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Updated Fuel Portfolio Scenario Modeling to Inform 2024 Low Carbon Fuel Standard Rulemaking

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Executive Summary

California's Low Carbon Fuel Standard (LCFS) has been a critical part of its climate policy portfolio and has helped reduce greenhouse gas (GHG) emissions from its transportation sector since 2010. The LCFS sets an annually declining target for the average carbon intensity (CI) of transportation fuels and uses a system of credits (for emissions reductions from fuels with CI scores lower than the target) and deficits (for excess emissions from fuels with higher CI scores than the target) to facilitate compliance. Producers who receive deficits must procure an equal number of credits; this creates a market for those credits, generating revenue to support lower-carbon transportation fuel providers. Generation of credits has significantly exceeded that of deficits since late 2020, leading to a marked decline in credit price that threatens to undermine the incentives needed to continue innovation and deployment of lower-carbon fuels and technologies needed for carbon neutrality targets. The California Air Resources Board (CARB) initiated a rulemaking in January, 2024, to make amendments to the LCFS with the primary goal of setting new targets that would stabilize the credit market, which in turn could increase credit prices. UC Davis Policy Institute for Energy, Environment, and the Economy researchers have been engaged in this process since its beginning, and published a report in late 2023 evaluating several potential target and program design options for the upcoming rulemaking using the Fuel Portfolio Scenario Model (FPSM).

This report provides updates to that work, primarily in two key areas. First, it incorporates the impacts of proposed LCFS amendments, the details of which were released after our previous publication in 2023. Second, and more importantly, it accounts for new data that have emerged since the previous work that significantly changed expectations around developments in the fuel market. Deployment of renewable diesel (RD) production capacity in the U.S. has greatly exceeded even very recent projections, and the majority of the production continues to flow to California. Current evidence indicates that this trend of rapid RD capacity growth is likely to continue through the mid-2020's, creating a massive pool of relatively low-cost biofuel (given incentives beyond the LCFS) produced with an established technology that could enter California's market. Under these conditions, it is unlikely that the proposed LCFS amendments will achieve their goal of stabilizing the credit market and supporting significantly higher credit prices. Moreover, the new RD capacity trend makes it likely that the proposed Automatic Acceleration Mechanism (AAM) will trigger multiple automatic increases in the LCFS program target trajectory in the late 2020's, which will significantly increase costs to gasoline consumers. While this RD could allow for additional near-term GHG reductions as calculated by the LCFS, significant uncertainty exists around its actual GHG impacts at the scales implied by the current growth trend; it comes with significant sustainability risks related to indirect land use change (ILUC), and competition with food crops. Neither existing measures (e.g. current ILUC impact adjustments on applicable fuel pathways) nor proposed measures (feedstock sustainability requirements) provide adequate protection against these risks. The anticipated growth in RD will predominantly rely on crop-based vegetable oil feedstocks, which may struggle to achieve the deep CI reductions required to be compatible with California's long-term goal of carbon neutrality by 2045.

Several options exist to address these emergent problems. Higher LCFS targets could marginally increase credit prices, but would also increase the incentive to use crop-based RD; as long as that compliance option is available, it could out-compete more innovative, but uncertain ones. Other approaches, such as improving upon LCFS ILUC impact accounting protocols entail an extensive (multi-year) development process, by the time they took effect the current rate of RD growth could have resulted in significant negative impacts, including land conversion. Implementing a cap on consumption of lipid- or crop-based biofuels (which would cover RD as well as biodiesel and hydrotreated sustainable aviation fuels) was discussed in pre-rulemaking workshops, but excluded from the proposed amendments. In this paper we model some plausible cap designs, and find they could effectively limit the growth of potentially risky biofuels and bring aggregate credit supply and demand back into balance. By restricting the supply of low-cost RD, the credit price would be more likely to rise to levels capable of supporting California's long-term transition to carbon neutrality, by supporting the deployment of innovative fuels that could achieve deep GHG reductions with less risk of negative impacts from ILUC. We present several scenarios with different cap designs and levels; a 500 million gasoline gallon equivalents (GGE) cap on crop-based fuels, or a 2 billion GGE cap on lipid-based fuels are projected to result in an approximately balanced supply of credits and deficits through the remainder of this decade.

Introduction

The Low Carbon Fuel Standard (LCFS) is a critical part of California's portfolio of policies to reduce greenhouse gas (GHG) emissions from transportation. The California Air Resources Board (CARB), the program's administrator, has opened a rulemaking to amend the LCFS to address a number of issues. The most important among them is the decline in LCFS credit prices since late 2020. This decline reduces the value of LCFS incentives to low carbon fuel producers; low LCFS credit prices may make it difficult for the state to maintain the pace of decarbonized technology innovation necessary to meet statutory goals. CARB began pre-rulemaking workshops in late 2022, and released draft amendment text along with the Initial Statement of Reasons in December 2023. The initial rulemaking period closes February 20, 2024, and a public hearing for the board to consider amendments will be scheduled sometime in 2024.

This report updates modeling published in 2023 by researchers with the UC Davis Policy Institute for Energy, Environment, and the Economy (Policy Institute) to reflect the impact of proposed amendments on future LCFS credit supply and demand and explore the implications of significantly faster-than-expected deployment of hydrotreated renewable diesel in California (*1*).

The previous round of FPSM modeling was predominantly conducted in Spring and Summer of 2023, at which point only 2022 LCFS program data were available. Now, LCFS quarterly data through Q3 of 2023 are available. These data show a nearly 40% increase in consumption of renewable diesel (RD) to 1.8 billion gallons consumed in the most recent four quarters for which data are available (through Q3 2023) from 1.3 billion gallons consumed in the four quarters prior to that (*2*). This mirrors trends at the national level where RD capacity deployment greatly exceeded levels projected by the EIA (*3*, *4*) (Figure 1). Other independent evaluations of RD production capacity, and their impacts on feedstock markets, corroborate the updated DOE data and reinforce the conclusion of exceedingly rapid growth in this space (*5*–*7*).

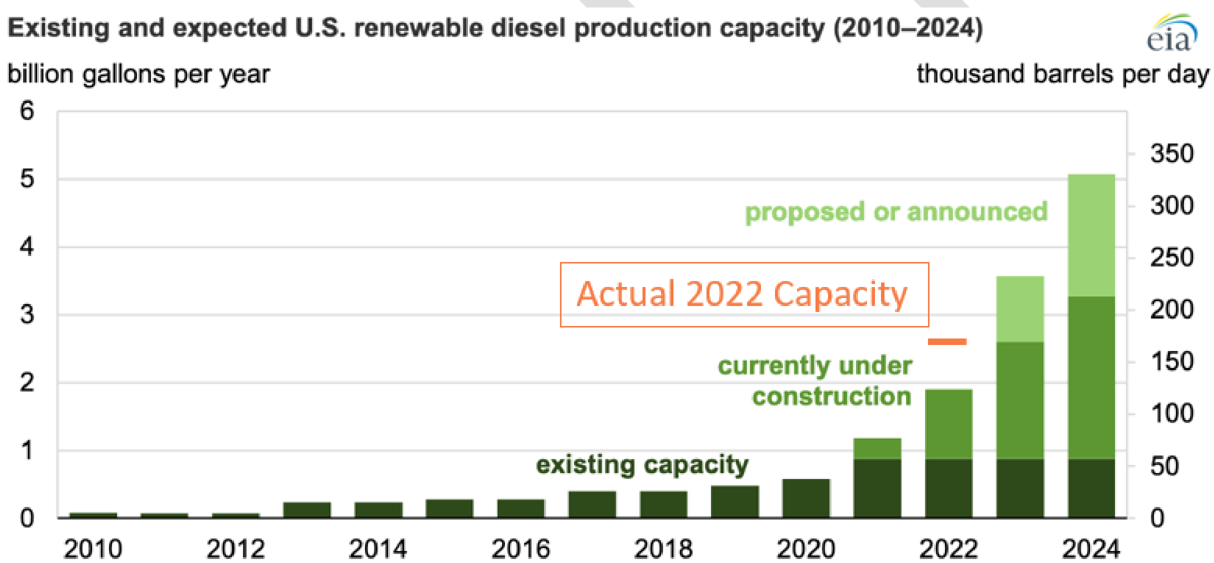

Figure 1. Source: 2021 Projection of renewable diesel deployment in the U.S. from the Energy Information Administration. EIA has since updated the information using 2023 data; actual 2022 capacity marker added by authors based on that source.(*3*, *4*) Renewable diesel capacity deployment has dramatically outpaced even recent expectations. The majority is consumed in California due to the LCFS incentive.

While U.S. RD production lagged behind capacity deployment in 2022 (as would be expected with facilities coming online throughout the year), data from the first 10 months of 2023 show aggregate production on a similarly rapid growth trajectory, already 40% above total 2022 levels (*2*). California consumption of RD has similarly grown. Annualized 2023 data project total consumption around 1.9 billion gallons, compared to around 1.4 billion in 2022. It is noteworthy that this occurred during a period of low LCFS credit prices, when conventional wisdom would suggest that lower incentive levels might not foster rapid growth. Federal policy provided a significant amount of support with historically high renewable identification number (RIN) prices; however, these have been gradually declining since a peak in mid-2022. This decline has not slowed the pace of growth. We lack access to producer-level economic data with which to verify the profitability of current or anticipated RD capacity projects, and the level of aggregate demand from RD, not only from California but from other jurisdictions with similar LCFS-like programs is also uncertain. So, while we cannot conclusively speak to how future market conditions will impact supply, the trend is broadly supportive of the idea that policies other than the LCFS (like the federal RIN and biomass-based diesel tax credit) make U.S. RD production cost effective, leaving the CA LCFS incentive to cover any gap and transport cost to California. Market forces theoretically could halt this capacity growth if policy support in aggregate proves inadequate to cover RD production costs, but current evidence supports continued growth in capacity to produce RD and hydrotreated SAF for the next several years and the continued ability of large fractions of this new capacity to come to market in California.

This major change in the landscape of California's low carbon fuel market requires updating several assumptions made in previous versions of FPSM, as well as evaluating how the continuation of this trend would affect LCFS credit markets going forward. Driven by the rapid expansion of RD, aggregate consumption of lipid-based fuels has already exceeded the maximum volumes projected in Brown *et al.* (2021) (*8*) and has almost matched the maximum volumes expected in the late 2020s from Ro, Murphy, and Wang (2023) (*1*). More importantly, the implied trajectory of hydrotreatment capacity growth in the U.S. suggests a much higher potential supply of RD than previously assumed in these studies. The fact that the Phillips 66 and Marathon refinery conversions in the Bay Area are expected to come online at significant fractions of their nameplate capacity, around 1.7 billion gallons/year in aggregate, in 2024 suggests that the availability of RD to California will continue to grow rapidly in the near future. The rapid rise in RD consumption reflected in more recently available 2023 data indicates that large volumes can and could be expected to enter the California market even during periods of historically low LCFS credit prices. As such, the assumptions made around limits to both the pace of RD growth and the maximum amount of hydrotreated fuel capacity available to California must be reevaluated.

Methods

The modeling presented in this report used the Fuel Portfolio Scenario Model (FPSM). This spreadsheet-based scenario analysis tool was developed by Policy Institute researchers. It builds on the illustrative compliance scenario modeling methods used to inform previous LCFS rulemakings. Full methodology for FPSM, as well as analysis of other LCFS scenarios, can be found in Ro, Murphy and Wang (2023), and Chapter 9 of Brown *et al.* (2021) (*1*, *8*). This section will only describe changes made to FPSM to enable the specific analyses presented here. Details of proposed amendments are taken from Appendices A-1 and A-2 of the LCFS rulemaking document package, with additional explanation derived from the Initial Statement of Reasons (*9–11*). In what follows, we describe each changed provision or situation modeled, followed by our modeling approach, in turn.

Amended ZEV Infrastructure Capacity Credit Provisions

Proposed amendments would significantly reduce the scale of protocols to provide LCFS credits for specified zero-emission vehicle (ZEV) fueling infrastructure capacity. Current protocols allow hydrogen refueling infrastructure (HRI) and fast charging infrastructure (FCI) installations for light-duty (LD) vehicles to generate credits, up to an amount equal to 2.5% of prior quarter deficits for each program. These provisions are generating significantly fewer credits than previous models anticipated, however, and they have not approached their maximum values (*1*, *12*). HRI pathways have, on average, generated credits equal to 0.55% of prior quarter deficits from 2021Q1 to 2023Q3 (the most recent quarter for which data are available). FCI pathways have generated an average of 0.38% of prior quarter deficits over the same period, with both numbers growing slowly over time. Proposed amendments would reduce the cap for each protocol significantly, in favor of similar medium- and heavy-duty options discussed below, and make other operational changes. Under proposed amendments, both LD HRI and FCI capacity credit provisions would be limited to generating 0.5% of prior quarter deficits. HRI provisions are already generating more credits than this. However, because the number of deficits increases over time as LCFS program targets increase (until such point that fuels generating the most deficits – petroleum fuels – decline sufficiently in volume), continued growth would be necessary to maintain this share of credit generation.

Updated Approach. We elect to assume that [1] HRI provisions, including both projects certified under the existing rules and those certified under the proposed amendments generate credits at their capped level until eligibility for new pathways closes at the end of 2030, and [2] credits decline to zero over the following 10 years. While FCI protocols are still below 0.5% of prior quarter deficits, their current rate of growth would have them hit that mark by late 2024. As such, we make the same assumption as HRI: that they will generate credits equal to 0.5% of prior year deficits through 2030 and decline from there.

New Medium- and Heavy-Duty ZEV Infrastructure Capacity Credits

CARB proposes adopting new infrastructure capacity credit provisions targeted at medium- and heavy-duty (MHD) electric vehicles (EVs) and hydrogen vehicles. These proposed provisions largely follow the same design as existing infrastructure capacity credits for LD electric and hydrogen vehicles, with a cap for each FCI and HRI of 2.5% of prior quarter deficits, or 5% in aggregate.

Updated Approach. Given the similarity in structure to initial LD provisions, the proposed changes were integrated into FPSM by duplicating the approach used for LD HRI and FCI protocols and updating with appropriate caps and targets. Table 24 of the Standardized Regulatory Impact Assessment provides an estimate of total credit revenue generation through 2046 (*13*). However, this value appears to assume maximum utilization of the provisions throughout their entire period of activity. This assumption appears to have been made to assess the maximum potential financial impacts of the program and is exceptionally unlikely to occur in practice. No other sources of guidance for expected utilization have been identified and, given the short timeframe for public comment on the proposed provisions, development of a predictive model was impractical. Given the stronger fundamental need for fueling infrastructure in the MHD space, we assume that these provisions will ultimately generate half of their maximum potential credits, or 2.5% of prior year deficits in aggregate. Of these credits, 60% are distributed to HRI and 40% to FCI. This follows the approximate distribution of credits in existing LD HRI and FCI pathways, reflecting the expectation of lower utilization for HRI and, therefore, a greater opportunity for capacity credit generation. We assume that these pathways will reach their cap in 2028, then decline over 10 years once the window for new pathways closes at the end of 2030.

Changes to Direct Air Capture Project Eligibility
The LCFS allows crediting of direct air capture (DAC) anywhere globally. The proposed amendments seek to restrict eligibility for crediting of DAC to projects located in California, only. Previous versions of FPSM assumed limited LCFS crediting of DAC through the 2030s, with 100,000 metric tons credited in 2030 and 5 million in 2045. This does not include DAC integrated into fuel production, the impacts of which are reflected as a reduction in certified fuel carbon intensity (CI) score. This is significantly less than the aggregate carbon capture and storage (CCS) goal articulated in Californa's Scoping Plan, though that goal considers all CCS applications not just DAC (*14*).

Updated Approach. Given the relatively low anticipated generation of DAC credits through the period of this analysis ending in 2035, the previous assumptions were left unchanged.

Changes to e-Forklift crediting
Proposed amendments would eliminate the ability of utilities or other e-forklift owners to generate credits for e-forklift charging through estimation of charging activity based on population data. Instead, reporting of charging activity from the fueling station would be required. We expect this to reduce the aggregate amount of credit generation from e-forklift pathways due to the increased stringency of reporting requirements.

Updated Approach. At present, we have no data or models from which to quantitatively predict the impact of these changes. We carry forward the previous assumption of static credit generation, maintaining yearly credits from the most recent historical data point.

Updating RD Deployment Assumptions
As discussed at the outset, RD U.S. production capacity, and consumption in California and nationally, is on a rapid growth path. For this reason, relaxing prior constraints around RD deployment in FPSM and assuming that large amounts of RD can enter the California market in the next 5 years is critical.

Updated Approach. We relaxed previous assumptions about limits to both the pace and aggregate size of RD growth. In order to evaluate different approaches to volumetric limits on categories of feedstock (see Options to Restrict RD Growth to Stabilize the LCFS Credit Market, below), the previous constraint method - total lipid-based distillate fuel production - was changed to caps on the five primary classes of lipid feedstock consumed in California: used cooking oil, tallow, corn oil (meaning technical corn oil, an inedible byproduct of corn ethanol production), soybean oil, and canola oil. CARB reports an “other” category for biodiesel (BD) production, while canola oil is grouped into “other” for RD production at present. It is likely that the vast majority of the “other” category of RD is made from canola oil. Total volumes of “other” BD were very low, often negative (likely representing administrative adjustments to credit generation) and so we omit “other” BD from the model and assume that “other” RD is entirely canola oil.

Actual availability of UCO, tallow, and corn oil increases at a 3% annual rate from the most recent historical data. This approximately matched pre-2022 growth rates, UCO and tallow have grown more rapidly in recent years, but this is likely due to increased foreign imports with uncertain potential to continue this rate of growth. The 3% growth rate in this space is meant to approximate growing production of wastes and residues due to population and economic growth from current sources. Crop-based oils are assumed to be available up to the specified cap, due to the large international market for vegetable oils. Complete elimination of the all caps led to the model predicting an immediate and total conversion of the entire diesel pool to RD, which is unrealistic. A constraint to limit total growth of lipid based fuels to no more than 500 million GGE per year, aligning with the growth between 2022 and annualized 2023 data was added to prevent unrealistically rapid conversion rates. At present, no data are available with which to determine an long-term absolute physical limit on total lipid or crop-based lipid consumption. California already imports fuels made from several categories of feedstock, implying that the upper bound on aggregate consumption may be the global supply of lipids, which is more than sufficient to fully displace all diesel and jet fuel consumption within the near term. Given current market conditions and the rapid growth of RD in the last two years, it is difficult to find an empirical basis upon which to limit the rate of growth in these fuels. Without such a basis, the limits on wastes and residues retained their previous approach - 3% annual growth from the most recent historical data - and a limit of 2 billion gallons of crop-based fuels was assumed for the “uncapped” scenarios. This led to significant increases in RD consumption in all future years and petroleum diesel being displaced from the fuel pool by 2032 in uncapped scenarios, it is possible that even this rapid rate of growth is an underestimate.

Deficit Generation by Intrastate Aviation Fuel

Currently, the LCFS provides opt-in status to generate credits for sustainable aviation fuel (SAF). The proposed amendments call for intrastate aviation fossil jet fuel to generate deficits starting in 2028. Intrastate travel is defined as flights that start and end in California, though other definitions have been proposed.

Undated Approach. Previous versions of FPSM reflected SAF’s opt-in status. This update adds intrastate conventional jet fuel usage as a deficit-generating fuel from 2028. UC Berkeley modeling from a recent RIMI project estimated intrastate fuel consumption to be 403 million gallons in 2019, 475 million in 2030, and 488 million in 2035, we adopt these and interpolate for intermediate years.(*15*) In prior versions, FPSM modeling assumed that future ICAO, Federal, and State policy, combined with voluntary efforts, would result in SAF deployment sufficient to approximately match total intrastate aviation fuel consumption by 2030 and thereafter. We retain that assumption for the update. As in prior versions, FPSM assumes that all significant volumes of SAF deployed through 2035 will be lipid-based hydrotreated esters and fatty acids (HEFA). While other technologies have been proposed to produce SAF, including alcohol-to-jet synthesis, cellulosic biofuels, or e-fuel synthesis, none have deployed at commercial scale to date and insufficient data exist to model real-world performance with confidence. We therefore continue to omit projections of novel fuel technologies entering into this space; these can be added when data are available. Within the lipid-based fuel categories, feedstock is allocated among three categories of lipid-based fuel (BD, RDI, and SAF) in the following order: first BD at the blend rate (as a fraction of total liquid diesel and diesel substitutes), then SAF, then RD, with each feedstock using the lowest-CI feedstock first. This method is designed to yield aggregate feedstock portfolios across all lipid-based fuels that approximately align with historical feedstock utilization patterns, adjusting for likely growth.

Automatic Acceleration Mechanism (AAM)

CARB proposes adopting Automatic Acceleration Mechanism (AAM) which advances all annual CI benchmarks by one year when certain conditions are met. Starting 2027, if the credit bank to average quarterly deficit ratio exceeds three and credit generation exceeds deficit generation, the AAM is triggered unless it was triggered in the immediately prior calendar year. Because the trigger criteria for the AAM had not been proposed at the time of our previous publication, we were unable to model its effect for the 2023 publication.

Updated Approach. Due to the limitations of the original structure of the FPSM, we integrated the AAM into the FPSM for this update by manually advancing the compliance trajectory by one year, the year after banked credits exceeded ¾ of prior year deficits. This entailed, when conditions were triggered, an additional scenario run starting from the year after the triggering event through the end of the trajectory.

Other Updates from 2023 Report

We made additional updates to input assumptions based on more recently available LCFS data, as described below.

Electricity CI score. FPSM estimates grid average CI changes over time by interpolating between the most recent historical data and an assumed zero CI in 2045. We updated FPSM parameters to reflect a slightly higher average electricity CI score in 2023 than the interpolated trajectory based on the published 2022 value predicted, future interpolated values through 2045 were therefore also increased.

CaRFG, ULSD, and fossil jet fuel baseline CI. The base year (2010) CI values for CaRFG, ULSD, and fossil jet fuel have been updated (99.44 to 99.15, 100.45 to 105.76, 89.37 to 89.43, respectively), and the benchmarks for years 2024 through 2045 reflect these revisions. The reduction target trajectories used in the FPSM reflect these revisions as well.

Non-road electricity pathways. We updated non-road electricity pathways (eCHE, eTRU, fixed guideway, e-forklift, etc.) energy based on recent data showing higher recent growth than previously projected. We increased energy used for these in 2023, as well as in future years.

Petroleum fuel projects. Because petroleum fuel projects (refinery investments, renewable hydrogen refinery, innovative crude, etc.) earn credits based on carbon savings through investments vis-a-vis their own baselines, FPSM projects credits directly in this case (rather than projecting an amount of fuel and associated CI score). Recent data on credits continue to lag previous projections, so these have been reduced to reflect this underperformance and the impact of a planned phase-out of these pathway categories, as laid out in the proposed amendments.

Renewable natural gas (RNG). Average RNG CI has declined since the 2023 FPSM report, due to the increased penetration of livestock digester gas into this market. We adjusted FPSM assumptions to reflect more recent shares of RNG feedstocks (i.e., higher share of livestock digester gas, and lower share of landfill gas) to reflect these trends for 2023, resulting in a slightly greater credit generation trajectory. The previous assumption of 4% annual CI improvements for all RNG categories after 2030 was retained.

Results

The previously published FPSM report projected 22.4 million total deficits and 30.2 million credits in 2023. Annualized estimates based on the first three quarters of 2023 data project 22.5 million total deficits and 29.4 million credits. While the aggregate figures from the data do not deviate substantially from previous projections, the composition does. The significant increase in RD credits is counteracted by a downward adjustment of on-road EV credits due to the slightly higher CI score, and of project-based credits, as well as updating to the latest incremental crude oil deficit value, which has increased from prior levels. Changes to electricity CI, fossil fuel baseline CI, non-road EV pathways, RNG CI, and Refinery Project Credits yielded net credit impacts of less than a half-million each in 2030. Some of these categories increased credit generation (non-road EVs, RNG) and others a net decrease (on-road EVs, project-based credits). On net, apart from the impact of proposed amendments, and the data-driven changes in RD deployment assumptions, the 2023 report continues to represent the current and anticipated condition of the LCFS with good accuracy (*1*).

Most of the proposed amendments in the current LCFS rulemaking are unlikely to significantly change the credit balance in 2030 and 2035 compared to estimates in Ro, Murphy, and Wang (2023) (*1*). An exception is the Auto-Adjustment Mechanism (AAM), which was discussed but not explicitly modeled in the previous paper. Most of the proposed changes align well with concepts proposed by CARB staff during pre-rulemaking workshops, and so were included in the previous report with reasonable fidelity. The new MHD HRI and FCI credits were the notable exception, in that they were insufficiently described to allow us to model them. However, the reduction in LD HRI and FCI capacity to generate credits largely offsets the assumed credit streams from these pathways, yielding only a slight increase of credits overall, around a half million projected credits in 2030 (compared to almost 40 million deficits in 2030).

Updated data and revised projections on RD deployment, however, have significantly shifted credit dynamics in the LCFS market, and with it, FPSM projections of long-term LCFS credit balances. Ro, Murphy, and Wang (2023) concluded that the proposed 2030 amendments with a 30% reduction target by 2030, as we understood them then, were likely to yield an approximate balance between credit supply and demand, through the mid-2020's at least (Figure 2). Based on updated modeling, this conclusion is no longer the case. The model runs published in 2023 (performed before Q2 or Q3 2023 LCFS program data were released) anticipated total consumption of petroleum diesel in 2023 to be around 1.8 billion gallons, and RD consumption around 1.5 billion gallons. While full 2023 data are not yet available, annualizing the averages of the first three quarters of published data, we anticipate diesel consumption to be around 1.5 billion gallons, with 1.8 billion gallons of RD. Essentially, nearly 300 million gallons of RD above the anticipated amount (which itself reflected expectations of robust growth) materialized *the year after the projection was made*. If we assume a 43 gCO_2e/MJ carbon intensity for this new supply (roughly the average of all RD consumed in CA through the first 3 quarters of 2023), the additional 300 million gallons imply around 500,000 fewer deficits generated by petroleum diesel, and 1.9 million additional credits, adding around 2.4 million credits to the bank compared to projections from a year before.

The AAM makes a much more significant difference in net credit balance in 2030 and beyond, though it is only triggered under specified market conditions. The updated model projected two AAM-triggering events, in 2027 and 2029 under the currently proposed LCFS amendments, driven principally by the recent changes in RD availability. This compares to a single triggering event, in 2027, when using parameters from the 2023 report. The two AAM-triggering events yield a 39% LCFS target in 2030.

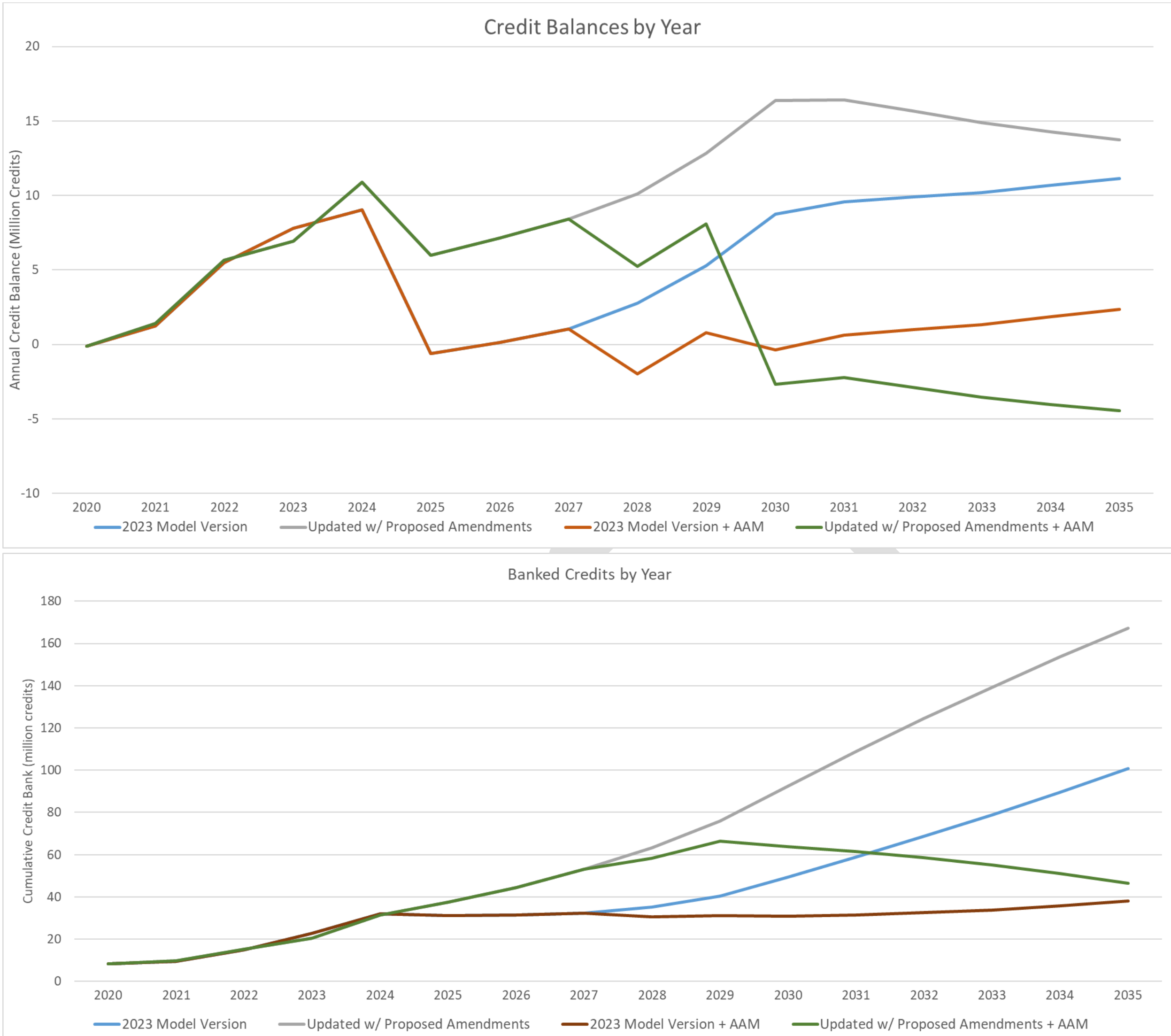

Figure 2: (a, above) Yearly net credit balances and (b, below) net banked credits from updated FPSM modeling of LCFS through 2035, results from previous publication (Ro, Murphy, Wang, 2023) are included for comparison. The scenarios modeled in our previous report would be expected to trigger the Auto Acceleration Mechanism (AAM) would be triggered once, in 2027. The updated scenarios with proposed amendments is projected to trigger the AAM twice, in 2027, and 2029.

Discussion and Policy Implications

Based on the updated modeling presented in this report, the primary finding of our 2023 report, regarding 2030 LCFS program targets, no longer holds. The proposed 30% 2030 CI reduction target, even with the deficit-increasing effects of the AAM, now appears unlikely to bring credit supply and demand into approximate balance before 2030. Instead, current trends indicate a LCFS market with a significant oversupply of credits persisting until the late 2020's and possibly into the 2030's. This oversupply will continue market conditions similar to those that have prevailed since 2022 and continue today. As a result, while some incremental increase in LCFS credit price might be expected as a result of the higher targets, significant price increases are unlikely until either a fundamental shift in the price and supply dynamics around RD (and to some extent SAF) or the market returns to an approximate balance between credits and deficits, neither of which appears likely until 2030 or later.

Continued deployment of hydrotreated fuel production capacity, and the relative ease with which drop-in fuels like RD and SAF can be transported mean that the potential supply to California is sufficient to satisfy most or all of California's liquid diesel demand, and likely a fraction of jet fuel demand as well, by the mid-2020's. Vegetable oil prices, while high, have not demonstrated themselves to be an impediment to continued growth, and absent a more severe collapse of biomass-based diesel (D4) RIN prices few other market-mediated brakes on growth seem likely.

Taken together, this implies that obligated parties in the LCFS will have a readily available source of inexpensive credits available from hydrotreated fuels, especially RD, through the mid-2020's at least. As long as this supply exists, we would expect little upward pressure on LCFS credit prices; obligated parties will have little incentive to invest in innovative, but riskier, approaches to reducing GHG emissions from transportation fuels until either the supply of inexpensive RD is exhausted or it has displaced all petroleum diesel, and all aviation fuel is subject to a deficit obligation.

Raising the LCFS target above the proposed 30% CI reduction in 2030 would increase demand for credits and could incrementally increase LCFS credit price, however higher targets will not break the fundamental market relationship that is being established. RD and hydrotreated SAF appear likely to enjoy a cost advantage over other sources of compliance credit, and until either the low-cost supply runs out or California's market cannot accept more, we would expect only modest increases in LCFS credit price absent major shifts in policy incentives, especially at the federal level. Unless the growth of RD is significantly restricted, it is unlikely that the current market conditions will shift in order for LCFS credit prices to increase appreciably this decade.

It may seem like fully displacing petroleum diesel with inexpensive hydrotreated RD, as well as a significant fraction of jet fuel with hydrotreated SAF, would align with California's climate and environmental goals, however the volumes of these fuels required for that outcome present significant near- and long-term problems. First, while hydrotreated vegetable oil fuels likely reduce emissions of GHGs when substituted for petroleum, these benefits are modest. Waste-based fuels can reduce life cycle emissions by over 70% compared to petroleum, and even crop-based fuels can deliver 40% GHG reductions according to LCFS assessments and other independent analyses. Some reduction in GHG emissions may be possible by switching to renewable energy or renewable hydrogen sources during the production process, however these fuels lack a pathway to reduce emissions enough to achieve, or even approach carbon neutrality. Given California's long-term goal is to achieve carbon neutrality by 2045, hydrotreated lipid fuels like these are best suited to be bridge fuels, to reduce emissions in the near term while zero- or near-zero carbon solutions are brought to market. A limited amount of waste-based biofuel may have a role in the long-term fuel portfolio, but excessive deployment of crop-based fuels risks creating stranded assets or crowding out more sustainable solutions.

Second, the volume of RD implied by current growth trends raises substantial concerns around sustainability and GHG impacts that are unaccounted for by current LCFS CI assessment methods. Indirect land use change (ILUC) is particularly worrisome. Current LCFS CI assessment methods apply ILUC impact adjustments that were adopted in 2015, based on modeling of international agricultural commodity markets and land use patterns of the time. Both agricultural commodity markets and land use behavior have changed significantly over the last 9 years, due to improvements in technology, geopolitical factors, climate change, and more. The model used for the current ILUC assessment, GTAP-AEZ, derived the estimated land use impacts from biofuels by simulating a supply shock sized to match anticipated U.S. RFS volumes at the time. These focused predominantly on grain crops for ethanol production, and soybean for biodiesel. The recent growth in vegetable oil based biofuels, however, has moved beyond the parameters of the model used at the time. A recent comparison of current ILUC models by the U.S. EPA found a wide range of uncertainty around ILUC impact of soybean oil biofuels, ranging from 11 g CO_2e/MJ to over 260 g CO_2e/MJ (*16*). The current soybean oil ILUC impact estimate used by the LCFS is 29.1 g CO_2e/MJ, near the bottom end of that range. Given the uncertainty involved in ILUC assessment, and the asymmetric risks of overestimation vs. underestimation of ILUC impacts, adopting a value based on an estimate from a single model, especially one at the lower end of the uncertainty range established by multiple models, creates substantial risk of unrecognized GHG emissions, environmental harm, and stranded assets (*17*).

As a result, it is unlikely that continued growth of RD along current trends will help California meet its environmental goals, and risks creating a market in which emissions from the transportation fuel sector continue to rise even while LCFS targets are nominally met. Significant volumes of RD, including some from crop-based feedstocks, can contribute to California's progress toward carbon neutrality, but the current rate of growth crowds out investments in other low-carbon fuels. The aggregate consumption of RD, combined with expected growth due to Federal policy, as well as that in other states and other jurisdictions including Canada, which does not account for ILUC, can lead to profoundly negative GHG and other environmental impacts. Significant restrictions on the growth of RD appear to be the most feasible and certain, and possibly the only, way to reestablish the LCFS capacity to support innovative low carbon fuel technologies and a strong credit price, especially in the short timeframe relevant for these investment decisions.

It should also be noted that the proposed amendments, combined with the rapid growth of RD create a LCFS credit market that is likely to trigger the auto-adjustment mechanism twice, at the earliest possible opportunities. The credit bank to deficit ratio remains at a high enough level to trigger a third AAM event, however FPSM projects a sufficient decline in credits to block this from occurring. If a year of net credit surplus were to occur in the 2031-2034 time period, a third AAM trigger event could occur. The two anticipated AAM triggering events result in a 39% LCFS target by 2030, increasing by 4.5% per year thereafter. Revenue in the LCFS credit market predominantly originates from charges applied to petroleum gasoline that are passed through to consumers. Gas price impacts are a function of the fuel's carbon intensity score, the LCFS target, and the LCFS credit price. Higher targets, therefore, yield higher per-gallon retail gas price impacts. A 39% LCFS target combined with a $50 credit price would be expected to yield just over 20 cents per gallon in increased gasoline cost; higher credit prices would yield proportionately higher price impacts.

If California achieves its ambitious deployment goals, around 23% of the total fleet will be made up of ZEVs in 2030, the rest will be predominantly fueled by gasoline. The transition from gasoline vehicles to ZEVs is anticipated to move faster for higher-income consumers than lower-income ones as well. The AAM triggering events that would likely follow adoption of the proposed amendments without any restriction on RD growth could yield regressive impacts on California gasoline consumers. This impact may accompany a situation where the emissions benefits supposedly gained from the program turn out to be overstated, due to underestimated ILUC impacts. A more measured approach, that delays some increased target ambition until the transition to ZEVs has progressed further could mitigate this risk.

Impacts of Expanded Deficit Obligation on Intrastate Jet Fuel

Prior versions of FPSM assumed that all SAF entered the market as an opt-in fuel, and its only impact on broader fuel markets was to consume some of the cap on total lipid-based fuel capacity. Given the new deficit obligation, and the switch in FPSM methodology to feedstock category based caps, the impact of SAF assumptions on broader markets is magnified. The revised hierarchy of fuel types with regard to access to preferred feedstocks (BD first following historical patterns, then SAF followed by RD, with both taking the lowest-CI feedstocks first) was picked in part because of its compatibility with the underlying structure of FPSM. It is unlikely, however, that this highly simplified heuristic will accurately predict the actual feedstock use patterns by each fuel type, and FPSM results should be interpreted with that caveat in mind.

As a result of this allocation hierarchy, the deficit obligation for aviation fuel is often minimal or zero, because SAF is assumed to have first priority on feedstock and production capacity, and all intrastate aviation demand is therefore satisfied by SAF. This means that few, if any, fossil jet fuel deficits emerge in most modeling runs and the petroleum jet fuel deficit obligation is reflected in FPSM via increased petroleum diesel deficits. It is possible, though not certain, that this assumption is an essentially accurate representation of how markets will respond to future conditions, however it is also possible that producer preference to produce RD will continue to hold and there will be more petroleum jet fuel deficits, but fewer petroleum diesel deficits than these FPSM results would indicate. Since the GHG impacts of RD and SAF are largely determined by the feedstock used, net LCFS credit impacts are similar in either scenario.

FPSM assumes five primary classes of lipid feedstock (used cooking oil, tallow, corn oil, soybean oil, canola oil); GHG impacts in the model are primarily determined by how much of the feedstock pool is consumed to displace petroleum, and to a smaller degree by which fuel category consumes a specified blend of feedstock. As such, FPSM assumes the same CI scores for RD and SAF supplied to California based on the feedstock-weighted average. The impact of the feedstock allocation method on LCFS credit balance, or net emissions from the transportation fuel supply in California is small, though almost certainly non-zero. Work is ongoing at UC Davis at present to develop a more robust and realistic model of competitive dynamics within the lipid-based fuel space, including the differences in processing emissions.

At this point, it is unclear whether hydrotreated fuels will predominantly enter the California market as SAF or RD over the long run, RD dominates these volumes today however the Federal 45Z tax credits for SAF production have yet to be finalized and could significantly shift the economics in this space to support a shift to more SAF production output. Other anticipated policy actions, including ongoing efforts within California to increase support for SAF, future work from ICAO, or stronger voluntary commitments within the aviation sector could also impact this balance. The FPSM modeling presented here provides a reasonable approximation of likely behavior at the scale of the total lipid based fuel market (including biodiesel, RD, and SAF). FPSM results should not be interpreted as making a credible quantitative prediction about the likely feedstock mix for any specific category of fuels, however.

Options for Restricting RD Growth to Stabilize the LCFS Credit Market

In theory, the approach used by the LCFS at present should be able to guide the market towards a reasonable volume of RD. The current approach, however, depends on accurate assessment of ILUC impacts from biofuels and the current assessment is out of date, and based on modeling assumptions that are no longer reflect current biofuel and agricultural markets.(*18*–*23*) Updating the ILUC impact factors in the LCFS would require an extensive and complex research and analysis project, followed by a public engagement process to disseminate the new model and seek feedback. All told, this process would likely require 2-3 years at a minimum before actionable policy guidance would be delivered. The current rate of RD growth does not allow this extensive a delay before arriving at a more protective policy. By the time updated ILUC factors were developed, large amounts of land may be converted to cultivation for oil crops, resulting in millions of tons of CO_2 emissions. If an updated set of ILUC impact factors, or the development of a new approach to ILUC risk mitigation is the preferred outcome, an interim policy to mitigate growth in this space is needed as well.

To date, the only options for ILUC risk mitigation discussed by CARB during the pre-rulemaking workshop process have been feedstock sustainability certification requirements and a cap on the issuance of LCFS credits for specified categories of biofuels. Feedstock sustainability certification provides useful assurance that the practices used in the production of a given lot of feedstock meet specified criteria, however they are incapable of mitigating indirect risks like ILUC, which are driven by aggregate demand within a given market, which in the case of vegetable oils, is effectively global. There is ample potential supply of crop-based vegetable oil that would meet proposed sustainability criteria, directing that feedstock to biofuel production means the consumers who would have otherwise used that oil (e.g. human food producers, animal feed producers, soap and cosmetic makers, etc.) must find alternative sources of vegetable oil; historically some of these sources include unsustainable alternatives, including those that require conversion of additional land into cultivated use. (*24*–*26*)

Stakeholders have suggested capping the consumption of all crop-based fuels, or all lipid-based fuels. Both options can achieve the ultimate goal of mitigating the risks associated with unrestricted RD growth. Because lipid feedstocks (e.g. used cooking oil, tallow, technical corn oil, soybean oil, etc.) are largely fungible with each other in many applications, a lipid-based cap would be expected to provide better protection against resource shuffling within vegetable oil markets. Both forms of a cap entail administrative complexities, however several plausible solutions exist (see below). If properly designed and implemented, a cap would provide very good certainty that critical limits on RD deployment would not be exceeded due to growing use in the California market. Critically, a cap was evaluated as part of the Standardized Regulatory Impact Assessment associated with the current rulemaking, as part of Alternative 1. This alternative was rejected because it provided fewer GHG reductions than the proposed amendments, however this is primarily due to a lower 2030 CI target. Our prior work demonstrated, and this report confirms, that targets of 30% or higher are feasible even with a cap on crop-based fuels.

To help illustrate the impacts of different cap designs and target levels, we created several scenarios in FPSM: crop-based fuel caps of 500 million and 1 billion gasoline gallon equivalents (GGE) per year and lipid-based fuel caps of 2 and 3 billion gallons per year. These values were chosen as instructive examples of plausible cap levels to illustrate the magnitude of anticipated market impacts and do not imply specific policy recommendations. For comparison, 2022 consumption of crop-based feedstocks was around 450 million GGE, and consumption of lipid-based fuels was around 1.95 billion GGE. The results, along with those for the current amendments are presented in Figure 3 (next page), with anticipated AAM triggering events included in the projections of credit balance and bank. The Proposed Amendment, 3 billion GGE lipid-based fuels cap, and 1 billion GGE crop-based fuels cap scenarios all trigger the AAM twice, in 2027 and 2029. The 2 billion GGE lipid-based fuel cap, and the 500 million crop-based fuel cap avoid triggering the AAM altogether, in our scenarios. They would, however, require a reduction in total use from 2023 or 2024 levels of consumption of the capped fuel categories, which could have significant market impacts and lead to market uncertainty regarding the reliability of policy signals; phasing in these caps over several years could help mitigate this risk.

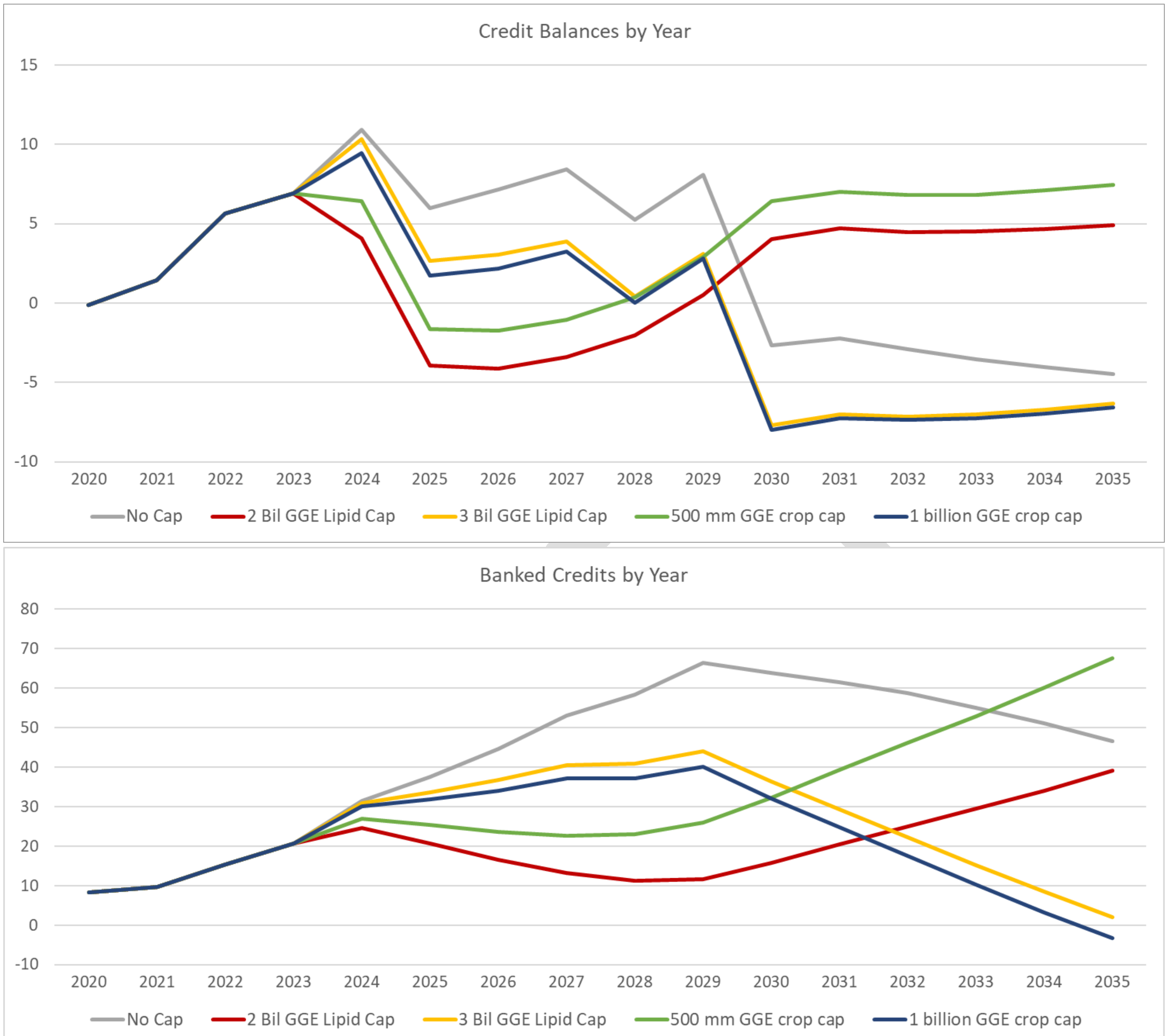

Figure 3: (a, above) Yearly net credit balances and (b, below) net banked credits from FPSM modeling of several lipid fuel scenarios. AAM-triggering events manually added when prior year banked credits exceed ¾ of prior year deficits and yearly deficits>credits. The gray "No Cap" line reflects modeled results for the LCFS amendments at the time of writing (February, 2024).

Previous FPSM modeling anticipated the proposed LCFS target trajectory, including the significant 5% "step-down" in 2025, would bring credit and deficit generation back into approximate balance for most of the mid-2020's before the bank began growing again. The projected magnitude of this expansion was comparatively small, of a size that could be addressed by a single AAM-triggering event in the late 2020's. The faster-than-expected deployment of RD implies not only the need for multiple AAM-triggering events before the balance between credits and deficits is restored, but that it is likely that a bank of 40 million credits or more will accumulate and persist for several years before being drawn down. A bank of that size could exert considerable downward pressure on credit prices.

This modeling implies that establishing a cap on crop- or lipid-based fuels at roughly 2022 consumption levels would be expected to restore an approximate balance between credit supply and demand, and help create conditions that support a strong LCFS credit price. Higher caps, including those set at levels California could easily reach in 2024 at present growth rates, are unlikely to stabilize the market without an extended period of credit oversupply and multiple AAM-triggering events. Since these caps entail a decline in consumption from current (post-2022) levels, a phase-in may be needed to prevent a shock to the market.

Conclusion

This report presents results from updates to the Fuel Portfolio Scenario Model to reflect proposed amendments to the LCFS from the current rulemaking, as well as a significant shift in projections of hydrotreated lipid-based fuel availability, predominantly renewable diesel. The proposed amendments, with the exception of the deficit obligation for intrastate jet fuel and the AAM, are expected to yield comparatively minor changes in credit balance through 2035. Updated projections of RD deployment, as well as new data about RD consumption in California, however, prompt a critical reconsideration of conclusions from previous modeling. RD capacity is growing much faster than anticipated at the national level, with growth anticipated to continue for the next 2-3 years at a minimum. This creates a vast pool of low-cost renewable diesel that can supply large amounts of LCFS credit. Until this pool is exhausted, or California markets for it are saturated, it is unlikely that the proposed amendments will achieve their primary goal of strengthening the LCFS credit price. The amount of growth projected presents significant sustainability concerns, especially related to ILUC, and neither existing LCFS provisions nor any in the proposed amendments provide adequate protection. Moreover, if the projected growth trends continue, it is likely that the AAM will be triggered more than once before balance is restored in the credit market.

Adopting a new approach to ILUC risk mitigation, or updating the modeling required by the previous approach entails a multi-year research and policy development process; by which point significant environmental harm and damage to California’s progress toward climate goals will have been irrevocably done. A cap on fuels from crop or lipid feedstocks has already passed through some of the administrative steps required for adoption, and offers the best option for quickly arresting the growth in RD markets. A cap could either be used as a stopgap until a more nuanced solution is developed, or it could be retained indefinitely. A 500 million GGE cap on crop-based fuels, or a 2 billion GGE cap on lipid-based fuels appear likely to restore balance between credit supply and demand, strengthen the LCFS credit price, and are fully compatible with California achieving its medium- and long-term climate goals. Several options for the design of such a cap are briefly described.

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