (2021a) report as being supplied to the whole country, which suggests that all renewable diesel produced in PADD 3 is now either being shipped to California or Oregon or being exported. We believe that it is likely that the EIA dataset used by Fuels Institute (2020) to identify fuel movements is incomplete – however it is possible that our own analysis has missed something and understates supply of renewable diesel in regions other than from the West Coast.

3.5. Current renewable diesel capacity

The U.S. Energy Information Administration reports that as of the start of 2021 the U.S. had about 800 million gallons of renewable diesel production capacity across 6 plants (Table 2). This does not include co-processing capacity.

Table 2. Capacity of renewable diesel facilities in the U.S.

State	Name	Capacity (million gallons)
Kansas	East Kansas Agri-Energy Renewable Diesel	3
North Dakota	Dakota Prairie Refining LLC	192
Louisiana	Diamond Green Diesel LLC	337
	REG-Geismar LLC	100
Wyoming	Wyoming Renewable Diesel CO	117
California	Altair Paramount LLC	42
Total		**791**

Source: (U.S. EIA, 2021i)

The total capacity has increased during the year and by July had reached about 900 million gallons (U.S. EIA, 2021d).

3.5.1. East Kansas Agri-Energy

The smallest of the listed currently operational facilities, East Kansas Agri-Energy's facility is co-located with an ethanol distillery. East Kansas Agri-Energy state that the facility processes DCO from the ethanol plant along with "other feedstocks processed on the market" (East Kansas Agri-Energy, 2015). They report the corn oil output from the ethanol plant as about 5.5 thousand metric tons; this would cover about half their feedstock demand if operating at full capacity. The only renewable diesel pathway registered for East Kansas Agri-Energy under the LCFS is for DCO (CARB, 2021b).

3.5.2. Dakota Prairie Refining

Dakota Prairie Refining is a converted oil refinery at Dickinson, North Dakota, run by Marathon (Marathon, 2021). Production started at the end of 2020 and the facility is due to reach full capacity by the end of 2021. Dakota Prairie Refining has LCFS pathways for fuel production from soy oil and CDO (CARB, 2021b), and reporting in the business press similarly identify CDO and soy oils as feedstocks[6].

3.5.3. Diamond Green Diesel

Diamon Green Diesel's plant at Norco Louisiana is the largest operational facility in the U.S., and has approved LCFS pathways for UCO, DCO and tallow (CARB, 2021b). The plant produced its first fuel in 2013 and was scheduled for a further capacity expansion during 2021 (Diamond Green Diesel, 2021) – this is likely to be part of the national capacity expansion identified in the EIA statistics between January and July.

3.5.4. REG-Geismar

REG Geismar's plant has LCFS pathway for renewable diesel from UCO, tallow, DCO and soy oil (CARB, 2021b). REG report production of 75 million gallons of renewable hydrocarbons from the plant annually (REG, 2021), which suggests about 75% capacity utilization. For 2018, REG's annual report (REG, 2019) shows soy oil consumption of 160 thousand metric tons, canola oil consumption of 240 thousand metric tons and 'lower-cost' feedstock consumption of 1.4 million metric tons, which is 77% of total feedstock consumption. These feedstock quantities cover both renewable diesel and biodiesel production.

3.5.5. Wyoming Renewable Diesel

The Wyoming Renewable Diesel plant was developed by The Sinclair Companies but was recently sold to HollyFrontier, becoming part of the HF Sinclair Corporation[7]. The plant has only a soy oil pathway registered under LCFS (CARB, 2021b), but HollyFrontier's website states that it supplies both soy and tallow biodiesel to California[8].

3.5.6. Altair Paramount

The Altair Paramount facility, now owned by World Energy, has LCFS pathways for renewable diesel from soy oil, and for tallow from the U.S., Canada, and Australia (CARB, 2021b). It is notable for having been one of the first producers of hydrotreated aviation fuels.

6 E.g. https://www.ogj.com/refining-processing/refining/article/14208184/marathon-completes-start-up-of-north-dakota-renewable-diesel-refinery; https://www.nsenergybusiness.com/projects/dickinson-renewable-diesel-facility/

7 https://uk.finance.yahoo.com/news/hollyfrontier-corporation-holly-energy-partners-100000254.html

8 https://hollyfrontier.com/investor-relations/press-releases/Press-Release-Details/2021/HollyFrontier-Corporation-and-Holly-Energy-Partners-Announce-Combination-with-Sinclair-Oil-and-Formation-of-HF-Sinclair-Corporation/default.aspx

3.5.7. Capacity utilization

Comparing the domestic RIN generation recorded in December 2020 (cf. section 4.1) to EIA's estimate of operational capacity on 1 January 2021 gives a 68% rate of capacity utilization for these facilities in that month. RIN generation fell slightly in January 2021 suggesting capacity utilization in that month of 57%.

3.6. Co-processed renewable diesel capacity

Two facilities have pathways to supply co-processed renewable diesel to the California LCFS market. Co-processing refers to the practice of adding some fraction of oils and fats to the petroleum feed of appropriate refinery units, for example the distillate hydrotreaters that are used to reduce the sulfur content of diesel fuel for on-road use. Co-processed renewable diesel is eligible to generate D5 advanced biofuels RINs rather than D4 biomass-based diesel RINs (see section 3.1). As shown in Figure 8 below, this co-processed renewable diesel is a small fraction of the overall renewable diesel supply.

Co-processing rates of up to 30% renewable content are reported in the literature (Johnson, 2019), and it is our understanding that rates of 10-15% may be typical in co-processing facilities. Kern Oil in California reports that they include up to 5% renewable content in their finished diesel (Kern Oil & Refining Co., 2020). The other renewable diesel co-processor is BP's Cherry Point refinery, which Lane (2021) identified as having capacity to produce up to 42 million gallons a year.

The 50 million gallons of renewable diesel generating D5 RINs in 2020 (cf. section 4.1) is consistent with BP's Cherry Point refinery running at or near its reported capacity with some modest additional production by Kern Oil (see section on co-processing capacity above).

3.7. Expansions to renewable diesel capacity

Hydrotreated renewable diesel (and jet) production capacity is currently increasing rapidly, not just in the United States but around the world. Analysis by U.S. EIA (2021h) of capacity expansion announcements suggests that capacity could reach 5 billion gallons by 2024. This assessment from EIA is not a forecast, rather it is a summary of what would be delivered if all announced projects are built on schedule. In practice this is unlikely – it is normal for some projects to be cancelled or delayed due to changing circumstances, and any forecast for the amount of capacity growth that will be achieved in practice should take this into account. For example, one forecast by ADI Analytics (Singh & Turaga, 2021) suggests that capacity growth will occur more slowly, reaching 2.6 billion gallons per year in 2024, while S&P Global Platts (2021b) predict 4 billion gallons capacity in place by 2025.

There are several more projects that have already been announced but that are unlikely to become operational by 2025. Building on a list of announced projects published by the Biofuel Digest (Lane, 2021) we have identified a total of 6.4 billion gallons of capacity at some stage of project development. These capacity numbers are illustrated in Figure 12, and the identified projects are listed by status in Table 3.

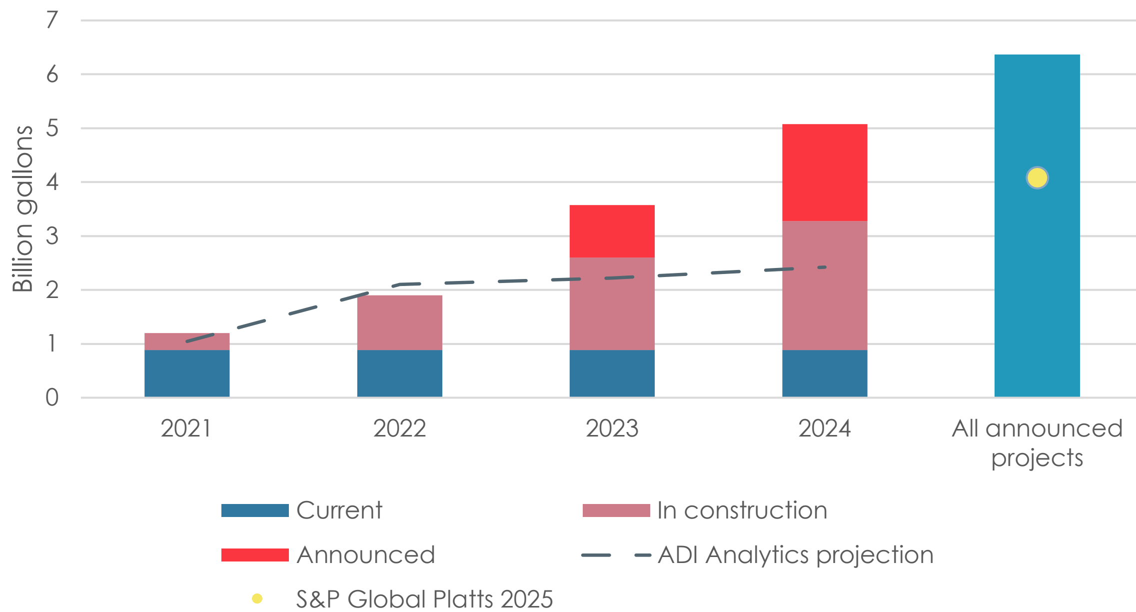

Figure 12. Potential growth in renewable diesel production capacity

Source: U.S. EIA (2021h), Lane (2021), S&P Global Platts (2021b), Singh & Turaga (2021)

It is unclear what feedstocks will be processed by the new plants coming online. The Biofuel Digest identifies the feedstock for the vast majority (6.1 billion gallons of capacity) as some combination of waste oils and virgin vegetable oils, and only 130 million gallons is identified in their database as processing waste only. Many project plans are non-committal about the potential split between use of soy oil and other oils and fats. For example, the largest four planned facilities are Marathon's refinery conversion at Martinez, Phillips 66's refinery conversion at Rodeo, Grön Fuels in Louisiana and Next Renewables. Marathon intend to process, "renewable feedstock sources including rendered fats, soybean and corn oil, and potentially other cooking and vegetable oils, but excluding palm oil" (TRC Solutions, 2021). Phillips 66 similarly state that "renewable feedstocks processed at the facility would include, but not limited to, the following: UCO; FOG; tallow (animal fat); inedible corn oil; canola oil; soybean oil; other vegetable-based oils, and/or emerging and other next-generation feedstocks (Cardno, 2021). The Grön Fuels project in Louisiana will process "soybean oil, corn oil and animal fats" (Office of Governor John Bel Edwards, 2020). The Next Renewables facility in Oregon will process, "Used cooking oils; animal tallows; seed oil; and soy oil", but no palm oil (Next Renewable Fuels, 2021). In short, the renewable diesel industry will seek to use whichever mix of feedstocks is most profitable given the balance between feedstock price and availability and the value of regulatory support.

Table 3. Targeted production capacity for renewable diesel facilities in the U.S.

Status	Facility	Target capacity (million gallons)
Operating	BP Cherry Point	40
	NextChem-Saola Energy-East Kansas Agri-Energy	10
	Holly Frontier Sinclair	120
	Total:	***160***
Expanding	Diamond Green Diesel Norco	680
	REG Geismar	340
	World Energy Paramount	300
	Total:	***1,320***
In conversion	Global Clean Energy Holdings	130
	Marathon Dickinson	180
	Total:	***310***
Under construction	CVR Wynnewood	100
	Diamond Green Diesel Texas	470
	Total:	***570***
Planning	ARA ReadiDiesel	30
	Emerald Biofuels	110
	Grön Fuels	900
	Holly Frontier Cheyenne	200
	Marathon Martinez	780
	Next Renewables	770
	Phillips 66 Rodeo	800
	Ryze Renewables Las Vegas	170
	Ryze Renewables Reno	170
	St. Joseph Renewable Fuels	90
	Total:	**4,010**
Grand Total		**6,370**

Source: U.S. EIA (2021h), Lane (2021), Barber & Godwin (2021), Bomgardner (2020)

4. Impacts of increased renewable diesel capacity on the oils and fats market

The boom in biodiesel and renewable diesel has meant that biofuel production has become a major consumer of oils and fats. OECD-FAO (2021) reports that 14% of virgin vegetable oil consumption in the U.S. is now for biofuels (70% is for human consumption and the rest is for 'other' uses such as oleochemicals). The lower value waste and residual oils and fats that can be used as feedstock could also potentially find uses in other markets such as animal feed. Increasing renewable diesel production therefore has implications for other oil and fat markets. In this chapter, we consider the implications for feedstock markets if the levels of renewable diesel capacity expansion identified in section 4.7 were to be achieved as additional supply. Chapter 6 then discusses that in practice the expansion of renewable diesel might instead result in a displacement of feedstock away from the biodiesel sector.

We are not aware of any comprehensive federal level reporting on the feedstocks used for renewable diesel in the U.S., but as we believe that all or almost all renewable diesel in the U.S. is supplied to the California and Oregon market the feedstock mix can be inferred by cross referencing LCFS credit generation data from CARB and Oregon DEQ with carbon intensity pathways under the LCFS and CFP[9] and renewable diesel supply data from EPA (CARB, 2021a; Oregon DEQ, 2021b; U.S. EPA, 2021a). The national renewable diesel feedstock mix estimated on this basis is shown in Figure 13. As the EPA do not publish renewable-diesel-specific feedstock information, the additional fuel volumes supplied away from the West Coast are identified as 'other'. Waste and residual oils are the dominant feedstocks for the renewable diesel supplied to California, accounting for at least 500 million gallons of supply in 2020. There is also some material supplied to the California market listed as "other" – we understand that this 'other' category includes fuel supplied using temporary carbon intensity pathways and could also include some soy renewable diesel.

9 Carbon intensity assumptions are required to estimate volumes from credit generation.

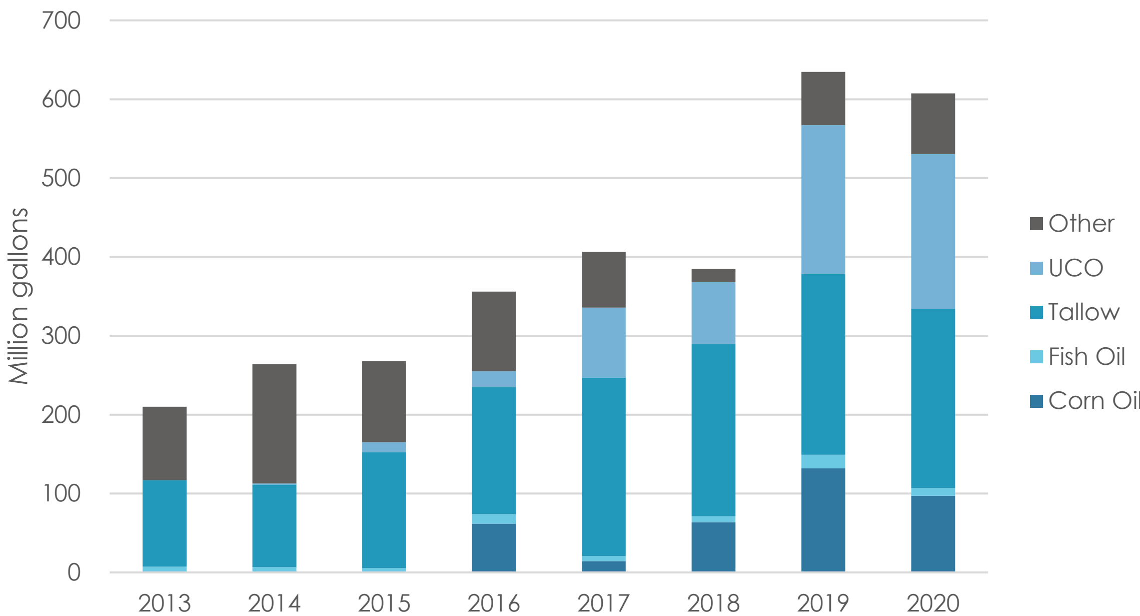

Figure 13. Estimated feedstock breakdown for renewable diesel supplied in the U.S.

Source: Own estimation based on cross-referencing data from EPA, Oregon DEQ and CARB.

While Figure 13 shows an estimated feedstock breakdown for all renewable diesel supplied in the U.S., a recent change in the way that the EIA reports on biofuel feedstock use provides a basis to estimate the feedstock mix for renewable diesel produced in the U.S. The EIA has for some years published data identifying feedstocks for biodiesel production excluding renewable diesel, but since the start of 2021 this has been replaced by a new data product detailing the U.S. feedstock mix across all biofuels (U.S. EIA, 2021b), which groups biodiesel and renewable diesel together. For 2021 up to July the overall mix of oils and fats used as biomass-based-diesel feedstocks is shown in Figure 14.

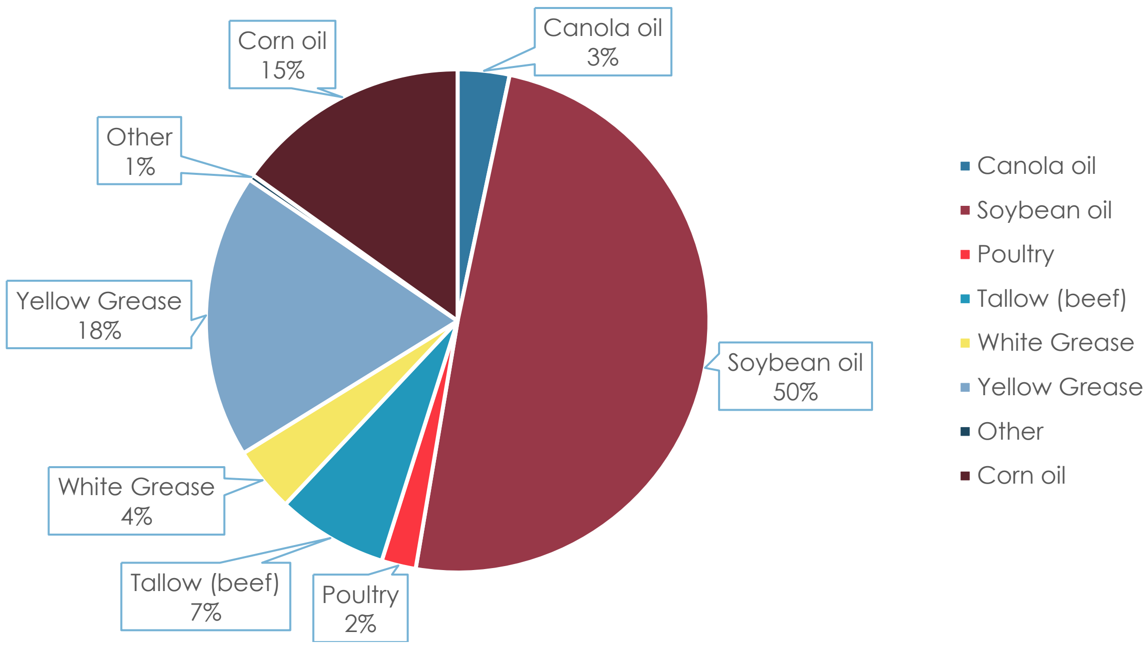

Figure 14. Feedstock mix for oil- and fat-based biofuels in the U.S., January to July 2021

Source: U.S. EIA (2021b)

While the new EIA data does not explicitly distinguish renewable diesel feedstocks from biodiesel feedstocks, the change in the scope of the EIA data at the end of 2020 from biodiesel only to biodiesel plus renewable diesel makes it possible to draw inferences about the national feedstock mix for renewable diesel production. This can be done by looking at the difference between the biodiesel plus renewable diesel feedstock mix at the start of 2021 and the biodiesel-only feedstock mix at the end of 2020. Assuming that the feedstock composition for renewable diesel is somewhat stable, the change in reported feedstock use between the old and new data can be taken as indicative of the feedstock used for renewable diesel. Figure 15 shows the feedstock mix obtained by taking the difference between the reported feedstocks for biodiesel only in the second half of 2020 and the reported feedstocks for all biomass-based diesel in the first half of 2021. As we would expect, this analysis confirms that U.S. renewable diesel production is dominated by the feedstocks reported for renewable diesel supplied in California (UCO, animal fats, DCO). Comparing Figure 13 to Figure 15 we see that there appears to be a larger fraction of animal fats used for the renewable diesel supplied in the U.S. than for domestic production. This suggests that animal-fat-based fuels make up a large fraction of imports, but given that the data for both of these figures are derived based on making assumptions on related datasets we are cautious of drawing firm conclusions from the differences between them. Taken together, the California and EIA data suggest that there is at most a relatively limited use of soy oil as a feedstock for renewable diesel supplied in the U.S.

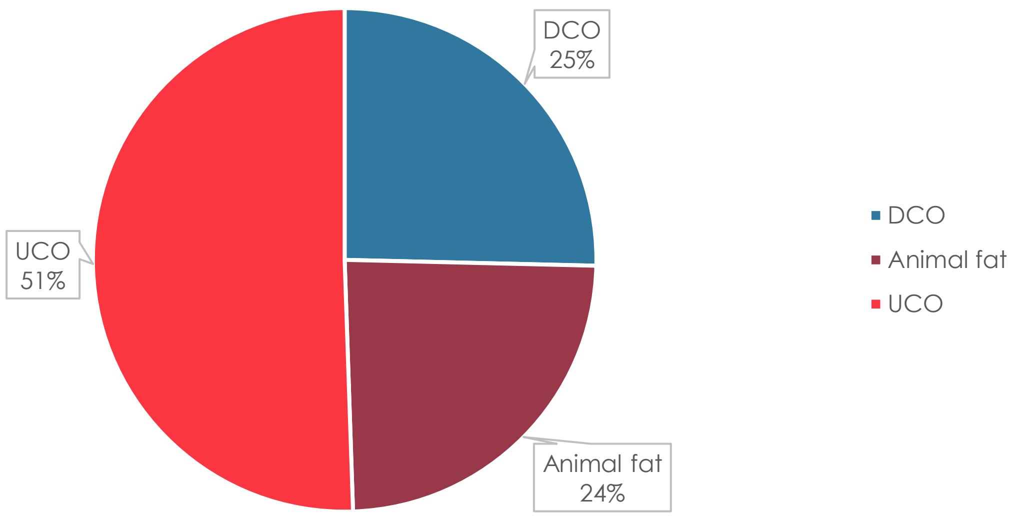

Figure 15. Renewable diesel feedstock mix implied by difference between EIA datasets

Source: Own calculation based on U.S. EIA (2021b) and U.S. EIA (2019a), see main text.

While virgin vegetable oils are not currently used (to any large extent) for renewable diesel production, they remain important for the biodiesel market as shown in Figure 14. As noted in section 4.7 most planned renewable diesel facilities in the U.S. identify virgin vegetable oils as potential feedstocks. Looking at all biomass-based diesel production in the U.S. (including biodiesel), soy oil and canola oil remain important. Extrapolating data up to September from U.S. EIA (2021b) for feedstocks used for all biomass-based diesel suggests that in 2021 the industry will consume around 3.9 million metric tons of soy oil and 600 million metric tons of canola oil, plus 1.1 million metric tons of DCO and 2.5 million metric tons of other waste and residual oils and fats. These numbers are similar to estimates of soy use for fuel for the 2020-21 marketing year from (USDA ERS, 2021) and from the World Agricultural Supply and Demand Estimates (USDA, 2021b).

4.1. Feedstock availability

The rate of planned renewable diesel capacity expansions has caused some analysts to predict a squeeze on vegetable oil supplies. If all of the announced capacity identified by U.S. EIA (2021h) were to come online as announced and operate at 100% of capacity, total feedstock consumption for renewable diesel would increase by 17 million metric tons, a factor of 10 by 2024 (Figure 16). In April, Reuters reported[10] that BMO Capital Markets had predicted an incremental demand increase for soy oil of 3.6 million metric tons by 2023. This would be

10 https://www.reuters.com/business/energy/us-renewable-fuels-market-could-face-feedstock-deficit-2021-04-09/

consistent with about a third of the additional capacity identified for 2023 by the EIA producing soy-oil-based fuel.

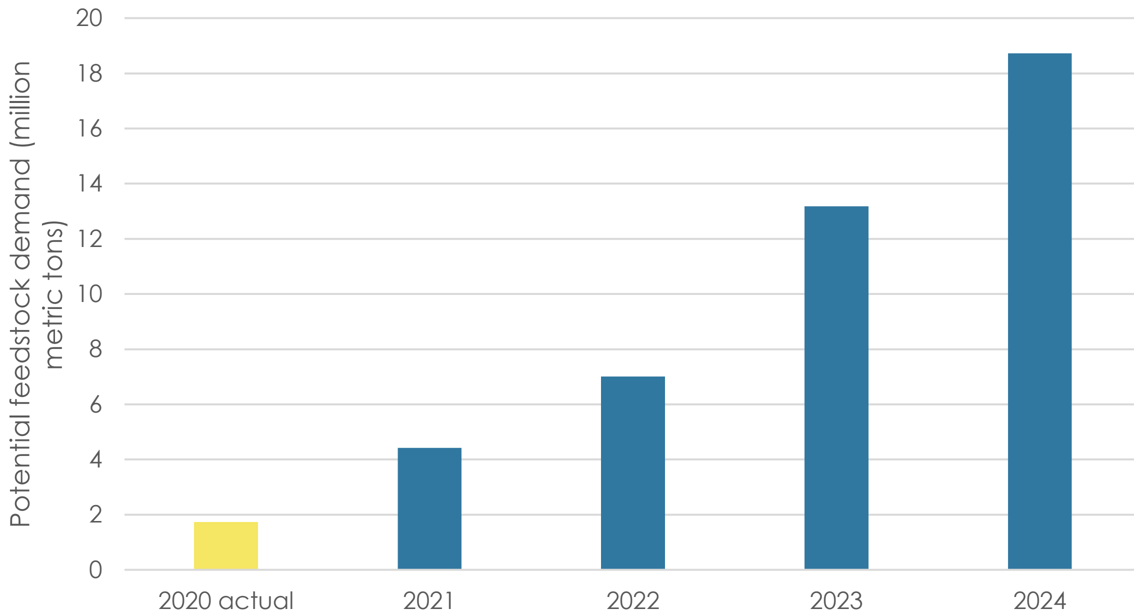

Figure 16. Potential feedstock demand for renewable diesel if all announced projects produced at 100% of capacity

Source: calculated based on U.S. EIA (2021h)

This is not an insignificant increase in demand. The United States currently produces slightly less than this amount as virgin vegetable oil[11], about 14 million metric tons of vegetable oils a year in total. It consumes roughly the same amount of vegetable oil in food applications (OECD-FAO, 2021). This shows that consumption of food-grade oils for biofuel production is supported by U.S. net vegetable oil imports. Indeed, historically increases in biomass-based diesel production in the U.S. have coincided with increases in vegetable oil imports (Figure 17), including in particular imports of palm oil and canola/rapeseed oil (cf. Searle, 2014).

11 Not including waste vegetable oils and animal fats.

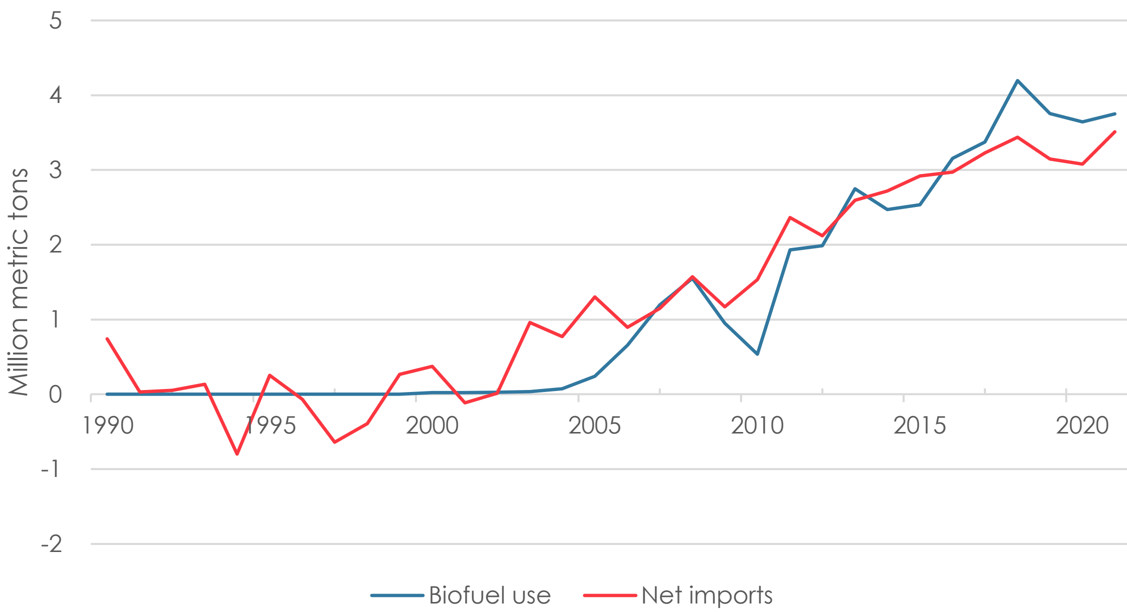

Figure 17. Increases in U.S. consumption of vegetable oils for biofuel production and in net vegetable oil imports, 1990 to 2021

Source: OECD-FAO (2021)

It is not realistic to expect all announced facilities to be completed on time and to achieve full utilization, but let us consider what would be needed to deliver even half of this maximum rate of expansion in the 2025 timeframe. To achieve 2.5 billion gallons of additional renewable diesel production without displacing other uses would require an increase in feedstock supply by 7.6 million metric tons.

OECD-FAO (2021) projects a 200 thousand metric ton increase in U.S. vegetable oil production from 2020 to 2025. The projection for soy oil production only from the World Agricultural Supply and Demand Estimates (WASDE) (USDA, 2021a) is more aggressive, anticipating a 1.2 million metric ton increase between the 2020/21 and 2025/26 seasons alongside a 1.4 million metric ton increase of the use of soy oil for biofuels, but this is still well short of the scale required.

There may also be some potential to increase collections of waste/residual oils and fats, but this is likely to be limited. In setting the 2021 biomass-based diesel obligation, the EPA noted that, "Most of the waste oils, fats, and greases that can be recovered economically are already being recovered and used in biodiesel and renewable diesel production or for other purposes." U.S. EPA (2021a) suggests that production of biofuels from waste and residual oils and fats may be expected to increase at about 30 million gallons a year, based on extrapolating the trend seen from 2012 to 2020. That implies an increase in supply of about 550 thousand metric tons by 2025. Zhou et al. (2020) reviews the potential for increased supply of waste oils and fats, but also for increases in demand from other markets. There is some prospect of increased generation of animal fats associated with increased livestock numbers, but Zhou et al. (2020) finds that demand for animal fats from other markets is expected to increase faster than production so that there will be no increase in availability for biofuels. (Zhou et al., 2020) finds a better outlook for UCO availability, with an increase of about 120 thousand metric tons from 2020 to 2025.

It is noted in U.S. EPA (2021a) that production of biofuels from DCO could in theory be increased by 200 million gallons per year, but that this would "require shifting distillers corn oil from other existing uses" which would then need to be met with alternative materials, and would therefore only shift rather than resolve the overall feedstock supply issue. DCO production is expected by Zhou et al. (2020) to decrease after 2020 in line with an anticipated reduction in corn ethanol supply volumes, but more recent USDA projections have ethanol consumption stable from 2020 to 2030 (Interagency Agricultural Projections Committee, 2021). U.S. EPA (2019) anticipated that increased deployment of corn oil extraction from distillers' grains would allow for modest production increases (suggesting 50 a thousand metric ton increase from 2019 to 2020), but EIA data suggest that biofuel production from DCO in fact fell slightly in 2020 (U.S. EIA, 2020a). In any case, removal of additional corn oil from distillers' grains would increase feedstock availability for renewable diesel production, but proportionately reduce the mass and calories available in distillers' grains used for animal feed. Based on the analysis in Zhou et al. (2020) it seems reasonable to conclude that the EPA's 550 thousand metric tons can be taken as a maximum on the additional supply of these resources that could be available for biofuels by 2025.

Adding the USDA forecast for increased soy oil production to the EPA forecast for increased use of waste oils and fats gives a total supply increment from 2020 to 2025 of 1.75 million metric tons – only a quarter of what would be needed to deliver 2.5 billion gallons of production per year. This implies that if renewable diesel production expands in line with current plans, then either the feedstock must be displaced from other current users or U.S. vegetable oil imports will need to increase dramatically to compensate.

4.2. Imports of waste oils and fats

The U.S. is currently understood to be a net exporter of UCO. Fuels Institute (2020) identifies UCO with HS code 15 18 00[12], and UN Comtrade (2020) data shows exports of up to 350 thousand metric tons a year[13], and more limited imports (Figure 18). The destination of these exports is dominantly Singapore (likely for processing at the Neste facility) and Europe (likely for conversion to biodiesel and supply under the EU Renewable Energy Directive and UK Renewable Transport Fuel Obligation). It is likely that this HS code also includes some material that is sold into non-biofuel markets. USA Trade data also shows significant exports to Singapore of pig fat and tallow (300 thousand metric tons and 50 thousand metric tons respectively in 2020) at prices that could be consistent with biofuel feedstock use.

12 Animal or vegetable fats and oils and their fractions; oxidized, boiled or otherwise chemically modified, (excluding those of heading no. 1516), inedible mixtures or preparations of fats or oils.

13 This is more than reported by (Fuels Institute, 2020); we believe that they referenced USA Trade data which excluded on-road exports.

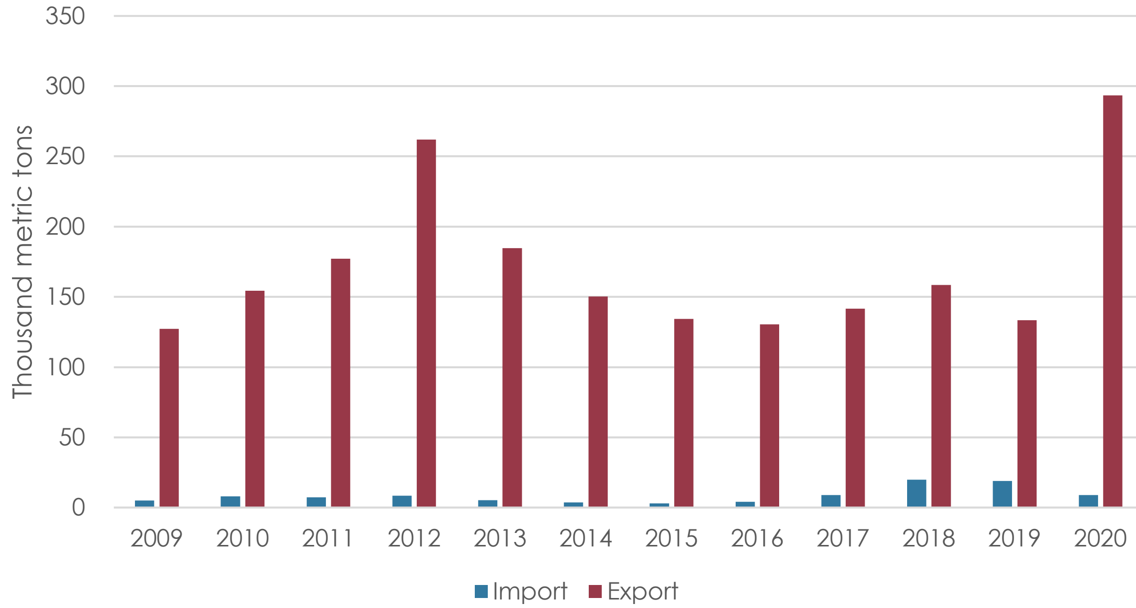

Figure 18. U.S. imports and exports of inedible oils and fats under HS code 15 18 00

Source: UN Comtrade (2020)

Feedstock availability for U.S. renewable diesel production could be increased by reducing U.S. exports of UCO and animal fats. To the extent that these materials are currently exported for processing by Neste in Singapore, this may result in reduced availability of wastes-based renewable diesel for import. Feedstock availability could also be increased by importing UCO or animal fats. The EU biofuel market already consumes large quantities of imported UCO (Flach et al., 2021), and the U.S. could follow this example and increase the sourcing of UCO or other waste oils from overseas.

It is difficult to assess the potential global supply of UCO, as its availability for biofuel use is dependent on building collection networks and supply chains. The growth of the biodiesel industry globally has encouraged the development of UCO collection industries in many countries, but there is undoubtedly still significant potential to increase collection rates. It should be noted that where collection systems already exist, this is generally because markets for UCO already exist as well. This may be local biodiesel production or animal feed use, and in some countries used cooking oil may be 'recycled' as so-called 'gutter oil' and sold to domestic consumers. This last practice is considered undesirable for health reasons and countries such as China are seeking to eliminate it, which could increase potential resource availability for biofuels. It is believed that at the global level there is still substantial scope to increase biofuel production from UCO, and Kristiana et al. (2022) estimates that it may be possible to increase the supply from Asia to other markets by millions of metric tons per year, although this level may not be readily achievable in practice – van Grinsven et al. (2020) suggests global potential closer to 3 million metric tons.

Increasing reliance on UCO imports does, however, create the risk of 'mislabeling fraud' whereby virgin vegetable oils would be incorrectly labelled as used. The added value of UCO-based renewable diesel in the LCFS and CFP markets creates an incentive to misrepresent renewable diesel from palm or soy oil as being UCO based, to increase the number of credits generated (in section 3.3 we suggest that the value difference between UCO renewable diesel and soy renewable diesel in the California LCFS could be as much as a dollar a gallon). Fraud risk in the global UCO supply chain is already an issue of concern in the EU (van Grinsven et al., 2020) and should be taken seriously if the U.S. increases its use of imports.

4.3. Increasing vegetable oil production

In the absence of waste or residual oils able to fill the gap in demand, increased renewable diesel production could only be delivered through increased consumption of virgin vegetable oils. For increased consumption to be possible without significant reductions in consumption for food (this possibility is further discussed in the next section, 5.4) the annual production of vegetable oils would have to increase by millions of metric tons.

In principle there is potential to increase U.S. vegetable oil production beyond the rate predicted in the WASDE by increasing the amount of land devoted to soy and canola. Even though soy oil remains the primary feedstock for biomass-based diesel production in the U.S., it is generally understood that soy oil demand (and price) is only a weak driver of soybean production levels. This is because most of the value of the soy crop resides in the meal co-product (Malins, 2020; U.S. EPA, 2019). Even with a strong demand for additional vegetable oil for renewable diesel processing it is therefore unclear whether soy production could be expected to expand significantly. The canola crop is likely to be more responsive to the oil market (as most of the value of the canola crop is in the oil), but total current canola oil production in the U.S. is only about 700 thousand metric tons (UN Food and Agriculture Organisation, 2020) and so it would seem unlikely that production increases on the level that would be required could be delivered. McCollum et al. (2021) review the extent to which U.S. farmers would be willing to expand oilseed production to meet additional demand from the renewable fuel industry, in particular by replacing a wheat crop or fallow period with a canola crop. They conclude, "that a highly favorable scenario may be needed for oilseed SAF production to be feasible in any of the study region states", i.e., that a large increase in the price of canola would be required to drive increases in production.

Soy oil production in the U.S. could also be increased without increasing total soybean production by increasing the amount of soybeans that are crushed within the U.S. rather than exported to be crushed overseas. The WASDE shows that about half of U.S. soybean production (60 million metric tons) is currently crushed domestically, and the other half exported. In 2020 about half of those exports went to China (UN Comtrade, 2020). Increasing the fraction of U.S. soybean production crushed domestically would allow increased meal exports while increasing domestic soy oil availability. It would simultaneously reduce the availability of soy oil from crushing in other countries, and this deficit would need to be covered with other vegetable oils. In China, for example, the main imported oil is palm oil (USDA FAS, 2021). Reducing soybean exports to China in favor of soy meal exports would be expected to lead to increased palm oil imports to China. While it would certainly be possible to deliver some increase in domestic soybean crush, it should not be taken for granted that markets could readily be found for a large increase in soy meal exports. The global import market for soybeans is many times larger than that for soy meal – for instance UN Comtrade (2020) reports that in 2020 China imported 100 million metric tons of soybeans but only two tonnes of soy meal.

If domestic vegetable oil production is not able to increase to supply the required feedstock for renewable diesel facilities, then the other alternative would be further increases in vegetable oil imports, accompanied by production increases in other countries. Figure 19 shows that since 2003 increased U.S. vegetable oil imports have been delivered by a combination of canola oil (mostly from Canada) and palm oil (mostly from Indonesia and Malaysia).

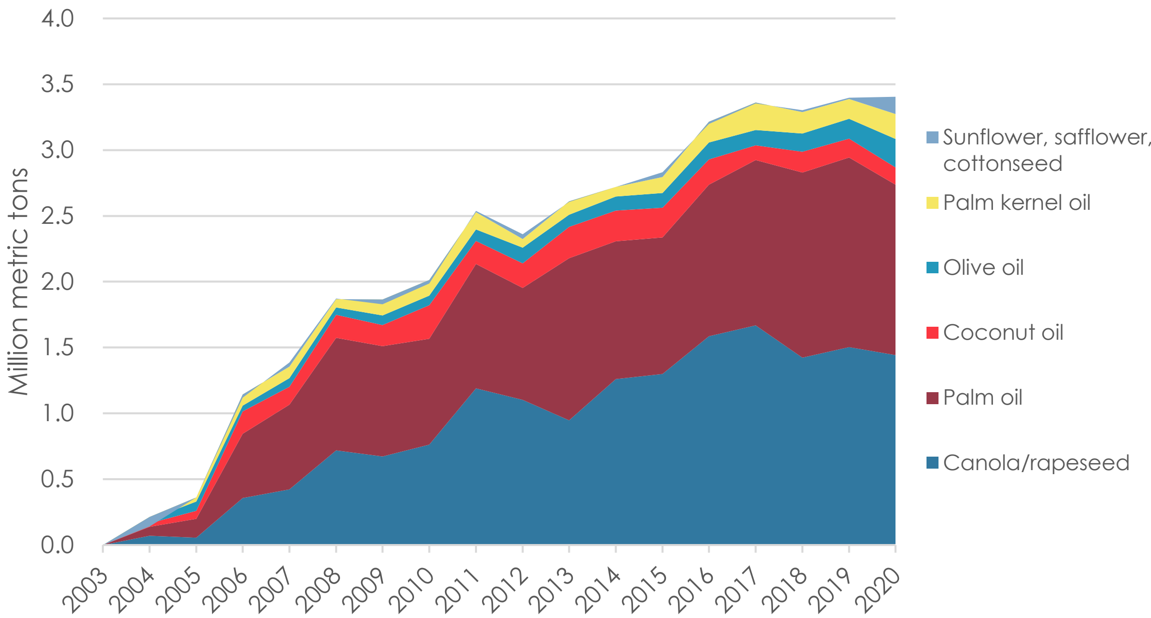

Figure 19. Increase in imports to the U.S. of major vegetable oils since 2003

Source: UN Comtrade (2020)

Increasing the global production of palm oil and/or canola oil might have other negative implications. The palm oil market is considered particularly problematic from a climate change perspective because of the link between palm oil expansion and both deforestation and peat drainage in Southeast Asia (Malins, 2018c). Indirect land use change (ILUC) estimates for the EPA and CARB suggest that increasing palm oil supply results in higher land use change emissions than for any other vegetable oil considered. As a result of these higher ILUC values renewable diesel produced from palm oil cannot generate D4 RINs or LCFS credits, but palm oil demand could still be indirectly increased.

The ILUC analyses by EPA and CARB for soy biodiesel assume that palm oil production increases will play only a limited role in meeting demand for soy oil as a biofuel feedstock. A very rapid expansion of renewable diesel production from soy oil might, however, lead to a much-increased role for palm oil palm oil as a substitute. In that case existing ILUC estimates for soy may systematically understate the link to the palm oil market (see also Santeramo & Searle, 2018).

Overall, it seems reasonable to conclude that delivering as much as 7.6 million tons of additional feedstock for renewable diesel could be expected to result in what the EPA refer to as, "market disruption, higher costs, and/or reduced GHG benefits" (U.S. EPA, 2019).

4.4. Impacts on vegetable oil prices

Indirect land use change impacts are not the only potential negative externality from renewable diesel expansion. A rapid increase in vegetable oil demand would also put upward pressure on vegetable oil prices, with negative consequences for other consumers. The question of the relationship between biofuel demand and food-commodity prices remains contentious. Some analysts continue to argue that the impact of biofuel demand on prices is weak or non-existent, but the more general consensus is that higher demand from the biofuel market does lead to higher prices overall, and that price effects can be most serious if demand increases very rapidly (Malins, 2017a).

Several market analysts have identified the current boom in renewable diesel capacity as a driver of recent price increases in the vegetable oil market (e.g. Maltais, 2021; Stratas Advisors, 2020; Terazono & Jacobs, 2021; U.S. EIA, 2021g). As can be seen from Figure 20, soy oil prices have risen to record highs since the start of 2020. Food producer's organizations such as the American Bakers' Association have called on the EPA to reduce the level of mandates under the RFS in order to reduce pressure on vegetable oil prices (Eller, 2021). With capacity increases scheduled to continue coming online until at least 2025, this upwards price pressure is likely to continue for the foreseeable future.

Figure 20. Soy oil price

Source: Hofstrand (2014)

5. Market implications of capacity expansion

As detailed in the previous chapters, over the next five years or so renewable diesel (and jet) production capacity in the U.S. is set to increase from 800 million gallons a year perhaps to as much as 6.4 billion gallons a year, an eight-fold increase. This rate of capacity increase (of the order of a billion gallons a year) is much faster than the rate of growth in the non-cellulosic advanced biofuel mandate under the RFS. As discussed in section 3.1, since the passage of the RFS2 the level of the non-cellulosic part of the advanced biofuel mandate has been a good predictor of the rate of biodiesel plus renewable diesel supply. Unless there is a significant shift in market dynamics, the size of the advanced mandate could therefore be considered a ceiling on potential renewable diesel supply. The non-cellulosic part of the advanced mandate will increase by 250 million gallons 2021 to 2022, and the annual increase averages 120 million gallons a year for the five years from 2017 to 2022. If renewable diesel meets the whole of that increase in the mandate with no change in biodiesel supply it would result in about 1.3 billion gallons in 2022.

There is nothing in the EPA's recent volume rules to suggest that it would consider it appropriate to propose dramatically higher advanced biofuel mandates after 2022. Indeed, the most recent volume rules have highlighted the risk of negative market and environmental impacts if the supply of biomass-based diesel is further increased (U.S. EPA, 2019, 2021a). In the absence of congressional action there is going to be an apparent inconsistency between the rate of renewable diesel capacity growth and the level of demand created by the RFS. This inconsistency would need to be resolved by some combination of the following outcomes:

1. Supply more U.S. produced renewable diesel to meet the RFS advanced and biomass-based diesel mandates at the expense of reduced biodiesel production;
2. Supply more U.S. produced renewable diesel to meet the RFS renewable fuel mandate at the expense of reduced corn ethanol production;
3. Supply more U.S. produced renewable diesel to meet the RFS biomass-based diesel mandate at the expense of reduced imports of renewable diesel;
4. Dispose of increased renewable diesel production by increasing renewable diesel exports;
5. Rationalization of capacity through capacity cancellations, delays or closures.

In the following sections, we discuss the implications and likelihood of each of these outcomes.

5.1. Supply more U.S. produced renewable diesel to meet the RFS advanced and biomass-based diesel mandates at the expense of reduced biodiesel production

As was illustrated in Figure 3 in section 3.1, even though the supply of renewable diesel has increased significantly in recent years the volume of renewable diesel supplied in the U.S. is still only about half the volume of biodiesel supplied. The volume of biodiesel supplied to the U.S. market peaked in 2016 and has been relatively stable since. One way to accommodate more renewable diesel within the RFS would be to deliver a corresponding reduction in the biodiesel supply, either by reducing capacity utilization or by closing some biodiesel plants. Donnell Rehagen of the National biodiesel Board has previously commented that. "There's a limited pool of feedstock used in production of biodiesel and renewable diesel, and they all rely on that same pool, which is only so big" (Kotrba, 2018).

Renewable diesel has several advantages over biodiesel as a blendstock. It is not subject to blend limitations; it performs consistently better then fossil diesel in terms of air pollution (whereas biodiesel can reduce particulate matter but increase NOx emissions, O'Malley & Searle, 2021); and it has slightly higher energy density. The production costs for the two fuels are both dominated by feedstock (about 75% of the cost for both) but are comparable overall (Brown et al., 2020; Hofstrand, 2014). Capital expenditure requirements are greater for renewable diesel, but still account for less than 10% of levelised cost (Brown et al., 2020). Recent years have seen a number of biodiesel plant closures in the U.S. (S&P Global Platts, 2021b), and EIA data already shows a slight reduction in total U.S. production capacity from a peak of just under 2.6 billion gallons per year in 2019 to 2.4 billion gallons per year in 2021 (U.S. EIA, 2020a, 2021c). Increased competition from renewable diesel production is identified as one reason for these closures (S&P Global Platts, 2021b).

Biodiesel producers whose supply chain is based on waste and residual oils and fats may be particularly vulnerable to competition from renewable diesel producers. This is because those feedstocks will be in high demand for production of renewable diesel to be sold into the California market, where the biodiesel blend wall and NOx limits constrain the potential to increase biodiesel sales. Without access to the value of LCFS or CFP credits, biodiesel producers may not be able to compete with renewable diesel producers to secure waste oil and fat supplies. More than two million metric tons of feedstock could be made available to the renewable diesel industry by reducing production of biodiesel from waste and residual oils, allowing an additional 500 million gallons of renewable diesel production.

While some further shrinkage in the biodiesel sector seems very plausible, fully replacing biodiesel in the U.S. market may be less likely. Outside of the LCFS, CFP and similar regulations, supplying biodiesel from soybean up to a B5 blend should remain a competitive way of generating D4 RINs for compliance with the biomass-based diesel and advanced mandates of the RFS. Several states (e.g., Minnesota, Iowa, New Mexico, Kentucky, North Dakota) have biodiesel blending mandates and/or tax credits that will support continued local use of biodiesel at B5 or B20 blends (AFDC, 2021b).

If national biodiesel consumption was halved over the next five years, this would create space for an additional 900 million gallons of renewable diesel supply contributing to the RFS advanced and biomass-based diesel mandates. This is a significant volume increase, but still much less than the announced capacity increases, and therefore biodiesel displacement alone would not resolve the over-capacity issue.

5.2. Supply more U.S. produced renewable diesel to meet the RFS renewable fuel mandate at the expense of reduced corn ethanol production

Up until now, renewable diesel supply has been primarily supported by the market for D4 and D5 RINs to comply with the RFS advanced and biomass-based diesel mandates, but it is also eligible to contribute to compliance with the much larger renewable fuel mandate. The renewable fuel mandate is currently met primarily with corn ethanol, blended up to 10% by volume in gasoline as 'E10'. The EPA notes in the preamble on the proposed 2022 RFS volume rule that, "the use of E10 alone has not been sufficient to achieve the 15 billion gallons of ethanol use due to declining gasoline demand" and states that the stack of subsidies available to renewable diesel (in particular the blender tax credit, which is not available to ethanol producers) has been enough for it to contribute towards the renewable fuel mandate in recent years (U.S. EPA, 2021c).

If the advanced fuel mandate is more difficult for obligated suppliers to comply with than the renewable fuel mandate (for instance if there is an excess of corn ethanol generating D6 RINs), then D6 RINs trade for lower prices than D4 or D5 RINs. If, however, it is difficult for obligated suppliers to meet their renewable fuel obligations due to a shortage of D6 RINs (for example if corn ethanol supply is limited by the blend wall) then the D6 price will rise to meet the prices of other RINs. Figure 21 shows that the relationship between RIN categories has shifted between these two regimes during the past five years. It can be seen that during 2019 D6 RINs traded for on average about 35% of the value of D4 RINs, whereas during 2021 (up to October) they traded for on average 93% of the price of D4 RINs.[14]

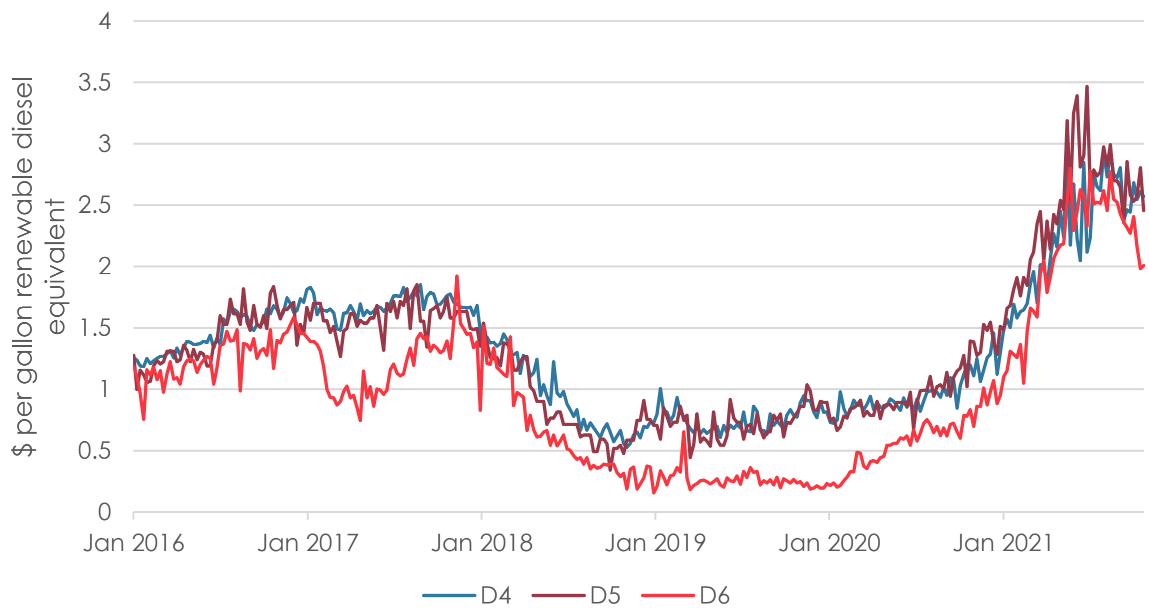

Figure 21. RIN prices in $ per gallon renewable diesel equivalent

Source: U.S. EPA (2021b)

If the price of the D6 RINs were to remain persistently high (above $1 per gallon RDE for example) then this could allow renewable diesel supply to increase beyond the level of the advanced mandate. The non-advanced renewable fuel mandate is set at 8.8 billion gallons

14 Averages taken by weeks, not weighted for number of RINs sold in each trade.

RDE[15] for 2022, and therefore expansion into this part of the market could support a significant fraction of new renewable diesel capacity. The draft impact analysis for the 2022 RFS volume rule (U.S. EPA, 2021a) forecasts that an additional 600 million gallons RDE of renewable diesel will be supplied to make up for a shortfall in corn ethanol supply, bringing total predicted renewable diesel supply to 1.6 billion gallons RDE in 2022 (biodiesel supply is forecast to be more or less static).[16]

5.3. Supply more U.S. produced renewable diesel to meet the RFS biomass-based diesel mandate at the expense of reduced imports of renewable diesel

As discussed in section 4.2, the U.S. imports significant quantities of renewable diesel from the Neste facility in Singapore, most of it for supply to the California market. An increasing availability of domestically produced renewable diesel could result in reduced market space for those imports. While reducing imports would seem an obvious way to increase the scope for supply of domestically produced fuel, in practice we would expect imports to continue for as long as there is a market for them. In particular, Neste's imports rely on the value signal that the California LCFS provides for renewable diesel from waste oils and fats, and this signal should remain strong. As we will discuss in chapter 5, U.S. producers of renewable diesel and biodiesel are likely to end up in intense competition for waste oil and fat resources. The Neste facility in Singapore will be somewhat protected from this increased competition because of its more diversified supply chains (Neste's LCFS pathways suggest that they source material from Asia and Australasia, although some feedstock is also shipped from the U.S. to Singapore for processing, cf. Fuels Institute, 2020). There is plenty of opportunity to supply additional renewable diesel in the California market (about 2.5 billion gallons of liquid fossil diesel that could still be displaced according to CARB, 2018), and so as long as the LCFS credit price remains somewhat robust we would expect that imported renewable diesel from waste oils would be competitive in the U.S. market.

If, however, the value signal in California weakens (as has been predicted by CaliforniaCarbon.info, 2021, for example) then domestically produced soy-oil-based renewable diesel may become more competitive than imports. Displacing imports would make up to 300 million gallons of market space available.

5.4. Dispose of increased renewable diesel production by increasing renewable diesel exports

An alternative (or complement) to reducing imports would be to find new export markets for U.S. produced renewable diesel. The European Union and UK have strong renewable fuel markets under the Renewable Energy Directive and Renewable Transport Fuel Obligation respectively, and in the past the U.S. has at times been successful in exporting corn ethanol and soy biodiesel into the EU market. Increasing interest in renewable jet fuel as an aviation decarbonization option may also create new export opportunities. While European markets

15 15 billion gallons ethanol equivalent.

16 Note however that the EPA state that, "this [extra] volume is assumed to be supplied as imported conventional renewable diesel" rather than domestically produced renewable diesel.

are the most promising destination for exports on face value, European legislation includes limits on the use of food-based biofuels for road transport, and food-based biofuels are set to be excluded entirely from meeting EU aviation fuel mandates (European Commission, 2021). This may limit the appetite for soy-based fuels in Europe, while for producers of waste-based fuels the combined value of the California LCFS, RFS and tax credit is likely to remain as appealing a market as Europe. Exporters would also face competition from producers in the EU itself, where the refiners Eni, Total, Neste and Repsol all have significant existing hydrotreating capacity. It is therefore not at all certain that the EU and UK would represent a viable market for U.S. exports. Canada also has some potential as an export market (and as discussed in section 4.3 may already be taking significant volumes of exported material).

Elsewhere in the world there is potential in principle for markets to open up, but in the past most countries outside Europe and North America have been reluctant to impose biofuel mandates where they cannot be supplied with locally produced fuels. Other regions such as China may be as likely to become competitors as markets (S&P Global Platts, 2021a).

5.5. Rationalization of capacity through capacity cancellations, delays or closures

As noted in section 4.7, it is not inevitable that the full number of capacity additions to the renewable diesel market that have now been announced will actually be built. For example, Stratas Advisors (2020) suggests that a 400-million-gallon investment by Valero in Port Arthur may be reconsidered given potential for overcapacity, while S&P Global Platts (2021b) report that CVR Energy are delaying a planned hydrocracker conversion due to high feedstock costs. Given the tension in the feedstock market, the lack of certainty about the direction of the RFS mandate beyond 2022 and the limited number of export options for U.S. producers, it is possible to be quite confident that more of the announced capacity additions will be delayed or cancelled. It is rather more difficult, however, to predict exactly how much capacity will be realized.

Above, we noted that delivering production of 2.5 billion gallons of fuel, half of the potential capacity identified for 2024 by the EIA, would require 7.6 million tonnes of feedstock. In Chapter 5 we reviewed options for making feedstock available and found that achieving such additional volumes would be exceedingly difficult, and would probably require relying very heavily on imports and a very significant reduction in biodiesel production. To summarize the discussion in Chapter 5 and the rest of Chapter 6, by 2025 it might be possible to deliver up to the following increases in renewable diesel production (assuming that adequate) policy support is available):

- 150 million gallons from additional processing of waste and residual oils and fats;
- 300 million gallons from additional soy oil production in the U.S.;
- 100 million gallons of additional fuel from waste oils and fats by reducing exports and a further 100 million gallons by increasing imports;
- 500 million gallons by eliminating the production of biodiesel from waste oils and fats;
- 250 million gallons by increasing net U.S. vegetable oil imports by 900 thousand metric tons.

This would bring total U.S. production of renewable diesel to about 2 billion gallons a year, and we would consider this a high-end estimate for what might be delivered in reality without causing very strong market distortions[17]. It would imply an increase by 3.3 million metric tons in the consumption of oils and fats for biomass-based diesel production. Assuming an average two thirds capacity utilization (similar to the current capacity utilization rate estimated in section 4.5.8), this would be consistent with 3 billion gallons of total renewable diesel production capacity in 2025, which is close to the projection by Singh & Turaga (2021) that we discussed in section 4.7. That would mean 2 billion gallons of already announced capacity additions being delayed, cancelled or downsized.

17 Recognizing that each of the outcomes listed would still have some distortive effect on other markets.

6. Environmental and climate impacts of HVO production

While renewable fuel policies such as the RFS, LCFS and CFP are intended to contribute to climate change mitigation, there is uncertainty and therefore controversy about whether renewable diesel makes a significant contribution to reducing net emissions when indirect emissions effects are considered. This is especially true for renewable diesel from virgin vegetable oils, but the true net climate benefit is also a concern even for waste and residual oils and fats, when using them for renewable diesel displaces them from other markets. These concerns are well recognized by the EPA and have formed an important part of the context discussed for not increasing advanced biofuel mandates under the RFS above statutory levels in recent volume rules (U.S. EPA, 2019, 2021a). Figure 22 shows ILUC emissions estimated by U.S. regulators for renewable diesel produced from vegetable oils.

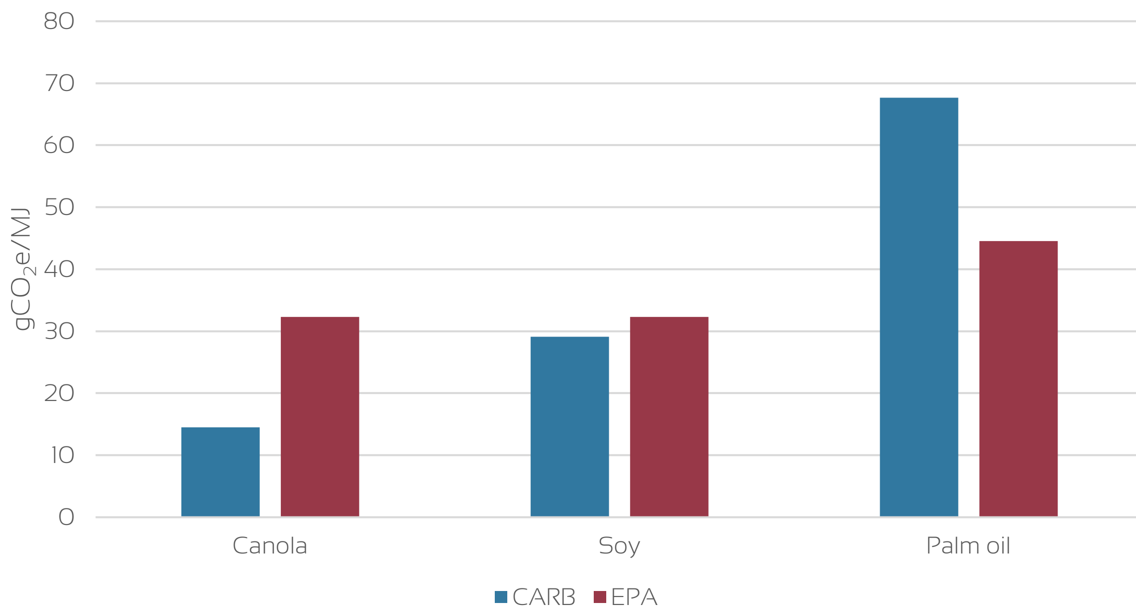

Figure 22. Estimated ILUC emissions from vegetable oil-based fuels

Source: CARB (2014); U.S. EPA (2010, 2011). Note: EPA palm oil ILUC estimate comes from a proposed rule that has not been finalized.

Palm oil expansion, especially in Indonesia and Malaysia, is associated with deforestation in tropical forests and the drainage of peat soils, both of which can result in the loss of large carbon stocks. Analysis for the European Commission suggests that 45% of new oil palm area globally is associated with deforestation, and a further 23% with peat drainage (European Union, 2019). As was shown in Figure 17, increased vegetable oil imports may have played a significant role in supporting the development of the U.S. biodiesel industry, and these increased imports have been split roughly 50:50 between canola oil and palm oil (see Figure 19).

In the 'supply sketch' that we provided at the end of the previous chapter, we suggested that U.S. vegetable oil imports might increase by 900 thousand metric tons to support increased renewable diesel production. If half of this increase in imports (450 thousand metric tons) came from palm oil producers then that would require 125 thousand hectares of oil palm plantations, at a typical palm oil yield of 3.6 metric ton per hectare. If the area of oil palm were to expand by 125 thousand hectares to supply this palm oil, then based on the European Commission analysis mentioned above one might expect this to be associated with 56 thousand hectares of deforestation and 29 thousand hectares of peat loss.

In practice, we would not expect this amount of deforestation to be caused. As has been discussed extensively in the literature on ILUC, one would expect part of the palm oil supply response to be delivered by increasing yields, and expect the supply response to be muted by a reduction in consumption of palm oil for food. Nevertheless, even if half or less of this amount of palm oil were to be delivered by area expansion, it could still be associated with tens of thousands of hectares of forest loss, with accompanying carbon emissions and biodiversity impacts.

Looked at globally, the soybean crop is also associated with tropical deforestation, especially in South America (Malins, 2020). There is no evidence of a strong link between soy expansion and deforestation in the United States, but if exports of soy oil from the U.S. were reduced this could indirectly drive increased supply in other regions.

Currently, the RFS, LCFS and CFP assume that there are no ILUC emissions associated with the use of waste or residual oils (UCO, DCO, animal fats). Not being attributed any indirect emissions is one of the reasons why these fuels achieve lower carbon intensities and higher value in the California and Oregon markets. When these materials have existing productive uses, however, displacing them can be expected to cause indirect demand increases. For example, O'Malley et al. (2021) argues that additional extraction of DCO from distillers' grains is likely to lead to increased demand for cereal feeds while displacing DCO from existing swine and poultry feed markets is likely to lead to increased demand for virgin vegetable oils. Given that such displacement emissions are likely for many of these lower value oils, the overall environmental impact of targeting these resources may be understated in current regulations (Malins, 2017b). The fundamental issue for all renewable diesel production pathways is that oils and fats are valuable resources – even the inedible ones – and that the global supply is limited. There is a very real risk that adding excess pressure to the vegetable oil market in the name of renewable energy policy will drive agricultural expansion that causes significant land use change carbon emissions.

7. Discussion

The biofuel industry in the U.S. and globally is again at a point of transition. Despite concerns about the environmental sustainability and scalability of converting large volumes of oils and fats into fuel, production capacity for hydrotreated renewable diesel and jet fuel is rapidly expanding not only in the U.S. but globally. Achieving the 5 billion gallons of renewable diesel production that have been announced for completion by 2024, without closing down biodiesel plants, would require an increase of 7.6 million metric tons in the commitment of oils and fats to biofuel use. That is equivalent to more than half of the vegetable oil currently consumed for food in the U.S. and would be unachievable without major market distortions and large increases in vegetable oil imports.

We have argued in this report that it is not realistic to believe that the announced rate of expansion of renewable diesel capacity will be delivered – it seems inevitable that some of the announced expansions will be delayed or cancelled. It also unrealistic to believe that even a reduced rate of expansion will be delivered without impacting the biodiesel industry. So long as state programs like the California LCFS and the Oregon CFP make it significantly more profitable to supply waste-oil-based renewable diesel in these states (above the biodiesel blend wall) than to supply waste-oil-based biodiesel in other states, biodiesel producers will struggle to compete for these feedstocks with an expanding renewable diesel industry. We have discussed the possibility that waste-oil-based biodiesel may be more or less eliminated over the next four years if the economics remain as they currently are.

The potential for state low carbon fuel standards to drive feedstock displacement out of other state markets in this way raises important questions for these programs. There is little if any net climate benefit for pulling waste oils out of existing markets and into the West Coast. If the primary impact of this is to result in the closure of an existing industry to allow the creation of a new one, it is not clear that this truly contributes to higher level climate objectives. It may be appropriate for the states with low carbon fuel standards to consider whether the contribution of renewable diesel should be capped to manage the potential for market distortion.

There are also broader unresolved questions about whether increasing the use of oils and fats for fuel is really sustainable in terms of its impact on food markets and the potential to drive further deforestation. We have discussed in this report that there is a risk that expanding renewable diesel production in North America could drive expansion of palm oil in Southeast Asia, and that without dealing with ongoing deforestation in that region there is a risk that this could cause net carbon emissions rather than savings. With a long-term view, considering the need to develop sustainable fuels for aviation as well as for on-road use, we could ask whether the current boom in vegetable oil hydrotreating has become a distraction from the commercialization of the cellulosic biofuel pathways that the RFS was originally intended to support.

Cellulosic drop-in biofuels have greater long-term scalability and GHG reduction potential, and as they rely on lower value resources they have the potential to be a cheaper solution if operating costs can be brought down over time.

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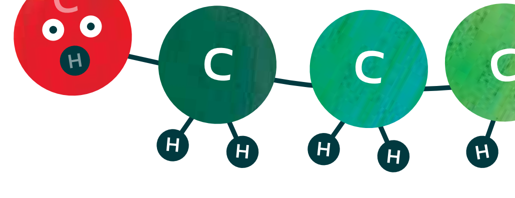
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