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RESEARCH REPORT

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Fuel Portfolio Scenario Modeling (FPSM) of 2030 and 2035 Low Carbon Fuel Standard Targets in California

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16. Abstract

The Low Carbon Fuel Standard (LCFS) plays a critical role in California's efforts to reduce greenhouse gas (GHG) and air pollutant emissions from transportation. The LCFS incentivizes the use of fuels with lower life cycle GHG emissions by using a credit market mechanism to provide incentives for low-carbon fuels, using revenue generated by charges applied to high-carbon ones. Maintaining an approximate balance between LCFS credit and deficit supplies helps support a stable LCFS credit price and the broader transition to low-carbon transportation. The Fuel Portfolio Scenario Model, presented here, evaluates bottom-up fuel supply and LCFS compliance to inform LCFS policy decisions. We considered two key fuel demand scenarios: (1) the Low Carbon Transportation scenario, reflecting the expected transition to low-carbon transportation in California over the next 15 years, and (2) the Driving to Zero scenario, featuring a significantly higher consumption of petroleum gasoline. In both scenarios, 2030 LCFS targets around 30% resulted in a near-balance between credits and deficits, with some banked credits remaining. Several additional scenarios were modeled to explore the impact of target trajectory timing, alternate post-2030 targets, greater biofuel use, and other parameters. This fuel portfolio scenario modeling work can meaningfully inform policy development.

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The California Resilient and Innovative Mobility Initiative

The California Resilient and Innovative Mobility Initiative (RIMI) serves as a living laboratory – bringing together university experts from across the four UC ITS campuses, policymakers, public agencies, industry stakeholders, and community leaders – to inform the state transportation system's immediate COVID-19 response and recovery needs, while establishing a long-term vision and pathway for directing innovative mobility to develop sustainable and resilient transportation in California. RIMI is organized around three core research pillars: Carbon Neutral Transportation, Emerging Transportation Technology, and Public Transit and Shared Mobility. Equity and high-road jobs serve as cross-cutting themes that are integrated across the three pillars.

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Executive Summary

Executive Summary

California has been a leader in reducing greenhouse gas (GHG) emissions, and the Low Carbon Fuel Standard (LCFS) is a critical element of California's policy portfolio to reduce GHG emissions from transportation sector. The LCFS sets a declining target for the life-cycle carbon intensity (CI) of transportation fuels. Fuels with lower CIs than the target generate credits while fuels with higher CIs generate deficits. Entities that distribute fuels are obligated to either reduce the CI of their fuel to meet the target or acquire enough credits to offset their deficits each year. The sale of credits creates a market with an LCFS credit price that varies over time. In recent years, the credit price has dropped due to rapid growth in alternative fuel deployment, the effects of the COVID-19 pandemic, and other factors. The California Air Resources Board (CARB) administers the program and has announced its intent to conduct a rulemaking to strengthen the 2030 program target. Their goal will be to increase demand for credits and support continued investment in low-carbon fuel technologies. Maintaining a balance between credit supply and demand helps keep a stable LCFS credit price, so that the LCFS can incentivize low-carbon fuels as intended and reduce GHG emissions.

In this study, the Fuel Portfolio Scenario Model (FPSM) was developed to assess the feasibility of different reduction targets and program designs for 2030 under various scenarios. The FPSM develops fuel portfolio scenarios based on the historical LCFS data, projections of future fuel availability, and forecasted demand for various types of transportation fuel generated by the Transportation Transitions Model (TTM). Fuel demand forecasts include the impact of recent Zero-Emission Vehicle (ZEV) rules, including Advanced Clean Cars II, Advanced Clean Trucks, and Advanced Clean Fleets. FPSM assembles these forecasts into scenarios using transparent, user-provided assumptions and assesses LCFS credit and deficit generation. Using the FPSM, this study presents the results from several scenarios related to topics relevant to the 2023 rulemaking for the LCFS.

This study mainly focuses on two fuel demand scenarios that differ, primarily, in the amount of gasoline demanded. A range of proposed reduction targets are considered. They center around options discussed by CARB during pre-rulemaking workshops, and also include targets proposed by stakeholders during the public comment process prior to the rulemaking. These include 2030 reduction targets of 25%, 27.5%, 30%, 32.5%, 35%, 37% and 40%, as well as several schedules for achieving these targets.

FPSM results indicate that a 30% LCFS target in 2030 is likely to be feasible under both higher and lower gasoline demand scenarios. Targets 25% or below are highly unlikely to bring the credit market into balance. Targets above 35% may be achievable, however, they would require ethanol to reduce CI significantly faster than historical rates, in addition to growth of bio-based diesel substitutes to total volumes that may cause significant negative sustainability or land use change impacts. In addition, targets around 30% are typically projected to have a bank of credits remaining in 2030, that can protect against market fluctuations or credit shortfall; higher 2030 targets typically imply smaller reserves and higher post-2030 deficit generation.

By 2030, electric vehicles (EVs) will generate more than half of total credits in the LCFS system, over 75% of which will come from light-duty EVs. By 2035, all new vehicles sold in California will be ZEVs. As ZEV sales fractions approach 100% leading up to this date, the LCFS reduction target must rise rapidly to keep pace with the increasing supply of EV credits.

The LCFS sets year-by-year targets used for compliance, which means that different trajectories are available for the same reduction target in future years. The impacts of different target reduction schedules were analyzed using the FPSM. For identical 30% targets for 2030, a more rapid increase of the reduction target in the early-2020s leads to fewer surplus credits through the mid-2020s and a faster depletion of the credit bank. The suggested trajectory proposed by CARB prior to the initiation of the formal rulemaking calls for a 5% target increase in 2025. This so-called “step down” is feasible but may significantly reduce the size of the accumulated credit bank. While this can help support a stronger LCFS credit price, it can also reduce the flexibility of regulators to adopt more ambitious targets post-2030.

This work demonstrates the capacity of FPSM to provide rapid, flexible scenario analysis to support LCFS policy design. Such analysis helps inform policy makers by testing a variety of target trajectories and/or policy provisions. While CARB’s 2023 rulemaking is expected to address and resolve critical issues related to long-term credit balance, the treatment of renewable natural gas under the LCFS, provision of capacity credits for medium and heavy-duty ZEVs, and the adoption of a target auto-acceleration mechanism, many other issues raised by recent research remain to be addressed. FPSM can be part of the toolkit that helps sustain the LCFS track record of successful policy.

Contents

Introduction

California has been a global leader in climate policy, having adopted a broad portfolio of programs to reduce emissions from many economic sectors. Transportation is a particularly challenging sector to address. The production and consumption of transportation fuels accounts for over half of California's total greenhouse gas (GHG) footprint, and transportation affects almost every facet of the economy and people's lives. Successfully reducing GHG emissions from transportation will be critical to California meeting its statutory GHG reduction targets, including a 40% decline in GHGs compared to a 1990 base year by 2030, and an 85% reduction of emissions as part of achieving overall carbon neutrality by 2045 (1,2). To meet this challenge, California has adopted many policies for decarbonizing the transportation sector by shifting from fossil fuels to low-carbon or carbon-neutral fuels and vehicle technologies.

The Low Carbon Fuel Standard (LCFS) is a critical element of California's policy portfolio, and it has been a model for similar fuel programs in other jurisdictions. To date, British Columbia, Oregon, Washington, Brazil, and the Canadian federal government have adopted similar clean fuel programs. The goal of the LCFS is to reduce carbon emissions from the transportation sector by regulating full life-cycle carbon intensity (CI) of transportation fuels, regardless of their form. To create certainty in the market and move toward decarbonization over many years, the target for the average CI of all transportation fuels declines over time. Transportation fuels which have lower CIs than the target generate credits fuels while higher-CI fuels than the CI standards generate deficits. Credits and deficits are measured in metric tons (tonnes) of carbon dioxide equivalent (CO_2e) using 100-year Global Warming Potential (GWP) equivalencies. They essentially reflect GHG reductions (for credits) or emissions (for deficits) that occur above or below that year's targets.

At the end of every compliance year, any fuel distributor holding deficits must obtain an equivalent number of credits to show that they have ultimately complied with the target. The targets require greater reductions in CI each year, which applies continually increasing pressure to reduce GHG emissions within the transportation system. High-carbon fuel producers therefore are incentivized to either reduce the CIs of their fuels. They can accomplish this by improving production efficiency, blending high CI fuels with low-carbon components, or buying credits from low-carbon fuel producers. This purchase of credits provides revenue for low-carbon fuel producers and creates an incentive for high-carbon fuel producers to ensure that low-carbon fuels enter the market. Fuel policies must balance support for fuels, such as crop-based biofuels, that have entered the market at scale but yield only modest GHG benefits against fuels that yield deeper GHG benefits but are further from commercial adoption, such as cellulosic fuels or renewable electricity. The LCFS accomplishes this by incentivizing the actual amount of emission reductions, ensuring that the lowest-carbon fuels receive the highest level of support.

The California Air Resources Board (CARB) is the regulator in charge of the LCFS. CARB regularly reviews and updates the LCFS reduction targets and issues detailed regulations to reflect up-to-date circumstances and the state-of-the-science. CARB has announced its intent to conduct a rulemaking in late 2023, with the purpose of increasing the 2030 program target. Intended changes include adding an automatic adjustment mechanism, additional infrastructure capacity credits, and adjusting some provisions on the production of renewable natural gas (RNG). This rulemaking will help align the LCFS with the strategic vision for long-run climate policy articulated in the 2022 CARB scoping plan. This plan lays out a high-level overview of how California intends to meet its 2030 and 2045 GHG reduction targets (3).

The purpose of this study is to provide an analysis of impacts which may be caused by anticipated updates and changes in the LCFS, particularly the selection of a 2030 CARB program target level. It builds on work and modeling tools described in the *Driving California's Transportation Emissions to Zero by 2045* (*Driving to Zero*) report (4). *Driving to Zero* was issued by authors from across the four University of California Institutes of Transportation Studies. It describes how California's transportation system could achieve the state's carbon neutrality goal with in-depth examinations of changes needed in the vehicles, fuels, transportation behavior, and policy. The work presented in this report is a continuation of the research and modeling presented in Chapter 9 of *Driving to Zero*. It focuses on estimating transportation fuel portfolios through 2035, corresponding credits and deficits, and it allows the development and analysis of various scenarios depending on potential changes.

To provide the necessary quantitative analysis, this report presents the Fuel Portfolio Scenario Model (FPSM), a scenario analysis tool based on the models used in the *Driving to Zero*. The FPSM organizes and curates the creation of fuel supply scenarios, based on the historical LCFS data and projections of future availability of specific classes of fuel. The FPSM allows for LCFS credit and deficit generation to be quickly estimated for any portfolio of fuels, which facilitates rapid analysis of LCFS policy scenarios, such as the impacts of different targets on credit balance. We show results from several modeling scenarios related to topics likely to be addressed in the 2023 rulemaking for the LCFS, including the selection of a program target for 2030, and the impacts of different target auto-adjustment mechanisms.

Methodology

The FPSM builds on similar tools developed over the last decade. The first publicly available scenario model of its type was the *Illustrative Compliance Scenario Calculator* published by CARB in advance of the 2018 LCFS rulemaking (5). This was published as a tool to facilitate scenario analysis regarding 2030 LCFS targets, as well as to organize engagement with LCFS stakeholders. The basic structure of the model was adapted for use in work that was eventually published in the report *California's Clean Fuel Future*, with significant enhancements to its capacity for evaluating multiple fuel demand scenarios and a broader portfolio of credit-generating fuels (6). That core model structure was adapted for the work presented in *Driving to Zero*, with numerous improvements and a shift from VISION to the UC Davis Transportation Transitions Model (TTM) for underlying vehicle fleet and activity projections. The FPSM reflects the continued evolution of functionality from the *Driving to Zero* model with better capacity for rapid scenario analysis, an improved user interface, and numerous improvements to fuel supply projections.

The FPSM is built in Microsoft Excel spreadsheets. It incorporates results from the TTM and historical quarterly summary fuel data reported by CARB as inputs for transportation fuel consumption and demand as well as manual inputs from the users of the FPSM. Historical data from CARB are combined with TTM projections to create a trajectory of demand across seven categories of fuel including gasoline, liquid gasoline substitutes, diesel, liquid diesel substitutes, natural gas, electricity, and hydrogen through 2050. These fuel demand trajectories are assumed to be inelastic, except for limited substitution across certain categories. A notable case of substitution is that the model allows relatively easy switching between gasoline and liquid gasoline substitutes or diesel and liquid diesel substitutes.

The FPSM builds portfolios of fuels from type-specific projections of fuel availability to satisfy the fuel category projections. For each portfolio of fuels, this model calculates expected fuel consumptions, credit and deficit generation, and life-cycle emissions for different scenarios with relevant variables including technological improvements and potential policy updates.

The FPSM does not perform optimization or statistical simulation on its own, nor does it estimate fuel costs or LCFS credit prices or simulate market response to credit balance. It is designed to allow rapid scenario analysis with as much flexibility as possible by describing expected results when the variables change. The current version of the model includes historical LCFS data from 2017 to 2022.

Scenario Selection and Variables

The purpose of the FPSM is to allow users to easily develop and test scenarios under consistent user-defined sets of modeling assumptions. Producing an FPSM scenario requires user input of fuel demand, reduction target, and control parameters. Fuel demand parameters are yearly projections for the seven top-level fuel categories listed above, divided into light-duty vehicle (LDV) and medium- and heavy-duty vehicle (MHDV) segments. Reduction targets are presented as yearly LCFS average CI reduction targets, expressed as percentage reductions from the baseline year (2010 in the case of California's LCFS). Control parameters reflect a wide range of assumptions and model parameters, including average annual production growth, CI improvement, or market transition points.

Based on these selections, graphical figures of outcomes through either 2030 or 2050 are auto-generated for gasoline pool consumption, diesel pool consumption, CI reduction target, net credit balance and bank, and total credit. This enables the rapid analysis of compliance.[1] The FPSM also allows multiple fuel demand scenarios, reduction target trajectories, and control parameter schemes to be created and saved, supporting further analysis.

Fuel Demand Scenarios and the Transportation Transitions Model

If California is to meet its climate goals, including carbon neutrality by 2045, it will have to undergo a profound change in the vehicles and technologies its drivers use. The most impactful will be the transition from petroleum-fueled internal combustion engine (ICE) vehicles to zero-emission vehicles (ZEVs), particularly battery electric vehicles (BEVs, often abbreviated "EVs"). The vast majority of both LDV and MHDV fleets are anticipated to switch from ICE to ZEV in coming decades, driven by several key policies. These include:

- The Advanced Clean Cars II rule (ACC2) sets increasing targets for light-duty ZEV sales until 2035. After this, all new vehicles sold or registered in California must be ZEVs such as electric vehicles, hydrogen fuel cell vehicles (HFCVs), and plug-in hybrid electric vehicles (PHEVs), meeting specified targets for all-electric range to qualify.
- The Advanced Clean Trucks rule (ACT), sets increasing targets for ZEV sales in the medium- and heavy-duty sector and requires that, by 2035, 55% of class 2b, 75% of class 4-8 straight trucks, and 40% of class 7-8 tractor sales are ZEVs.
- The Advanced Clean Fleets rule (ACF) requires that certain fleets, especially larger ones, have an increasing fraction of their vehicles be ZEVs. Large fleets, drayage trucks, and specified other fleets are required to be 100% ZEV by the early 2040s at the latest.

The TTM models the transition to ZEVs by assuming that California attains, but does not significantly exceed, regulatory targets set by these policies. It estimates the effect of other policies like the cap-and-trade system, as well as incentives for ZEV purchase, mobility equity initiatives, tailpipe emissions standards, and the expected fuel price impacts of the LCFS on vehicle sales in order to project annual vehicle fleet composition.[2]

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[1] While FPSM generates projections out to 2050, uncertainty about critical technological and economic parameters increases significantly after around 2035. Results should be interpreted accordingly. For this report, which is intended to focus on FPSM's use as a tool for policy development, we primarily focus on results through 2035.

[2] Estimation of fuel price impacts by the LCFS is done exogenously via approximate estimation of LCFS credit prices and representative target trajectories. Ideally, the impacts of LCFS credit price would be endogenously considered in an integrated assessment of fuel and vehicle impacts, however this approach is outside the scope of this work.

Results of the TTM model outline a trajectory towards carbon-neutral transportation that complies with California's environmental, transportation, and climate policies.

The TTM simulates vehicle sales, retirement, and use based on economic and technical parameters. It is based on the Argonne National Laboratory's VISION model. In the TTM, vehicles are classified based on their weight classes. For each class, the TTM generates results for fuel demand projections until 2050 broken into several fuel categories: petroleum gasoline; liquid gasoline substitutes including ethanol and drop-in renewable gasoline; petroleum diesel; liquid diesel substitutes including biodiesel (BD) and renewable diesel (RD); compressed natural gas (CNG); liquefied natural gas (LNG); electricity; and hydrogen. LNG was, at one point, thought to be a promising transportation fuel but has largely been abandoned in favor of CNG. Thus, for the purpose of FPSM modeling, LNG is integrated into CNG category.

In this study, several scenarios for the California vehicle fleet and driving activity are generated with the TTM and used to set the fuel demand for the FPSM. This report focuses on three scenarios:

- The business-as-usual (BAU) scenario represents outcomes in which the policy portfolio prior to the adoption of ACC2, ACT, and ACF is fully implemented, but no additional policies are adopted. The BAU scenario cannot meet any of California's climate targets.
- The low carbon transition (LCT) scenario includes the adoption of ACC2, ACT, and ACF and assumes additional policies are adopted in the future to ensure that California's transportation system achieves carbon neutrality by 2045, which is defined as $<$ 5 million tonnes of CO_2e.
- The driving to zero (DtZ) scenario reflects projections used for modeling in the *Driving to Zero* report, specifically the ZEV scenario for LDVs and the LC1 scenario for MHDVs. This scenario assumes full rebound of driving to pre-COVID-19 levels and slightly lower deployment rate for ZEV, particularly for heavy-duty HFCVs. The DtZ scenario was included as a scenario of interest because it projects significantly higher gasoline demand. This offers a useful comparison to assess the sensitivity of the FPSM and the LCFS system to changes in gasoline demand.

The DtZ scenario reflects the TTM outputs used for modeling in the *Driving to Zero* scenario, which has a similar combination of policies as the LCT scenario. However, the DtZ scenario was developed before ACC2 and ACF had been fully described, and before the impacts of the COVID-19 were reflected in state fuel consumption data. Therefore, the differences between LCT and DtZ are: (1) updated modeling of some policies, and (2) improved representation of historical fuel consumption, notably integrating the effects of the COVID-19 pandemic.

Modeled updates to policies resulted in a modest increase in the number of EVs on the road compared to the scenarios used in the DtZ scenario, yet these changes resulted in small shifts in net fuel consumption. A much larger change was seen after updating fuel consumption to reflect the impact of COVID-19, which caused a massive reduction in driving demand and gasoline consumption in 2020 and 2021. There was a significant rebound of gasoline demand in 2022, as lockdowns and emergency public health provisions were discontinued, however current consumption has not returned to historical levels prior to COVID-19. Based on TTM modeling and extrapolation from historical trends, post-pandemic driving behavior appears to have reduced gasoline consumption by about 750 million gallons per year. It is unknown at this point whether this reduction is permanent due to persistent changes in driving habits, notably an increase in telework, or if gasoline consumption will continue rebounding toward the historical consumption trajectory. The LCT scenario implicitly assumes permanence by integrating this decline in demand into the new long-run fuel demand trajectory, while the DtZ scenario does not. This means that LCT and DtZ are essentially a low and high gasoline demand scenario, with comparatively minor differences otherwise.

The vehicle fleet and driving activity scenarios described in this report are based on updates made to the TTM after the publication of *Driving to Zero*. We updated fuel economy assumptions for several vehicle categories in the TTM for California (CA TTM) according to published sources. For LDVs, we refer to *Table 4.12* (Production and Production-Weighted Fuel Economies of New Domestic and Import Cars, Light Trucks and Light Vehicles, Model Years 1975-2021a) in *The 2021 EPA Automotive Trends Report* (7). We directly use United States (US) Environmental Protection Agency (EPA) estimates of fuel economy of gasoline vehicles from 2010 to 2020. For LDV fuel economy assumptions beyond 2020, we extrapolate recent trends assuming a 2.5 miles per gasoline gallon equivalent and a 1.25 miles per gasoline gallon equivalent increase every five years for cars and light trucks, respectively (Table 1). We then calculate fuel economy from 2020 to 2050 accordingly.

Table 1. Fuel economy assumptions (miles per gasoline gallon equivalent) for gasoline cars and light trucks from 2010 to 2050 for new vehicles.

Vehicle Type	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car	25.7	28.2	30.7	33.2	35.7	38.2	40.7	43.2	45.7
Light Truck	18.8	21.1	22.4	23.6	24.9	26.1	27.4	28.6	29.9

For CNG medium-duty delivery trucks, we base assumptions on fuel economy data from the *Alternative Fuel Case Study: UPS Delivers with Alternative Fuels* from the Office of Energy Efficiency and Renewable Energy of the US Department of Energy (8). This study estimates the fuel economy of UPS delivery trucks to be 8.2 miles per gasoline gallon equivalent in 1999. This number is used directly in our new fuel economy assumption for CNG medium-duty delivery trucks. We still assume a 0.25 miles per gasoline gallon equivalent increase every five years, as in the previous version of the CA TTM. We then calculate the corresponding fuel economy from 2010 to 2050 (Table 2).

Table 2. Fuel economy assumptions (miles per gasoline gallon equivalent) for CNG medium-duty delivery trucks from 2010 to 2050.

Vehicle Type	2010	2015	2020	2025	2030	2035	2040	2045	2050
Medium-duty delivery truck	8.7	9.0	9.2	9.5	9.7	10.0	10.2	10.5	10.7

A final post-processing step was necessary to align the vehicle sub-categories in the TTM with conventions established in the LCFS. Vehicle classifications (e.g., LDV or MHDV) normally overlap with fuel categories because most MHDVs are currently fueled by diesel and LDVs are fueled by gasoline. This allows for the assumption that diesel pools are for MHDVs, and gasoline pools are for LDVs. However, there are some mismatches between the systems. For example, heavy-duty (HD) pickup trucks are classified as HDVs under the TTM, but they are classified as LDVs under the LCFS for the purpose of assigning energy economy ratios. Thus, to adjust the mismatches, the TTM results were post-processed to shift fuel demand of HD pickup trucks from the MHDV category to LDV.

The FPSM assembles portfolios of conventional and alternative fuels and then tests them for compliance with the LCFS under a variety of targets. Several reduction targets are of particular interest to the LCFS at present (Table 3). Under the current LCFS regulation, credits and deficits are calculated based on CI benchmarks for transportation fuels such as gasoline, diesel, and jet fuel and these benchmarks are required to be reduced either by 20% by 2030 (for gasoline and diesel) or as described in the rule (for jet fuel). The CI benchmarks for jet fuel were designed to be equal to the CI benchmarks for diesel after 2022 in the current rule, and thus the same approach was taken in this study. In addition, the current rule does not specify the targets after 2030, and thus the benchmarks will remain the same for all years after 2030 (represented as “20% C” in Table 3).

In pre-rulemaking workshops, CARB indicated particular interest in 25%, 30% and 35% reduction targets for 2030 to address the significant oversupply of credits in the market at-present. We also included 27.5% and 32.5% to evaluate the impact of intermediate steps between these points. Targets of 37% and 40% were evaluated to better understand system behavior and modeling assumptions required to support higher targets, as well as for comparison against other models in this space. For all target trajectories, year-by-year targets were chosen to align with an approximately linear increase in stringency through the mid-2020s, with slight increases in year-on-year target acceleration in later years. Following CARB’s typical practice, we sought to have target increases in round increments no smaller than a quarter percentage point where possible. Finally, we tested an additional 30% target in which there is a greater increase in target stringency in early years (2025-2026) to examine the impact of target timing, which is presented as “*30% F*” in Table 3. All scenarios assume a 6% per year target increase after 2030, for consistency, post-2030 target dynamics are briefly discussed below but largely outside the scope of this study.

Table 3. Carbon intensity reduction target trajectories from 2023 to 2035. Each trajectory requires a certain reduction target by 2030 (20% C: Current target with 20% by 2030, 30% F: 30% by 2030 with front-loading in early years).

By 2030	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
20% C	11.25	12.50	13.75	15.00	16.25	17.50	18.75	20.00	20.00	20.00	20.00	20.00	20.00
25%	11.25	12.50	14.50	16.50	18.50	20.50	23.00	25.00	31.00	37.00	43.00	49.00	55.00
27.5%	11.25	12.50	15.00	17.50	20.00	22.50	25.00	27.50	33.50	39.50	45.50	51.50	57.50
30%	11.25	12.50	15.50	18.50	21.00	24.00	27.00	30.00	36.00	42.00	48.00	54.00	60.00
30% F	11.25	12.50	16.50	20.00	22.50	25.00	27.50	30.00	36.00	42.00	48.00	54.00	60.00
32.5%	11.25	12.50	16.00	19.00	23.00	26.00	29.00	32.50	38.50	44.50	50.50	56.50	62.50
35%	11.25	12.50	16.00	19.50	23.50	27.50	31.00	35.00	41.00	47.00	53.00	59.00	65.00
37%	11.25	12.50	16.50	20.50	24.50	28.50	32.50	37.00	43.00	49.00	55.00	61.00	67.00
40%	11.25	12.50	17.00	21.50	26.00	30.50	35.00	40.00	46.00	52.00	58.00	64.00	70.00

Control Parameters

As mentioned above, the FPSM is intended to allow users to create various control parameter schemes to reflect policy or technology scenarios of interest, save these, and easily return to them without requiring significant manual modification of model parameters. For this purpose, the control parameters can be adjusted and updated easily in the model. The variables for performing scenario analysis under the control parameters are classified into five categories: CI improvement rates, goals and growth rates, project and infrastructure credits, blend rates and fractions, and distillates capacity. Most of the relevant variables, except for the reduction target trajectories and the TTM results selection, can be modified under the control parameter scheme, and the users are allowed to select one of the default schemes or add their own variables for the analysis. For example, the CI improvement rate for fuel takes two parameters: year and rate. The model assumes that a CI of fuel remains the same until the specified year, and then declines by a fixed rate each year afterwards. If there is no value for the year, the CI value declines by the rate continually. This allows for CI projections from external sources to be used as the basis for CI estimates as far into the future as they are available, and simple annual decreases at a user-specified rate take over thereafter.

The variables for goals and growth rates by fuel type deal with specific consumption goals, required plans, and growth rates for each fuel category. The fuels under control are electricity, liquid gasoline substitutes, sustainable aviation fuel (SAF), and natural gas (NG). This allows users to create scenarios in which the state meets specified milestones for the introduction of specified amounts of fuels or grid decarbonization targets.

- Electricity: Light-duty electric vehicle, heavy-duty electric vehicle, and electric forklift (e-forklift) credits can be phased out linearly over the duration year starting from the adjustment plan start year. This was added to reflect the potential distortionary effect that these vehicle classes can have on the LCFS market by receiving policy incentives after they have reached technological and market maturity. For the scenarios described in this report, neither category was phased out. Decarbonization of the electricity grid in California can also be modeled here. It is important to decrease the CI of electricity, because electrification of LDVs and MHDVs is one of the major plans for California to decarbonize the transportation sector. Currently, it is required to achieve 100% of retail electricity to be supplied with renewable and zero-carbon sources by 2045 under SB100 (9). This goal can be modified by changing the target year. In addition, the years when the renewable energy fraction of residential and non-residential charging reaches to 99% can also be adjusted here. The growth rates of offroad vehicles such as e-forklift, fixed guideway, electric power for ocean-going vessels (eOGV), electric cargo handling equipment (eCHE), and electric transport refrigeration units (eTRU) can be modified as well.
- Liquid gasoline substitutes: Specific consumption goals and growth rates for drop-in renewable gasoline and cellulosic ethanol can be modeled in this section. Drop-in renewable gasoline is not in the market yet and in the early stage of development, so the model is designed to take two goals as inputs so that it allows to express two different growth rates for the earlier and later stages. This is not intended to indicate a projection that such fuels will enter the market. Rather, it recognizes that without the provision of a low-carbon liquid gasoline substitute at significant volume by 2040, it will be extremely difficult for California's transportation system to achieve carbon neutrality. The model takes

year values and consumptions as inputs for the goals, and the growth rate for drop-in renewable gasoline is allowed to change after the second goal year. For cellulosic ethanol, a goal can be set by changing the year and target consumption, and the growth rate after the target year can be varied depending on scenarios.

- Distillates: In the FPSM, the CIs of RD, BD and SAF were estimated by feedstock availability. To estimate potential feedstock availability in the future, a certain growth rate for each feedstock was assumed with allowing adjustments. Detailed calculation methodology is described in the "FPSM Calculations" section, below. In addition, the goal for SAF by 2030 and growth rates of aviation demand before and after 2035 can be modeled here.
- NG: Fossil natural gas has rapidly been displaced from the CA LCFS by lower-carbon RNG, accounting for around 3% of total NG in 2022; this displacement is assumed to be complete in future years. Potential RNG supply in this model is based on a national RNG supply assessment (10). This source presents the potentials of RNG in two cases, low resource case and high resource case, and this model allows users to select a low, high, or average case (average case is derived from the low and high cases). The projected RNG resources are presented at the US national level, and California's share is assumed to be limited to a GDP-weighted share of that production. In general, the low availability case is used for the FPSM projections because it better aligns with historical RNG consumption in the LCFS. This section also allows users to model the schedule of phasing out the negative CI, or avoided methane credit, of livestock digester RNG. The model assumes that RNG demand will be satisfied in ascending merit order based on CIs. This approximately aligns with historical RNG consumption trends, in which livestock digester RNG, the lowest-CI available, entered the market after landfill RNG, municipal solid waste (MSW) digester RNG, and wastewater treatment RNG but rapidly grew to a dominant share of the market.

The variables in the project and infrastructure credits section include a refinery investment credit cap, a renewable hydrogen refinery credit cap and goal, an innovative crude credit goal, and infrastructure caps and goals for hydrogen refueling infrastructure (HRI) and direct current (DC) fast charging infrastructure (FCI). Although caps and years are specified in the regulation, these variables can be changed to test different regulatory schemes. In general, credits from these pathways are treated exogenously, by assuming linear growth to a user-specified target level and year.

Fuel blend rates and fractions can also be adjusted here. Blend rates of BD to total diesel and substitutes, 6% initially, and ethanol to total gasoline, 11% initially, were modeled in the same way. They take year values as when the initial rates will be used by, and new blend rates after the year are also modeled. The default blend rate for ethanol to gasoline was set as 11% through 2030 and 16% thereafter. This represents the 10% or 15% "blend wall" put in place by regulatory restrictions preventing higher blends, plus an additional one percentage point to reflect the use of E85 (85% ethanol blend) or higher blends. This assumption is based on historic LCFS data. The default ratio of sugar ethanol to total ethanol was set as 8% based on historical data from 2017 to 2021. However, depending on the feedstock availability and market conditions, the ratio can fluctuate. Thus, the ratio can be adjusted for different scenarios. Naphtha and renewable propane are generated as co-products of hydrotreated RD and SAF production and can themselves generate credits under the LCFS. FPSM assumes that the amount of these coproducts generated by production of fuels that are ultimately used in California will also be used in California and credited under the LCFS. We assume the coproduct production rate for naphtha and renewable propane relative to RD and SAF production are set as 5% and 4% by volume, respectively. The generation, use, and credit generation of process coproducts like these are subject to significant uncertainty. Future work is recommended to improve projections in this area.

The likely growth of lipid-based fuel production capacity in North America is sufficient to displace virtually all of California's petroleum diesel consumption by 2030, however sustainability constraints and inter-state competition for that supply mean that not all capacity is likely to be directed to California. Modeling these constraints and competitive dynamics is outside the scope of this work. To approximate these effects, the distillates cap was set at a default level of 1,750 million diesel gallon equivalents, consistent with previous CARB modeling. The maximum annual distillates capacity and growth rate can be adjusted here, and detailed calculation methodology will be described in the "FPSM Calculations" section, below.

Table 4 shows the parameters used in this study. While users can modify and adjust for their own alternative scenarios, the default values for this study were mainly adopted from the previous studies or other literature. The NA values mean that the parameters were not reflected in the scenarios as a default.

Table 4. Parameters used in the modeling and the default values. (LD EV: Light-duty electric vehicle, HD EV: Heavy-duty electric vehicle, eOGV: Electric ocean-going vessel, eCHE: Electric cargo handling equipment, eTRU: electric transport refrigeration unit, HRI: Hydrogen refueling infrastructure, FCI: Fast charging infrastructure).

Parameters	Unit	Value
Carbon intensity (CI) improvement rate		
Starch ethanol	%	2.0%
Sugar ethanol	%	4.0%
Cellulosic ethanol (post-2030)	%	4.0%
Biodiesel (BD) (post-2030)	%	0.0%
Renewable diesel (RD) (post-2030)	%	0.0%
Sustainable aviation fuel (SAF) (post-2030)	%	0.0%
Initial carbon intensity of renewable gasoline	g CO2e/MJ	35.0
Renewable gasoline (post-2025)	%	3.0%
Renewable naphtha (post-2025)	%	3.0%
Hydrogen (post-2030)	%	6.0%
Renewable natural gas (RNG) (post-2030)	%	4.0%

Parameters	Unit	Value
Goals and growth rates by fuel type		
Electricity		
LD EV credit adjustment plan - start	year	NA
LD EV credit adjustment plan - duration	years	NA
HD EV credit adjustment plan - start	year	NA
HD EV credit adjustment plan - duration	years	NA
Achieving zero-carbon electricity grid by	year	2045
Low-CI or smart charging of residential reaches 99% by	year	2040
Low-CI of non-residential reaches 99% by	year	2035
e-Forklift credits phase out - starting year	year	NA
e-Forklift credits phase out - duration	years	0
e-Forklifts growth rate	%	3.0%
Fixed guideway (before 2030)	%	1.0%
Fixed guideway (after 2030)	%	3.0%
eOGV / eCHE / eTRU	%	3.0%
Liquid Gasoline Substitutes		
Renewable gasoline cap goal 1 - year	year	2030
Renewable gasoline cap goal 1 - volume	mm GGE	200
Renewable gasoline cap goal 2 - year	year	2040
Renewable gasoline cap goal 2 - volume	mm GGE	1,000
Renewable gasoline growth rate after 2nd goal year	%	0.0%
Cellulosic Ethanol goal by 2030	mm gal	300
Cellulosic Ethanol volume growth rate (post-2030)	%	5.0%
Distillates		
Growth rate of each feedstock availability	%	1%
Off-road adjustment for diesel pool consumption		5%
Off-road adjustment phasing out start year		2035
SAF goal in California by 2030	mm GGE	540
Aviation demand growth rate (before 2035)	%	2.5%
Aviation demand growth rate (after 2035)	%	0.9%
Average fleet-wide fuel economy increase rate for aviation	%	1.4%

Parameters	Unit	Value
Natural gas		
RNG potential selection		Low
Livestock digester credit phase out - start		2035
Livestock digester credit phase out - end		2040
Project and Infrastructure Credits		
Refinery investment credit cap (% of prior year deficits)	%	2.5%
Renewable hydrogen refinery credit goal by 2030	MMT	NA
Renewable hydrogen refinery credit cap (% of prior year deficits)	%	2.5%
Infrastructure cap for FCI and HRI (% of prior year deficits)	%	2.5%
Last year for FCI and HRI	year	2025
FCI crediting years	years	5
HRI crediting years	years	15
Innovative crude credit goal by 2030	MMT	NA
Blend rate and fraction		
Keep current biodiesel blend rate (6 vol%) by	year	2050
Biodiesel blend rate after 2050	%	6.0%
Keep current Ethanol blend rate (11 vol%) by	year	2030
Ethanol blend rate after 2030	%	16.0%
Ratio of sugar ethanol and sugar ethanol plus starch ethanol	Vol %	8.0%
Naphtha fraction of RD	Vol %	5.0%
Renewable propane fraction of RD	Vol %	4.0%
Distillates capacity		
Annual maximum distillates capacity for lipid-based fuel	mm DGE	1,750

FPSM Calculations

The purpose of the primary inputs - demand scenarios, reduction target trajectories, and control parameter schemes - are to establish a set of assumptions and constraints to guide the primary calculations in the FPSM. Based on the inputs and fuel supply data taken from literature, the FPSM assembles a portfolio of fuels to meet the aggregate fuel demand under conditions defined by the control scheme. The life cycle emissions impacts are then subjected to credit and deficit assessment, as they would be under the LCFS, to determine the number of credits and deficits generated by each pathway in each year. If a year ends with a net excess of credits, they are banked for future years. If the year ends with a deficit, the bank is drawn on to cover the deficit. The FPSM does not attempt to simulate market response (e.g., investment or fuel production decisions), in response to market conditions, nor does it simulate existing cost-containment mechanisms in the event of persistent credit deficits. Its focus is to highlight anticipated credit market balance under a variety of scenarios.

CARB Summary Preprocessing

Historical (years through 2022) LCFS data for credits, deficits, and fuel volume are directly obtained from the quarterly summary report published by CARB (11). Where data were available on a quarterly basis, they were aggregated to annual values and combined with annual data from CARB to populate historical portions of the model. the cumulative bank, and cumulative buffer account are values from the fourth quarter of each year, and the volume-weighted averages of the quarterly reported CIs were used as the average CIs of each year. If new quarterly summary data are added, FPSM will automatically update the historical data used as a reference point for the following calculations for each fuel. These historical LCFS data were used to establish a historical baseline and validate internal calculations of credit and deficit balances. For years after historical data, the results from TTM projections were used as a baseline for further calculations. In addition, TTM results were also used to estimate values for each vehicle category in detail, such as a separation between LDVs and HDVs, which was not available under the historical LCFS data.

Some fuel categories projected in the FPSM did not have corresponding entries in the historical LCFS data, thus some historical baselines had to be calculated or inferred. For example, incremental electricity consumption—electricity that generates additional “incremental” credits using the LCFS Low-Carbon or Smart Charging pathways—was calculated in the FPSM using electricity consumption from historical LCFS data. In addition, some feedstock categories in the historical data were merged into one category in the FPSM, as a conservative estimate of CI impacts and growth potential. Sources of RNG were consolidated into three CI bins: livestock digesters (lowest, often negative CI), landfill gas (highest CI), and all other categories. These included wastewater sludge digesters, anaerobic municipal solid waste (MSW) digesters, and wastewater treatment plants according to the similar CI scores for fuels in these pathways. Each fuel type in the FPSM aggregates all fuel production from pathways in that category, so the FPSM projects a single trajectory for volume and CI growth for all corn ethanol, or all soybean-based RD and does not attempt to simulate varying CI scores from specific producers.

Gasoline and Liquid Gasoline Substitutes

In the TTM results, all liquid gasoline substitutes are aggregated into a single category following the label from early versions of the VISION model. In practice, the FPSM considered two liquid gasoline substitutes: ethanol and drop-in renewable gasoline. Thus, instead of having four categories as shown in the TTM results (LDV gasoline, LDV ethanol, HDV gasoline, and HDV ethanol), the FPSM primarily focused on three categories (gasoline, ethanol, and drop-in renewable gasoline substitutes). These were further subdivided into three sub-categories for ethanol depending on the feedstocks (cellulosic biomass, starch, and sugar), and two for drop-in liquid gasoline substitutes (naphtha and all other liquid drop-in renewable gasoline substitutes).

Naphtha is a low-value coproduct of hydrotreating lipids for producing SAF and RD. It has been approved by CARB with several pathways. However, comparatively few credits have been issued for these pathways given the volumes of RD and SAF—and therefore the potential volumes of coproduct naphtha—that have been credited under the LCFS. Thus, when merging historical LCFS data with TTM results, renewable naphtha in the historical data was considered as the only naphtha for historical years, and coproduct naphtha which was calculated from RD and SAF production was considered only thereafter.

At the time of writing, there is no current drop-in renewable gasoline pathway approved under the LCFS, though several candidates are at pre-commercial stages of development. Predicting which technology or production process may be approved as an eligible fuel pathway and how much will be produced are outside the scope of this study. Thus, this study calculates available potential of drop-in renewable gasoline based on the goal and growth rate from the control scheme and assumes that the difference between required drop-in renewable gasoline and available renewable gasoline must be met by an additional amount of petroleum gasoline. Several technologies, including cellulosic biofuels, synthetic fuels produced using renewable electricity (e-fuels), or algal fuels may be able to satisfy this demand. To some extent, the projected amount of drop-in renewable gasoline serves as an indicator of need and a target for future policy. The CI of renewable naphtha was estimated from the historical data and was assumed to decrease as described in the control scheme. In addition, as there is no current drop-in renewable gasoline, the CI of renewable gasoline was assumed to be the same as CI for renewable naphtha.

The calculation gasoline and gasoline substitute volumes begins with the gasoline consumption either from the historical LCFS data or the TTM results. The FPSM assumes that the amount of ethanol makes up a fixed fraction of total liquid gasoline and gasoline substitutes consumption, which is at 11% by volume in the near term, reflecting ubiquitous E10 (10% ethanol blend) plus other higher ethanol blends like E85 to account for one extra percentage point. Ethanol use optionally increases in future years in scenarios that assume a relaxation of the blend wall or growth in consumption of high-alcohol blends (e.g., E85). Drop-in renewable gasoline is assumed to be blended with ethanol at the same ratio as conventional petroleum gasoline. Higher ethanol blend rates or a greater diversity of ethanol blends can be simulated by adjusting the average blend rate to reflect desired levels. Past consumption of renewable naphtha is taken from historical data and projected as a modeled fraction of SAF and RD production. The TTM projections of gasoline substitutes were satisfied in four steps: (1) by ethanol blended into total liquids at the volumetric rate, (2) by the amount of renewable naphtha coproduct available, (3) by drop-in gasoline substitute up to the user-specified limit of such fuels, and (4) any remaining residual was assumed to be met by additional petroleum gasoline. This means, under some circumstances, the consumption of petroleum gasoline in the FPSM may be higher than the TTM results. This is because the VISION-based structure of TTM did not consider cost, regulatory, or sustainability constraints when projecting alternative fuel consumption. The FPSM therefore adjusted these projections downward by the method described above when necessary.

Once the total volume of each fuel was determined, the ethanol was categorized based on the feedstocks available in California: starch, sugar, and cellulosic biomass. Corn ethanol, sorghum ethanol, and wheat ethanol shown in the historical LCFS data were classified as starch ethanol. These sources have supplied most of the ethanol consumed in California. Sugarcane and molasses ethanol were classified as sugar ethanol, and fiber ethanol was classified as cellulosic ethanol. When assigning total ethanol to these categories, the model first assigned cellulosic ethanol and then separated remaining groups into starch and sugar ethanol. Compared to starch and sugar ethanol, which have been in the market for a longer time, cellulosic ethanol has recently emerged and contains higher uncertainty in its CI value and available technologies. Thus, the model estimated the cellulosic ethanol volume based on the goal and growth rate from the control schemes, and the remaining volume was separated into starch and sugar ethanol based on the historical fraction or as shown in the control scheme. It is important to track ethanol by different feedstocks because they have different CIs. The CI may vary depending on the processing technology even with the same feedstock, but the FPSM only considers an average CI for each feedstock category. There are four ethanol CI values calculated in this study: starch, sugar, cellulosic, and volume-weighted average-of-all. Historical ethanol CIs for total ethanol were directly obtained from historical LCFS data, and the historical CI of each type of ethanol was calculated from the reported volume and credits. For years subsequent to historical data, CI trajectories for all three categories of ethanol were projected using the user-specified rate of CI improvement. Although there may be a distortion due to differences in individual fuel pathways, it was confirmed that the historical CI and the calculated CI from the three categories of ethanol are not significantly different from each other, varying less than 0.5%. Emissions and LCFS credits were calculated based on these assigned volumes and CIs of three categories of ethanol.

Diesel, Liquid Diesel Substitutes, and Aviation Fuel with Distillate Constraint

Non-fossil lipid-based fuels, such as BD and RD, have emerged as scalable and commercially viable alternatives for petroleum diesel. They have already contributed significantly to reduce GHG emissions and other air pollutants from diesel vehicles. In addition to BD and RD, demand for SAF from hydrotreated lipids has also been increasing. This is helping to decarbonize the aviation sector. These fuels are eligible for LCFS credit generation as opt-in fuels. Although current BD, RD, and SAF production pathways are not carbon-neutral over their full life cycle, they can still reduce overall GHG emissions compared to petroleum diesel or jet fuel.

Lipid-based fuels present significant concerns, most importantly indirect land use change (ILUC) impacts. ILUC impacts can be caused by increased demand for an agricultural commodity, such as the feedstocks for biofuels. Impacts stem from the conversion of natural land to cultivated land, which releases carbon due to the loss of biomass and solid organic carbon in the soil. ILUC risk is strongly associated with crop-based feedstocks, though cross-oil substitution by many industrial consumers of vegetable oil means that ILUC impacts caused by waste feedstocks, such as used cooking oil, are not completely zero. To address these ILUC impacts under the LCFS, a predetermined ILUC factor is assigned to a fuel which is derived from a feedstock associated with the ILUC. Quantifying ILUC impacts involves the consideration of a variety of economic, agronomic, social, and ecological factors. The science on this topic is not yet settled due to major uncertainties. A recent article evaluating ILUC impacts of corn ethanol production supported by the US Renewable Fuel Standard was met with multiple critical response letters from academic researchers, and a recent National Academies expert workgroup that was convened to review life cycle assessment (LCA) methods relating to biofuels could not produce a definitive recommendation on modeling methodology. Instead, they highlighted the complexities of the field and need for future research (12–19). Existing ILUC models often lack reliable and sufficient calibration data about international commodity markets as well as grower preferences and, even if such data were available, they would have been collected prior to the rapid expansion of lipid-based renewable fuel production or the anticipated impacts of climate change on grower decision-making. Taken together, these factors explain the very high uncertainty in ILUC modeling. Resolving this uncertainty and fully modeling ILUC impacts are beyond the scope of this study. Instead, this study followed the approach used in previous studies (5,6).

In this study, the maximum capacity of lipid-based fuel production was limited to a level unlikely to cause any serious ILUC impacts (20,21). The baseline for this value was set at 1,750 million diesel gallons equivalents per year for all lipid-based fuels (BD, RD and SAF). This can be adjusted in the control scheme if needed. This approach generally aligns with concepts for a cap on crop-based feedstocks currently under consideration by CARB for adoption into the LCFS. This maximum capacity was determined based on results from other studies and was not calculated from a solid market or resource availability, so this value can be adjusted and updated along with the future research. The FPSM allows users to adjust the maximum capacity and its growth rate easily. This calculation only applies to future years when the historical data are not available. In the FPSM, similar to gasoline and liquid substitutes, diesel and liquid substitutes for LDVs and HDVs are not distinguished as in the TTM results. Thus, the FPSM contains four categories shown in the historical data including conventional diesel, BD, RD and SAF.

With the maximum capacity set for BD, RD and SAF as the upper limit, the model allocates the available supply of lipid feedstock to the fuels, in the order of SAF, BD, and RD. While the actual supply capacity or demand of each fuel may be interactive with each other, the FPSM assumes that the demands are met in this order. Their interactions in terms of resource availability, markets, or environmental benefits may be discussed in future research. Compared to the ground transportation sector, the aviation sector has less feasible alternatives to liquid jet fuel, so the demand for SAF was assumed to be satisfied first. Estimated demand for SAF by 2030 can be specified by the user and, for the scenarios described in this study, it was estimated based on forthcoming modeling work done by UC Berkeley and UC Davis researchers (including the authors of this report) under the Resilient and Innovative Mobility Initiative (RIMI) (22,23). At present, California has no explicit requirements for specific volumes of SAF to be consumed. However, with the presence of the LCFS opt-in, an informal target of 20% SAF consumption by 2030, and a recently-authorized Federal SAF tax credit, this was judged to be a reasonable target for 2030 consumption. The overall cap on total lipid-based fuels means that setting a higher or lower assumption for 2030 SAF consumption would yield a commensurate decrease or increase in BD and RD consumption. This would impact credit and deficit balances under the LCFS because SAF is an opt-in fuel while BD and RD are not. Aggregate carbon intensity of lipid-based fuels would also reflect the slightly higher hydrogen consumption for hydrotreated SAF production compared to RD. However, aggregate life cycle emissions across California's fuel pool are not strongly sensitive to SAF volume assumptions. Post-2030 demand or consumption of SAF was projected using user-specified travel demand growth assumptions and aircraft fuel economy improvement rates, carried over from the *Driving to Zero* study (4). Future work by this research team will more deeply evaluate impacts of SAF consumption levels and different policy designs.

Once the SAF demand was satisfied, BD and RD volumes were projected using a similar approach as for the gasoline and liquid substitutes. This parallels TTM results, wherein all diesel liquid substitutes are aggregated. The amount of BD was calculated first from the total diesel pool, and any remaining capacity for lipid-based fuels enters the market as RD. Any remaining diesel demand is then met with petroleum diesel. Similar to the case of gasoline and liquid substitutes, the calculation starts from the total diesel pool consumption for HDVs and LDVs from the TTM results. The FPSM first estimates BD volumes as a fraction of total liquid diesel demand, using the user-specified blend rate. Because BD is normally blended with conventional diesel while RD completely replaces conventional diesel, it was assumed that BD is blended with conventional diesel or RD at the specified blend rate. The BD blend rate and its projection can be modified as desired, and the default blend rate was set as 6% considering the typical blend rate at 5% and the additional 1% enters the market from the higher blends like B20 (20% BD blend).

After calculating total consumption, BD and RD were adjusted to account for the gap between the TTM results and historical data. TTM only accounts for on-road uses of fuel, while the LCFS also covers non-road uses. To adjust the difference, the total values of diesel, BD and RD, which were based on TTM results, were increased by 5% until 2035. After this time, the additional fuel consumption for off-road uses was decreased by 1% annually to 0%. The 5% rate was determined based on the average off-road portion of the diesel pool consumption, and it was phased out to 0% considering the transition of off-road equipment fuels from fossil fuel to electricity or hydrogen. This schedule can be modified by users within the control parameter schemes.

Similar to the ethanol from different feedstocks, BD, RD and SAF from different feedstocks have different CIs. Under the LCFS, BD includes canola, corn oil, soy oil, tallow, used cooking oil (UCO) and others as feedstocks, and RD includes corn oil, UCO, tallow, soy oil and other sources as feedstocks. The FPSM used these historical data to estimate the potential availability and CI of each type of fuel, and it was assumed that feedstocks were consumed in order ascending CI values. Future potential availability was calculated based on the growth rate modeled in the control scheme except for soy oil, which has the highest CI values for both BD and RD. The potential availability of soy oil was set without any limitation, so that soy oil could be used to make up for any shortage from other feedstocks, up to the total limit on lipid-based fuels. The CI values were calculated based on historical data. Improvement rates are described in the control scheme.

Using the break-down results and estimated CIs, the weighted average CIs of RD, BD, and SAF were calculated. While the average CI of BD was directly used to calculate the credits generated from BD, an additional step was added to calculate the CI value for RD and SAF. In contrast to BD, there is no clear benefit for a feedstock to be used for RD rather than SAF. Thus, instead of using each CI of RD or SAF, the FPSM used a weighted average CI of RD and SAF for credit calculation from RD and SAF. (Figure 1) It is important to note that actual CI of any given fuel will depend largely on the feedstock used to make the fuel. The FPSM essentially treats all lipid-based fuels as part of a single pool and does not attempt to project which feedstocks will go to SAF, RD, or BD. CI projections for any single lipid-based fuel category are, therefore, highly dependent on the order of operations used by the FPSM. The aggregate CI of all lipid-based fuels ultimately is a better indicator of real-world CI performance in this space than the CI of any single lipid-based fuel category. The amount of waste and residue oils grows more slowly than diesel demand so, in most scenarios, the CI of lipid-based fuels increases over time as higher-CI soy oil makes up an increasing fraction of total volumes. When diesel demand declines to the point where the total amount of lipid-based fuels is less than the cap, the FPSM assumes that fuels from soy oil are the first to exit the market, leading to a decline in CI in later years. Because of this trend, the carbon intensities of renewable diesel and biodiesel show increase-then-decrease behavior, which is more noticeable for renewable diesel due to larger volumes.

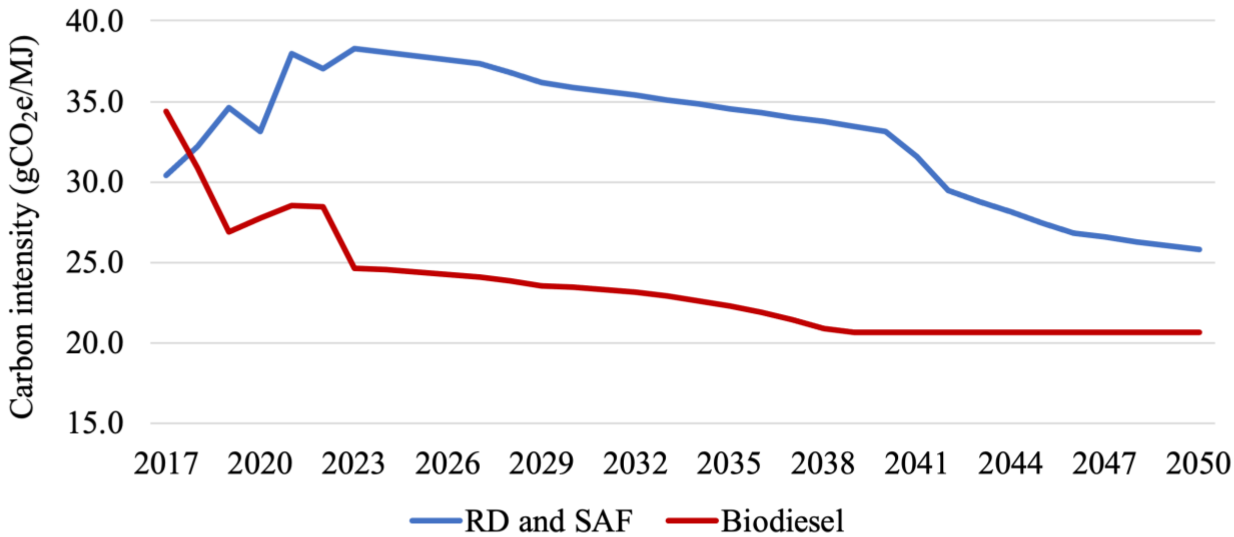


Figure 1. Carbon intensities of renewable diesel (RD), sustainable aviation fuel (SAF) and biodiesel over time (2017-2050). The rapid reduction in RD CI after 2041 is because that is the year in which all fossil diesel is displaced from California's fuel pool. Thus, reductions in liquid fuel demand after that point occur in the highest-CI feedstocks like soybean oil first, until crop-based oils are driven out of the system by the mid-2040s.

Natural Gas

Natural gas, including RNG, plays a small but important role in California's fuel portfolio. The TTM differentiates between compressed natural gas (CNG) and liquefied natural gas (LNG) for LDVs and HDVs, while the historical LCFS data subdivide natural gas fuels into bio-CNG, bio-LNG, fossil-CNG and fossil-LNG as the amount by source. Over the past five years, 90% of natural gas used as a transportation fuel in California has been in CNG vehicles, and this fraction continues to increase. Thus, the FPSM aggregated all NG use into a single CNG category. (11)

RNG dominates the total natural gas supply used under the LCFS due to the incentive offered for its lower CI compared to fossil natural gas (NG). The average CI of the natural gas pool is a function of the relative fraction of different feedstocks in the final mix.

To accurately estimate GHG emissions from natural gas, it is necessary to clarify the source or feedstock used in its production. Estimating this CI value starts from the estimates of potential RNG production by source, which is obtained from an ICF report which estimates the potential RNG in 2040 by source in the United States across high, medium, and low potential resource scenarios (10). California's potential supply of any category of resource was assumed to be limited to a population-weighted share of the national supply. The "Low" resource estimate from the ICF report best matches historical RNG consumption trends and is thus used as the default assumption on RNG resource availability. This may be underestimated potential supply to California because the state's LCFS typically offers the largest incentive for RNG, in both per-unit terms and when aggregated across the total market. Thus, the results for RNG in the FPSM may be viewed as a conservative (high) estimate of its CI. The FPSM allows users to select alternative supply scenarios from the ICF report, if desired. The four anaerobic digestion based RNG source categories in the ICF report were merged into three categories to match historical LCFS data (the gasification and power-to-gas pathways were judged to be too speculative to project significant volumes in the LCFS by 2030 and so excluded). Our model incorporates RNG source categories including dairy manure, municipal solid waste (MSW) and wastewater treatment plant (WWTP), and landfill.

Based on these estimated potential availabilities for 2040, the FPSM assumed a linear increase of supply until 2040 and then remains at those levels until 2050. Yearly volumes of natural gas consumption from the TTM projections were then satisfied in ascending order of CI, first livestock digester gas was used, then WWTP and MSW digester gas, and finally any remaining demand was met with landfill gas. A small and declining amount of fossil natural gas is still used in the LCFS, likely due to the presence of long-duration legacy contracts for some fleets, or similar business arrangements. The FPSM assumes the amount of fossil NG continues to decline over time. The ratio between RNG and fossil NG from this step was then used to separate RNG and fossil NG for LDVs and HDVs in the TTM results.

The ratio among RNG from different sources and fossil NG was also used to calculate average CI values for RNG and total NG, and the CI values were then used to calculate the credits generated from NG. While the CI values for landfill RNG and MSW/WWTP RNG were assumed to be improved by the rate designed in the control scheme, a different calculation was performed for dairy RNG due to the assumed expiration of avoided methane credits currently available to these pathways, due to anticipated future regulation (24). The CI value of dairy RNG was assumed to increase linearly according to the schedule set by the user. After the expiration eligibility for avoided methane credits – phased in between 2035 and 2040 - it was assumed to be the same as the CI of MSW/WWTP RNG.

Electricity

The TTM results contain two values for electricity: LDV and HDV. However, under the LCFS, there are several more types of credits generated from electricity as transportation fuel. The CARB differentiates between LDVs and MHDVs, as well as on-road and off-road uses, as each may have a different Energy Economy Ratio - EER - used for credit quantification. On-road types are further differentiated by charging location (residential or non-residential) and by grid electricity or low-CI electricity. Currently, EV charging credit generators either use the grid CI electricity or opt into “incremental crediting” programs using low-CI electricity procured from wind and solar generation or a smart charging program. To date, over 30% of total charging and 90% of non-residential charging take advantage of low-carbon incremental crediting provisions.[3]

Several assumptions were made for the FPSM to simplify the calculation. First, although there is electricity which has a lower CI value than the grid electricity but not necessarily zero, the FPSM assumed that all low-CI electricity is zero-CI electricity to simplify the model. Second, as assessed by CARB, the FPSM assumed that the CI of grid electricity will be zero in 2045 with a linear decrease from the current CI. Third, all residential EV charging was assumed to be for LDVs with categories for on-road electricity in the FPSM including residential grid electricity charging for LDVs, incremental credits from residential charging, non-residential grid and low-CI electricity charging for LDVs, and non-residential grid and low-CI charging for HDVs.

The calculation for electricity consumption is based on historical fractions and TTM results. As the consumption of electricity which generates incremental credits was not directly available from historical data, it was estimated based on other available data. In the historical data, it contains total electricity consumption as well as category-specific consumptions like grid-average CI, zero-CI, and other low-CI electricity. However, category-specific consumptions do not sum up to total electricity consumption, due to LCFS accounting and reporting methodology.

Use of incremental crediting, particularly for low-carbon electricity, has been growing since it was added to the program in 2018. The FPSM assumes this growth continues until almost all charging occurs using low-carbon electricity. Alternative assumptions about the relative prevalence of different charging categories can be modified by the user in the control scheme. The electricity consumption and relevant credits were then calculated based on the fractions and TTM results.

While the TTM only projects fuel consumption of on-road vehicles, the LCFS allows off-road vehicles or equipment, such as fixed guideways, electric ocean-going vessels (eOGV), electric transportation refrigeration unit (eTRU), electric forklift (e-Forklift) and electric cargo handling equipment (eCHE), to generate credits. Thus, the credits generated by electricity consumed in these types of vehicles or equipment were calculated based on historical data and user-specified assumptions. The FPSM assumes a linear increase of each category based on the assumed growth rates. Phasing out of credit generation can also be modeled as desired. The ratio of low CI or zero-CI electricity was assumed to increase linearly with a growth rate set by the user. E-forklifts are unusual compared to the other non-road EV pathways, due to the relatively high penetration of e-forklifts in the state fleet – thought to be over 50% at present though significant uncertainties remain in the fleet data. As a result, e-forklifts generate a large amount of LCFS credits despite their relatively small total fuel consumption.

[3] A third option, so-called "smart charging," varies electricity CI to reflect seasonal resource mixes across a 24-hour cycle. It seeks to incentivize charging at non-peak grid demand times. Given that the CIs for all times under these plans are greater than zero, and the relatively inexpensive options to procure renewable electricity that provides a zero CI, the smart charging options have gone comparatively unused. The FPSM scenarios presented here assume that this practice continues, and so the smart charging option is omitted from this report.

Others (Hydrogen and Projects)

Hydrogen currently plays a limited role in the transportation fuel pool. The TTM estimated that hydrogen will grow significantly in the future, particularly with an increasing demand for long-haul HDVs. In the FPSM, the projection from TTM results was used for hydrogen, and the CI values for hydrogen were modeled based on control parameters designed by the user.

In addition to credits from low-carbon transportation fuels, there is an opportunity for projects to generate credits under the LCFS. Capacity-based crediting projects include innovative crude oil, refinery investment credit, low complexity/low energy use refinery and renewable hydrogen refinery as well as hydrogen refueling infrastructure (HRI) and DC fast charging infrastructure (FCI).

Total credit generated from this sector is relatively lower than the credits from other transportation fuel pathways, so they were modeled based on linear growth from historical baselines to user-specified end targets. For example, the innovative crude credit and the renewable hydrogen refinery credit were designed to achieve goals by target years, and the refinery investment credit, HRI credit, and FCI credit were designed to be generated up to the maximum (determined by the percentage of prior year deficits) and then linearly decrease throughout the crediting years. The low complexity/low energy use refinery credit was assumed to be zero following the most recent historical data because there is no credit from this type of project after 2021. Default values for the scenarios presented in this report were carried over from *Driving to Zero* (4).

Results and Discussion

Compliance with LCFS was estimated by the FPSM based on the multiple fuel scenarios, model assumptions, and reduction targets. The temporal range FPSM nominally extends through 2050 but, due to the high sensitivity of model outputs to assumptions regarding ZEV deployment rate and the commercialization of novel technologies, uncertainty increases greatly over time, especially post-2035. As described in the methodology section, BAU, LCT and DtZ scenarios, were analyzed in the FPSM. However, BAU scenario results are not presented in this report because their relevance to near-term policy discussions is limited; they represent a world in which critical climate policies recently adopted by California—namely ACC2, ACT, and ACF—were not in effect.

Current Status in California and Demand Projections

Transportation in California still depends heavily on petroleum gasoline and diesel. Although the fraction of petroleum fuels has decreased over time, it is still above 80% of the total energy supply for transportation in California and is higher for the gasoline pool (Figure 2). Compared to the US renewable and low-carbon diesel pool consumption average of 6%, the 2022 ratio of renewable and low-carbon diesel fuel is about 42% of total in California.

Data from the first and second quarters of 2023 show the fraction of BD and RD in the diesel pool continuing to increase. Over 40% of the total LCFS credits were generated from RD and BD historically (Figure 3). The major challenge for continued growth of RD and BD will be the availability of feedstocks. Used cooking oil and other residues provided the majority of BD and RD through 2020. However, most available sources of these have been fully exploited for biofuel production. Soybean oil's share of BD and RD feedstocks began rapidly growing in 2021, and most future growth in North American lipid-based fuels—BD, RD and hydrotreated SAF—is anticipated to use soy or other crop oils as feedstock.

Ethanol has maintained a consistent presence in the LCFS market due to ubiquitous 10% ethanol blends (E10) in the retail gasoline market. The potential for growth in ethanol's credit generation is likely to be limited by the blend wall. FPSM assumes the blend wall will lift to 15% in 2031 but, even with this, declining total volumes of gasoline consumption likely limit credit generation potential. The CI of ethanol may decrease with the emergence of cellulosic ethanol and an increasing deployment of CCS on ethanol production facilities. Even so, ethanol's potential credit generation may be limited unless there is a significant increase in the use of flex-fuel vehicles which can be operated with an E85 blend or a broad adoption of mid-ethanol blends (e.g., E30). In addition, the impact of ethanol on credit generation may be further limited by the anticipated decline in liquid fuel consumption by LDVs, due to the increasing number of EVs and improved fuel economy in ICEVs.

Credits generated by RNG have increased recently. This is largely supported by anaerobic digestion of dairy manure feedstock. With the credits from avoided methane emissions, RNG from dairies is often assessed as having a negative CI value. The RNG from dairy manure has contributed about 16% of total credits in 2022, which is relatively high considering that it is 5% of total diesel pool energy consumption. However, the projection for RNG seems to be limited by limited sources of readily available wastes and residues that are not amenable to use in higher-value production systems than RNG; further research is needed to improve projections in this space. There are on-going debates regarding environmental justice issues associated with large-scale confined animal facilities, which should be taken into consideration (25,26).

CARB has indicated that it is considering the adoption of measures that would modestly reduce the potential supply of very low-CI livestock-derived RNG and phase out methane credits for avoided emissions by 2040. Possible effects these provisions modeled here, and the majority of these would not occur until after 2035, which is outside our range of analysis. The long-run growth potential of RNG appears limited. Multiple state policy actions, including ACT, ACF, and new incentives for purchasing ZEVs, have indicated that California's long-term vision for low-carbon transportation is centered on ZEVs rather than low-carbon combustion. This has led most fleets, OEMs, and related stakeholders to adopt a similar focus. Combined with the superior cost profile of EVs in most MHD applications, this implies limited growth potential for natural gas vehicles that could offer RNG entry into the transportation market, and thereby access to LCFS credits (27).

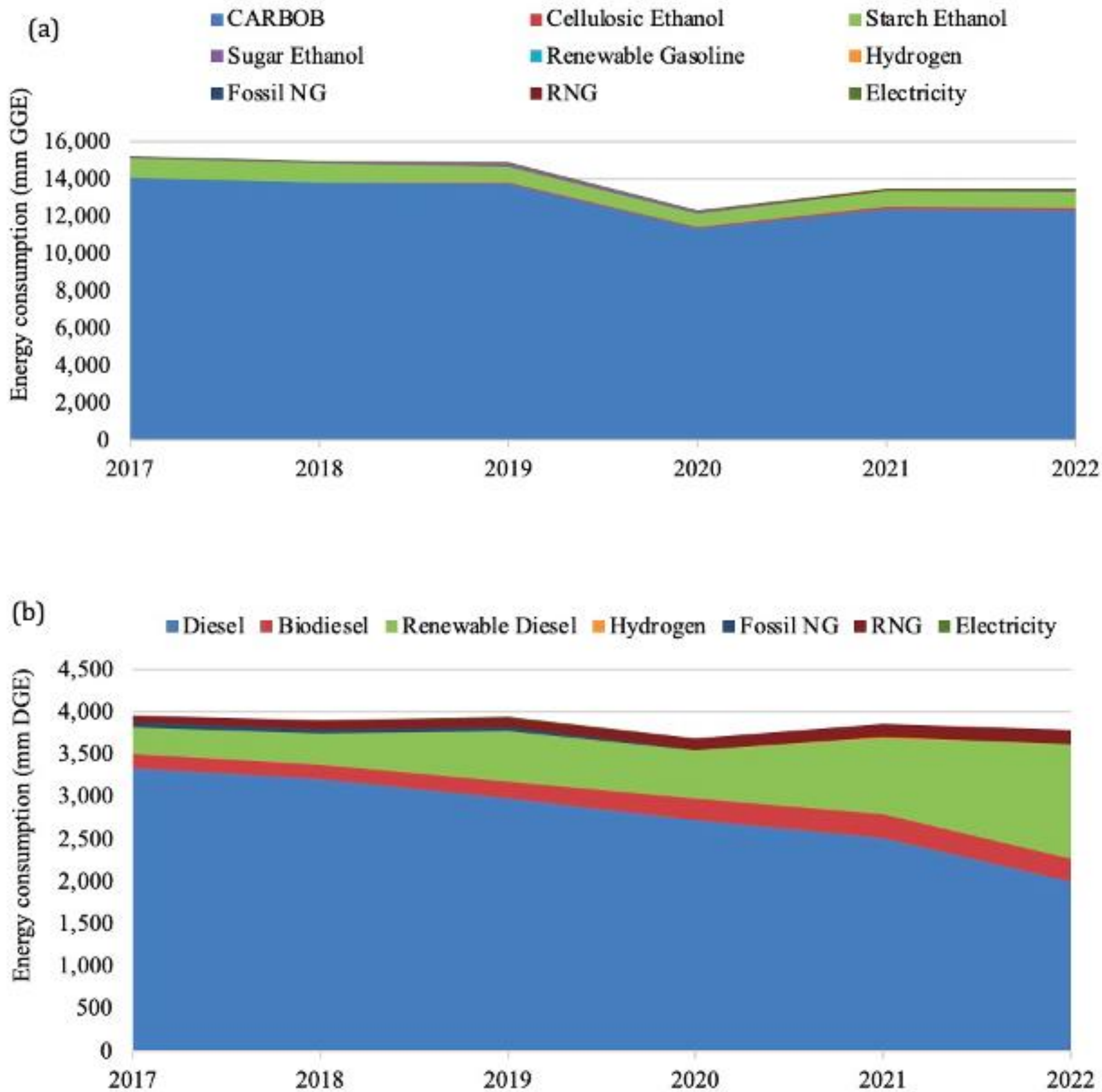


Figure 2. Historical transportation fuel consumption in California for (a) gasoline and (b) diesel pools (CARBOB: California Reformulated gasoline Blendstock for Oxygenate Blending, NG: Natural Gas, RNG: Renewable Natural Gas, mm GGE: million gasoline gallon equivalent, mm DGE: million diesel gallon equivalent).

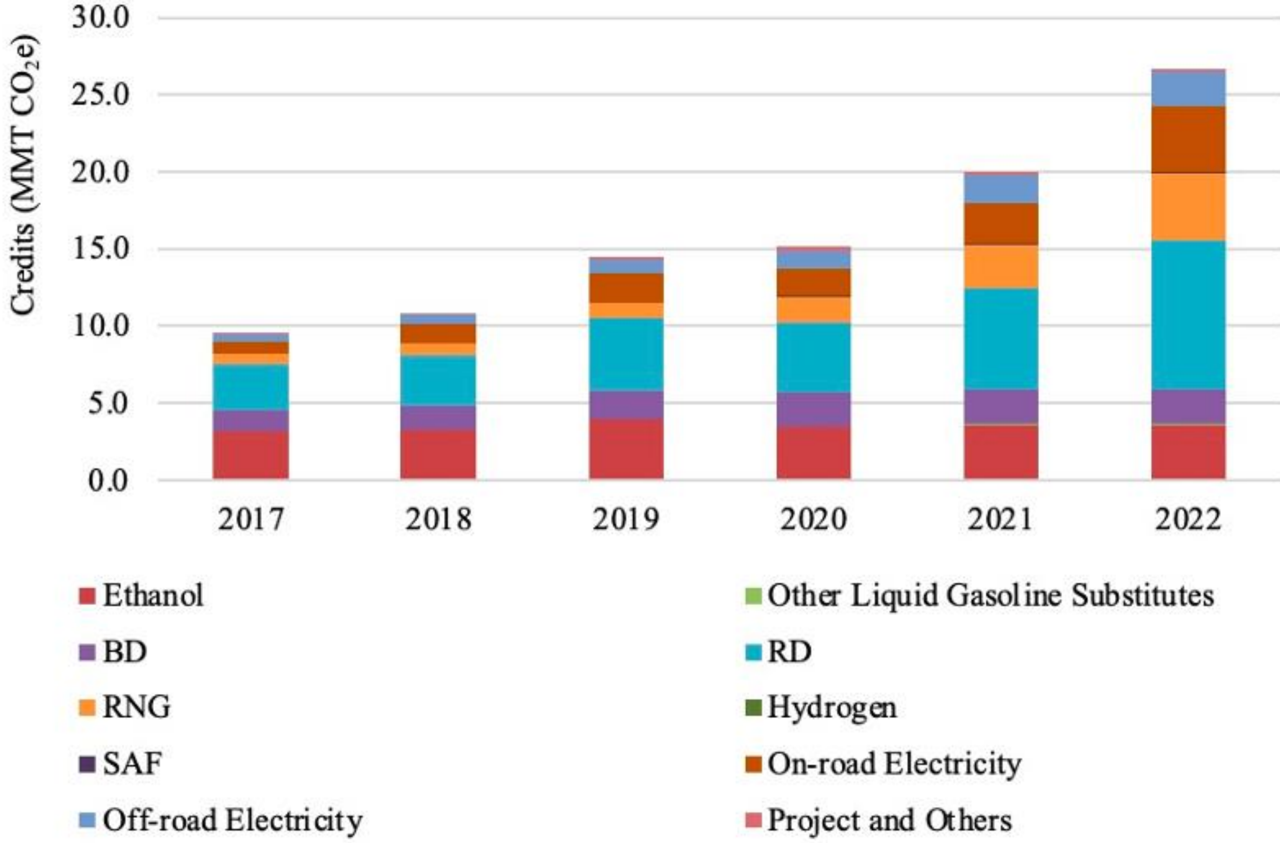


Figure 3. Historical credit generation under the LCFS in California (MMT CO_2e: million metric ton carbon dioxide equivalent, BD: biodiesel, RD: renewable diesel, RNG: renewable natural gas, SAF: sustainable aviation fuel).

The rate of fleet conversion to ZEVs and VMT trends are areas of particularly high uncertainty in this analysis. The TTM projections used to establish fuel consumption assume that California achieves, but does not greatly exceed, sales targets set out in ACC2 and ACT. They also assume that existing models of vehicle aging and retirement adequately predict the behavior of ZEVs over the coming decade.

There are several plausible ways in which real-world behavior could diverge from TTM projections, however. The EV sales fractions required for ACC2 compliance require a rapid build-out of EV supply chains, from acquisition and processing of critical minerals, through battery fabrication, to assembly of finished EVs. Major auto and truck OEMs have announced significant expansion of capacity in these areas. However, if capacity expansions are delayed, then the supply of EVs may be inadequate to meet ACC2, ACT, or ACF targets. Even if EVs are readily available, some vehicle owners may choose to retain ICEVs longer than current models predict, delaying the displacement of petroleum by electricity or low-carbon hydrogen. Fuels such as RD, RNG, or hydrogen could enter the market in higher-than-projected volumes to compensate, however, cost, infrastructure, or feedstock supply challenges may prevent them from delivering LCFS credit generation equivalent to EVs. Disruptions to the projected—and quite rapid—growth in EV supply would therefore reduce the potential LCFS credit supply and lower feasible LCFS targets.

Projecting VMT is similarly critical and challenging. Despite having adopted a state-wide policy requiring reductions in per-capita VMT in almost every major metropolitan area, California has been unable to arrest the long-term trend of VMT growth (28). TTM modeling projects a very gradual decline in per-vehicle VMT for ICE LDVs, though this is in part because the model projects high-mileage drivers to preferentially select EVs due to the operational cost advantages. If, however, per-vehicle ICE VMT continues to increase over the coming decade, gasoline consumption would increase, as would the generation of LCFS deficits, which complicates compliance with LCFS program targets.

The total gasoline pool consumption for each scenario (Figure 4), and the differences by fuel types, including gasoline, ethanol, and electricity for LDVs (Figure 5) are shown below. The primary difference between the old DtZ scenario and new LCT scenario is an assumption for the gasoline market trajectory after the COVID-19 pandemic. The DtZ scenario assumed a full recovery of driving to pre-COVID-19 pandemic level as shown in Figure 4 and Figure 5. Thus, throughout the analysis, the DtZ scenario was used as a high-gasoline-demand sensitivity scenario relative to the LCT scenario. The difference in petroleum gasoline consumption between LCT and DtZ is around 800 million gallons per year for most of the 2020s. For the most part, DtZ scenarios show similar credit bank levels in 2030 as LCT scenarios with 2030 LCFS targets two to three percentage points higher (see Section 3.2). This highlights the importance of accurately projecting VMT trends and understanding the long-term impacts of COVID on driving behavior.

The total GHG emissions for each scenario are shown in Figure 6. While reductions in line with California's GHG reduction targets, including both economy-wide and LCFS program targets, were achieved under both LCT and DtZ scenarios, they were not achieved under the BAU scenario due to emissions from fossil gasoline. Thus, the BAU scenario was excluded from the following analysis and figures as it lacks policy relevance and failed to achieve LCFS compliance under any of the assumptions and conditions tested.

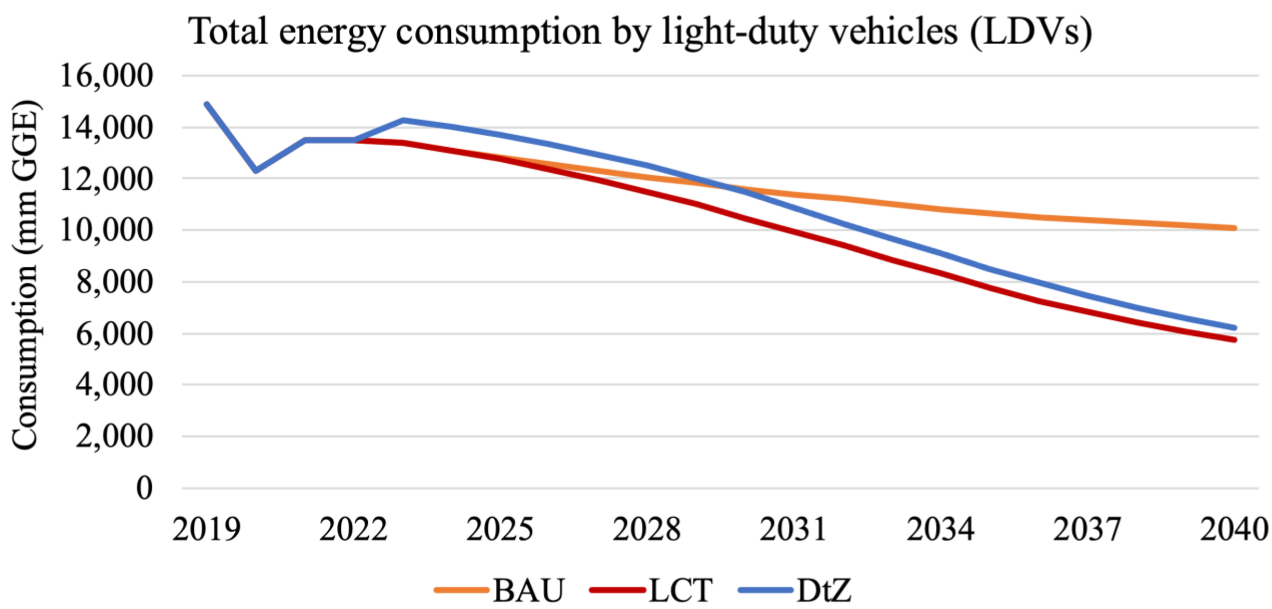


Figure 4. Total energy consumption by light-duty vehicles for each scenario.

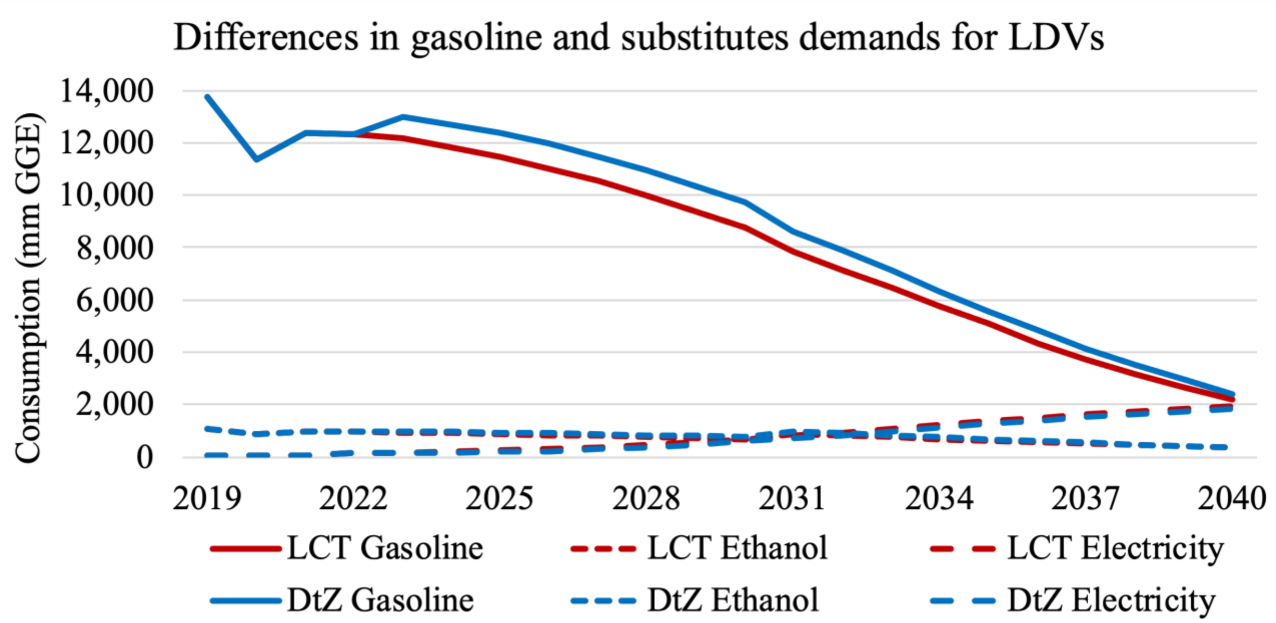


Figure 5. Differences in gasoline and gasoline substitutes demands for LDVs in LCT and DtZ scenarios.

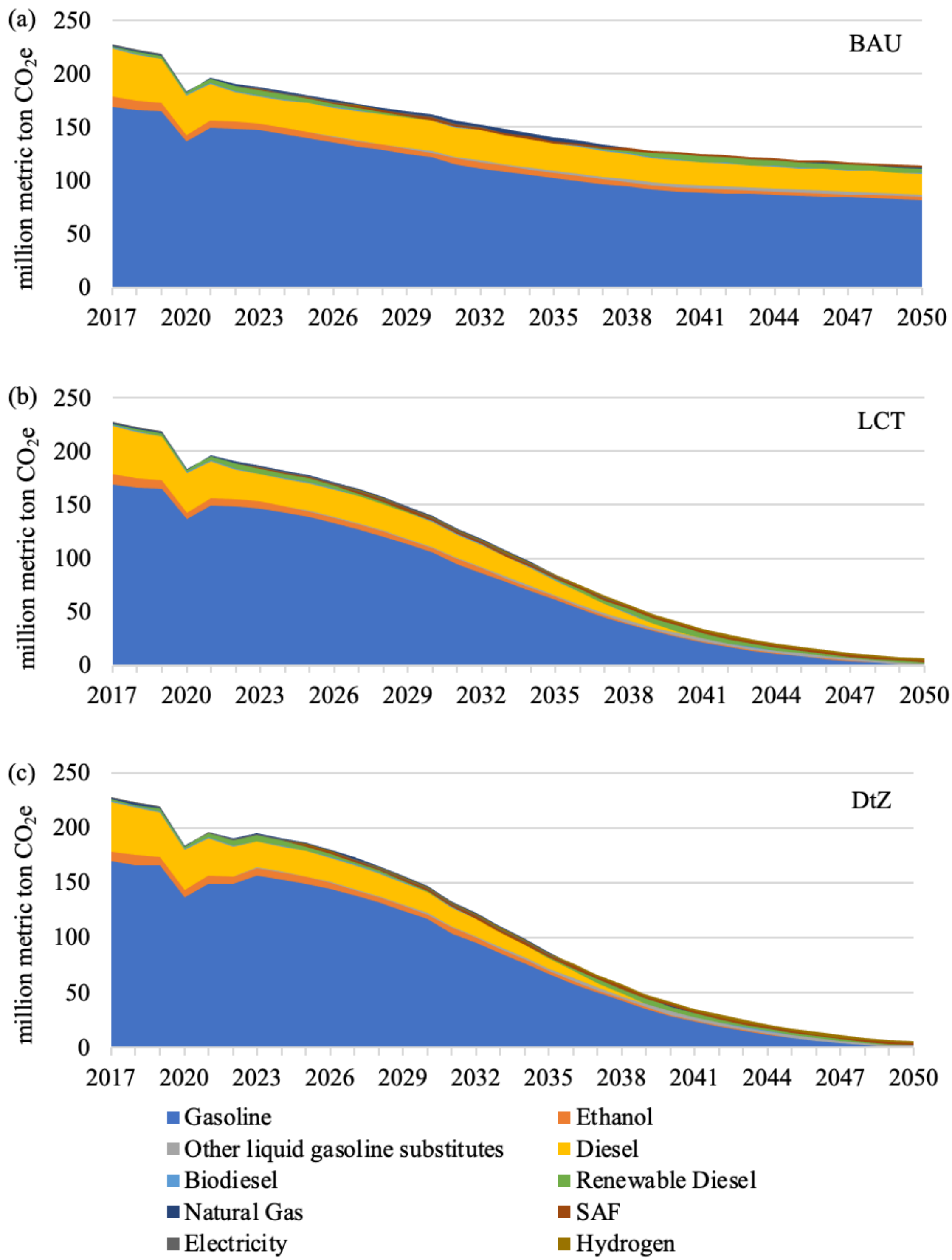
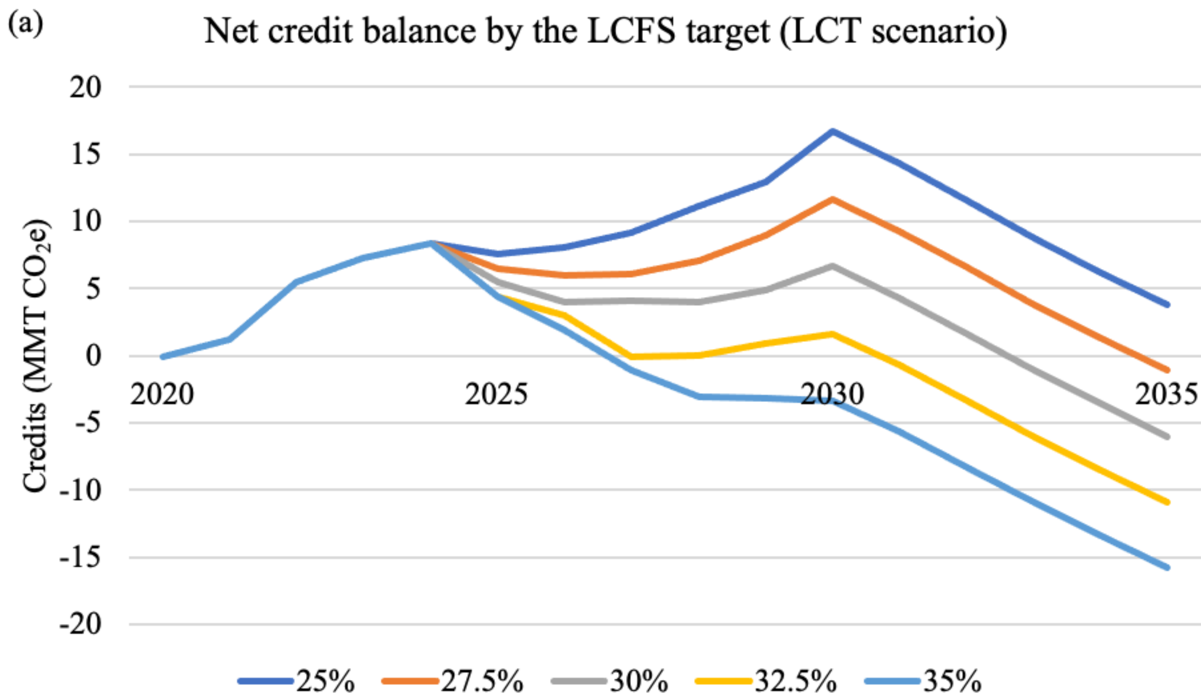


Figure 6. Total greenhouse gas (GHG) emissions from 2017 to 2050 for (a) BAU, (b) LCT, and (c) DtZ scenarios.

2030 LCFS Targets

Since 2020, the LCFS credit price has experienced a significant decline due to impacts from COVID-19 pandemic, faster-than-anticipated growth in RD production, and long-term structural trends. Raising the reduction target is a primary method for increasing the credit price to a level that sufficiently incentivizes investment in low-carbon fuel technologies. This can increase future deficit generation and reduce future credit generation.

CARB has announced that it will begin a rulemaking to update the LCFS, particularly focusing on the 2030 CI reduction target. Accordingly, this target was the primary focus of this analysis. As described above, the reduction targets of 25%, 27.5%, 30%, 32.5%, 35%, 37% and 40% by 2030 were tested with the FPSM. The results for credit balances and credit banks of the LCT scenario (Figure 7) and the DtZ scenario (Figure 8) are shown. The 37% and 40% target scenarios required significant changes to the underlying fuel pool and CI assumptions and are presented separately.



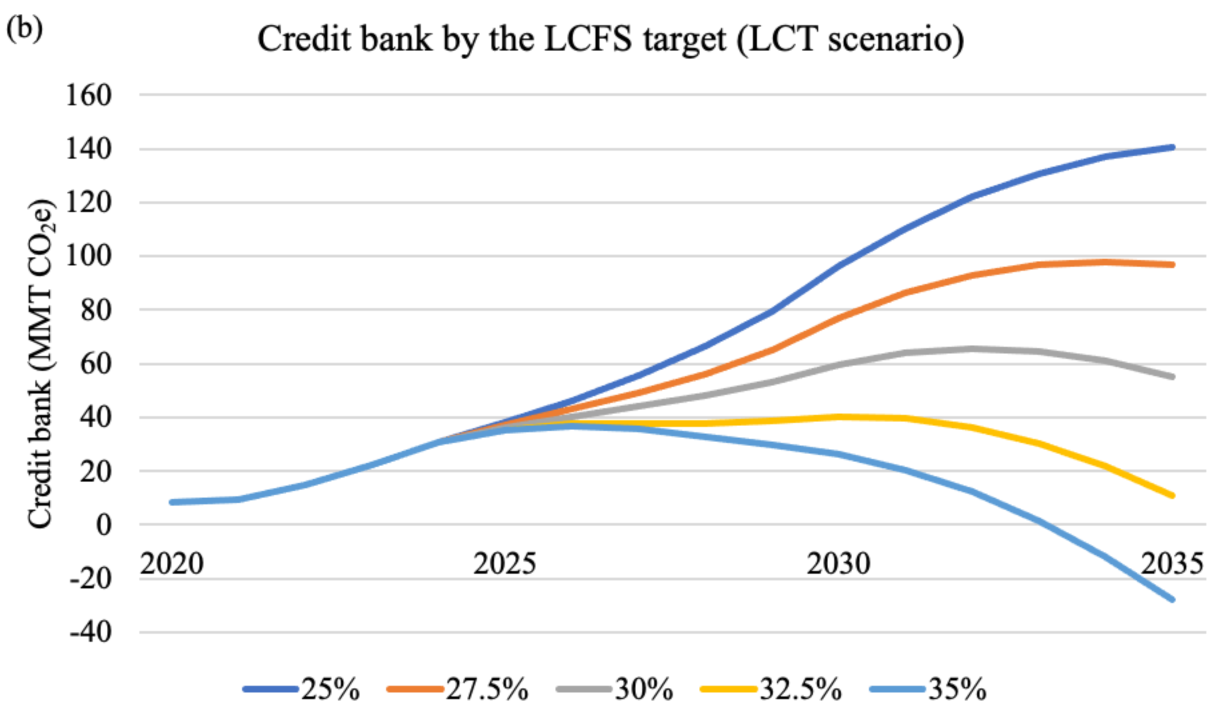


Figure 7. Net credit balances (a) and cumulative credit bank (b) by the tested LCFS targets for the LCT scenario.

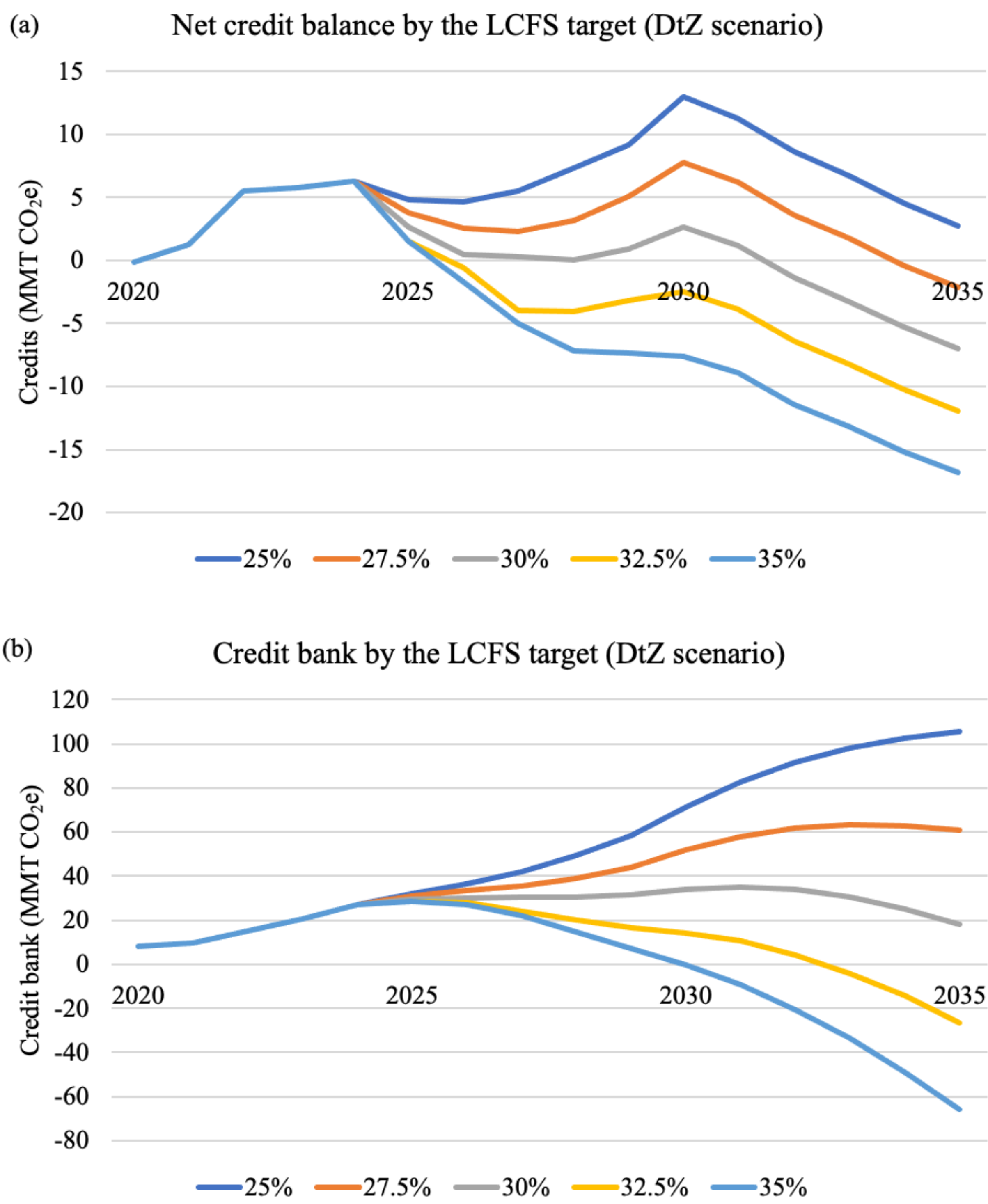


Figure 8. Net credit balances (a) and cumulative credit bank (b) by the tested LCFS targets for the DtZ scenario.

Comparing 2030 Target Scenarios:

All target scenarios indicated full compliance with LCFS targets through 2030, however annual credit generation and the number of banked credits in 2030 varied significantly across the range of considered targets. This is to be expected since FPSM does not simulate market reaction to target levels, in reality lower levels would likely lead to reductions in credit generation due to lower credit prices, and vice versa; as a result, the magnitude of the gap between different target levels may be somewhat overstated by FPSM's approach. This effect may be limited, however, by the relatively limited sensitivity of many critical credit generation pathways to LCFS credit prices or market conditions, e.g. as with EVs.

- The 30% target under the LCT scenario results in a net gain of around 7 million banked credits. The credit bank more than doubles by 2035 under the 25% and 27.5% reduction targets, grows gradually with the 30% reduction target, declines slightly with the 32.5% target, and shrinks significantly under the 35% target.
- Under the DtZ scenario, net credit surpluses were consistently lower. The 30% target results in a net gain of around 2.7 million banked credits in 2030.
- Under both the LCT and DtZ scenarios, the 35% reduction target ultimately depletes the credit bank. This happens by 2030 for DtZ and 2033 for LCT. With the DtZ scenario, the trend is similar to the LCT scenario, however it reflects a higher level of deficit generation due to greater gasoline demand.

In both scenarios, the rate of net credit growth increases in 2029 and 2030 due largely to the increase in EVs. This is despite a gradual non-linearity in target trajectories that result in slightly higher year-on-year target increases in these years (this nonlinearity is absent in current draft target proposals from CARB). The increasing rate of EV sales through the 2020s creates a nonlinearity in the transportation fleet's capacity to decarbonize. There are more low-cost credit generation opportunities in a fleet that is adding 500,000 EVs annually than there are in a fleet adding only 50,000.

While it is not essential to match the trajectory of target increases with the fleet's credit generation capacity, doing so creates a relatively stable amount of policy-induced pressure to deploy lower-carbon alternatives. This is conducive to a more stable LCFS credit market than one in which a linear target acceleration trajectory may, by design, result in some years of significant accumulation of excess credits and other years of significant drawdown of those stored credits.

Estimated sources of credits and deficits under the 30% target, along with anticipated volumes of fuel are presented below (

Table 5). Light-duty EVs are the largest source of credits in 2030, driven by the ACC2 rule. EVs, including LD, MHD, and non-road provide over 50% of total credits, with around 15% each coming from liquid diesel substitutes, BD, and RD, as well as RNG. By 2030, around 20% of the LDV fleet is projected to have switched to ZEVs, predominantly EVs. Combined with improved fuel economy, this may reduce petroleum gasoline consumption from over 13 billion gallons per year today to less than 9 billion. As California approaches 2035, after which no new ICE vehicles will be registered, sales fractions of EVs may approach 100%. The TTM results project that the LDV fleet will be approximately 50% EV by 2035.

Table 5. Credits and deficits generation by fuel type in 2030 with the 30% reduction target and the LCT scenario. The positive values are for credits, and the negative values are for deficits. Unit for fuel consumption is million gasoline gallons equivalent (mm GGE) unless noted as million diesel gallons equivalent (mm DGE).

Fuel	Credit (or Deficit)	Fuel Consumption
Gasoline	-32.66	8,754.7
Total ethanol	1.98	677.9
Cellulosic ethanol	1.04	204.6
Starch ethanol	0.79	435.4
Sugar ethanol	0.15	37.9
Drop-in liquid gasoline substitute	1.29	281.7
Diesel	-7.11	1,755.4
Biodiesel	1.09	172.9
Renewable diesel	5.08	1,097.1
Renewable natural gas (mm DGE)	6.45	169.1
Hydrogen – light-duty	0.95	51.4
Hydrogen – heavy-duty (mm DGE)	1.73	111.7
Sustainable aviation fuel	2.22	540.0
Electricity – light-duty	18.34	685.3
Electricity – heavy-duty (mm DGE)	4.46	95.2
Off-road electricity	1.81	97.7
Incremental crude deficits	-0.97	
Projects, infrastructure, and others	2.00	

Results from these scenarios are highly sensitive to assumptions about the long-term gasoline consumption trend, as well as the rate of EV deployment. The comparison between the LCT and DtZ scenarios serve to illustrate this sensitivity to gasoline consumption. The credit balance in 2030 and beyond is also quite sensitive to the availability of projected volumes of very low-CI RNG, the CI of liquid diesel substitutes, and project-based credit generation; future research is recommended to more comprehensively explore sensitivity to these, and other parameters.

GHG Emissions from Selected Scenarios

Under all scenarios evaluated, the displacement of petroleum fuels by lower-carbon non-petroleum alternatives lead to a reduction in life cycle GHG emissions over the modeled timeframe. LCT-based scenarios showed slightly lower life cycle GHGs than DtZ, owing to the lower demand for petroleum gasoline and a more rapid fleet transition to ZEVs. The LCT scenario achieves a nearly 25% reduction in 2030 life cycle GHGs compared to a 2020 baseline, whereas DtZ reduces emissions by slightly over 20% over the same time period. Both scenarios reduce 2035 GHG emissions by over 50% compared to the 2020 baseline. While analysis past 2035 is outside the scope of this study, both LCT and DtZ are on trajectories capable of meeting a carbon neutrality target within the transportation sector by 2045[4].

Total GHG emissions for LCT, DtZ, and BAU scenarios differ with different control parameter schemes and assumptions (Figure 9). For both LCT and DtZ scenarios, GHG emissions were slightly lower in the high-biofuel case than the default case, and they became more similar over time with a decrease of liquid fuel portion in the total fuel portfolio. Thus, increase of biofuel production may affect a short-term GHG reduction goal, but its impacts may diminish for a long-term GHG reduction goal.

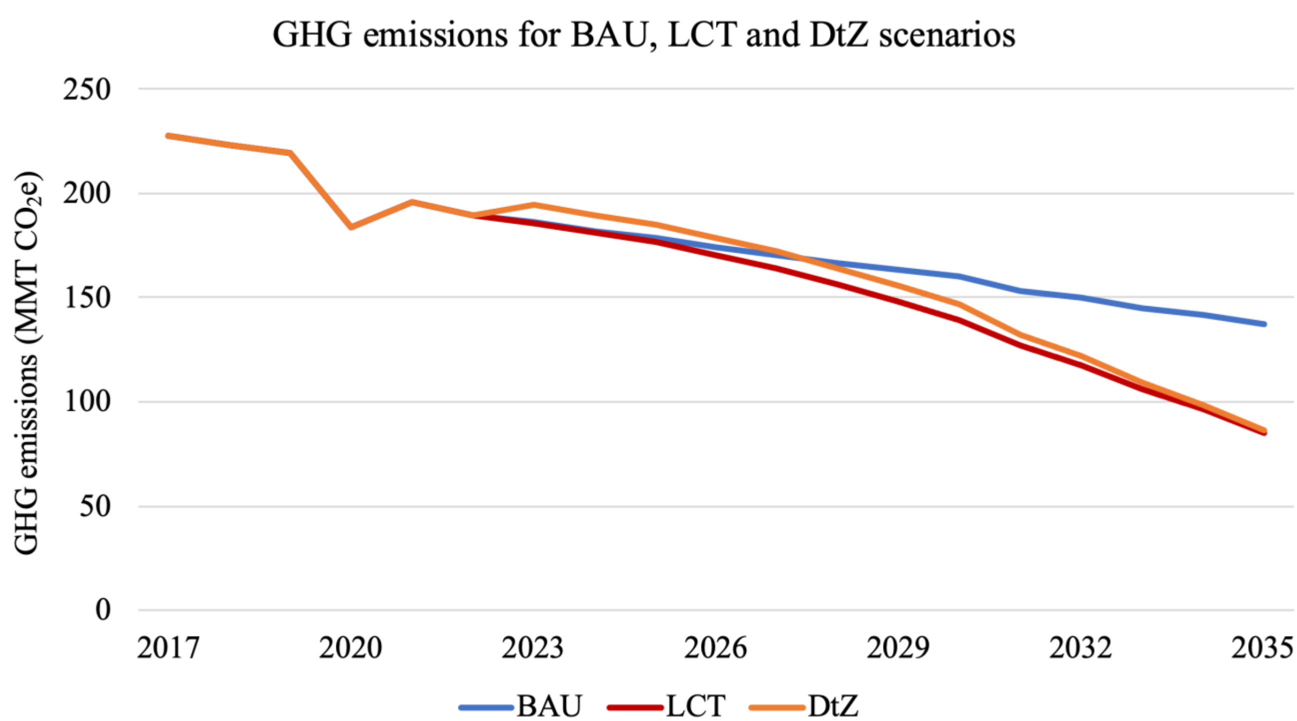


Figure 9. GHG emissions for BAU, LCT and DtZ scenarios. Note: the BAU scenario starts from the same baseline as the LCT scenario, and so adopts the assumption that 2022 data fully reflect the post-covid gasoline consumption trend. This leads to several years where BAU emissions are nominally below the DtZ case.

[4] Carbon neutrality, in this case, assumes the presence of ~5 million tonnes/year of net-negative carbon dioxide removal (CDR), such as CCS, beyond any CDR already credited in fuel pathways, as well as the emergence of ~1 billion gallons/year of low-carbon liquid gasoline substitute production capacity by 2040. See the *Driving California's Transportation Emissions to Zero by 2045* report for fore detail on carbon neutrality scenarios.

High Biofuel Scenarios

Under the default assumptions for control parameters (Table 4), the 37% and 40% reduction targets were not able to be met by either LCT or DtZ scenario. As mentioned above, FPSM allows an easy and rapid analysis of an alternative scenarios. This allowed us to test additional scenarios with modified control parameters to investigate the feasibility of 37% and 40% reduction targets. For this analysis, three additional control parameter schemes were tested. These adjustments focus on lipid-based fuel, ethanol, or both at the same time (

Table 6).

The first adjustment, called “ICF-Lipid,” was applied to the lipid-based fuels. In this scheme, the distillates capacity was increased from 1.75 billion gallons of total lipid-based fuel (BD + RD + SAF) to 2.75 billion gallons. The biodiesel blend rate was modified from the default 6% (on an energy basis), to a growing trajectory that reaches 16 % by 2030.

The second adjustment, called “ICF-Ethanol,” was applied to the ethanol fuels. It increases the improvement rates of ethanol CI based largely on assumed deployment of carbon-capture-and-storage (CCS) technology at ethanol production facilities in the mid-late 2020s. The adjustment also increases the ethanol blend wall sooner than the default scheme.

The third adjustment is a combination of the first and second adjustments, and it is called “ICF-Combined.”

These parameters were chosen to align with modeling results submitted by ICF to CARB comment docket following a pre-rulemaking workshop (29). The ICF modeling extends only through 2030, so we omit post-2030 impacts in this section.

With these adjusted control parameters, 37% and 40% reduction targets were tested for both LCT and DtZ scenarios. The results for net credit balance and credit bank vary widely (Figure 10 and Figure 11). The ICF-Lipid adjustment provided a significantly larger impact on credit balance through 2030. The ICF-Ethanol scenario yielded net deficits under both the 37% and 40% target scenarios for both LCT and DtZ demand scenarios, resulting in a rapidly depleted credit bank.

Table 6. Adjustments for control parameters to test 37% and 40% reduction targets.

Parameters	Unit	Default	Adjusted
"ICF-Lipid" case adjustment			
Biodiesel blend rate update year (from 6%)	year	NA	2030
Updated biodiesel blend rate	%	6%	16%
Annual maximum distillates capacity for lipid-based fuel	mm DGE	1,750	2,750
"ICF-Ethanol" case adjustments			
Carbon intensity improvement rate			
Starch ethanol (before 2030)	%	2%	10%
Starch ethanol (after 2030)	%	2%	3%
Sugar ethanol (before 2030)	%	4%	10%
Sugar ethanol (after 2030)	%	4%	3%
Cellulosic ethanol (before 2030)	%	0%	6%
Cellulosic ethanol (after 2030)	%	4%	4%
Blend rate			
Increasing ethanol blend rate from 11 vol% to 16 vol%	year	2030	2024

Under the LCT scenario, the ICF-Lipid adjustments maintained an approximate balance between credits and deficits for the 37% target but saw significant net deficits emerge in 2029 and 2030 under the 40% target trajectory. Under the DtZ demand scenario, the 37% target resulted in a declining but still robust credit bank, but a nearly depleted one at 40%. The combination of both ethanol and lipid fuel credit generation enhancements in the ICF-Combined adjustment led to projected compliance with a 40% target under both LCT and DtZ scenarios.

The key differences between the LCT and DtZ scenarios, and the scenarios presented in the ICF modeling, center on the amount and CI of biofuels entering California's market in the coming decade. Given the uncertainties around EV production and the fleet turnover rate, there are few other options capable of generating sufficient credits to support targets significantly above 30%. This suggests that a likely effect of higher targets would be to significantly increase the amount of biofuel consumed by California for LCFS compliance. The increased ethanol consumption reflects (1) an extremely rapid adoption of E15 as a ubiquitous retail gasoline blend or (2) rapidly expanding consumption of mid- to high-ethanol blends by flex-fuel vehicles, coupled with declines in ethanol CI that are significantly more rapid than historical trends.

Taken as a whole, these results support the idea that targets higher than 30% or even 35% may be feasibly achieved. However, pursuing these options could require both significantly above-trend improvement in ethanol CI as well as continued rapid growth in consumption of lipid-based fuels[5]. Current and announced capacity for lipid-based fuel production in North America is approximately 5-7 billion gallons per year. Some of this would presumably be consumed in Canada to satisfy new federal regulatory requirements there. Meeting the approximately 2.75 billion gallons consumption of such fuels would, therefore, either imply that California consumes significantly more than a population- or GDP-weighted share of North American lipid-based fuels, or a massive expansion of North American supply.

Questions have emerged among stakeholders regarding the amount of lipid feedstock that could be sustainably produced to support expanded biofuel production. Most growth in this space is likely to come from crop-based vegetable oils such as soybean oil, which have uncertain—but potentially quite large—emissions associated with indirect land use change. CARB has invited feedback on the topic of a cap on crop-based biofuels, largely to address concerns that the LCFS is leading to undesirable impacts from land conversion. While they have offered no indication regarding the level at which such a cap would be set, or even that a cap would be included in any proposed rulemaking, it is likely that the ICF-Lipid adjustments reflect a level that would significantly exceed such a cap. GHG emissions from this scenario may be lower than those under the DtZ or LCT scenarios, however, the significant expansion of lipid-based fuel production capacity creates the possibility of large GHG impacts from land use change, including ILUC. Resolving this uncertainty is outside the scope of this report.

[5] This is not an exhaustive list of the conditions which would allow higher targets, but rather is based on the conditions of interest identified in the ICF modeling and regulatory comment.

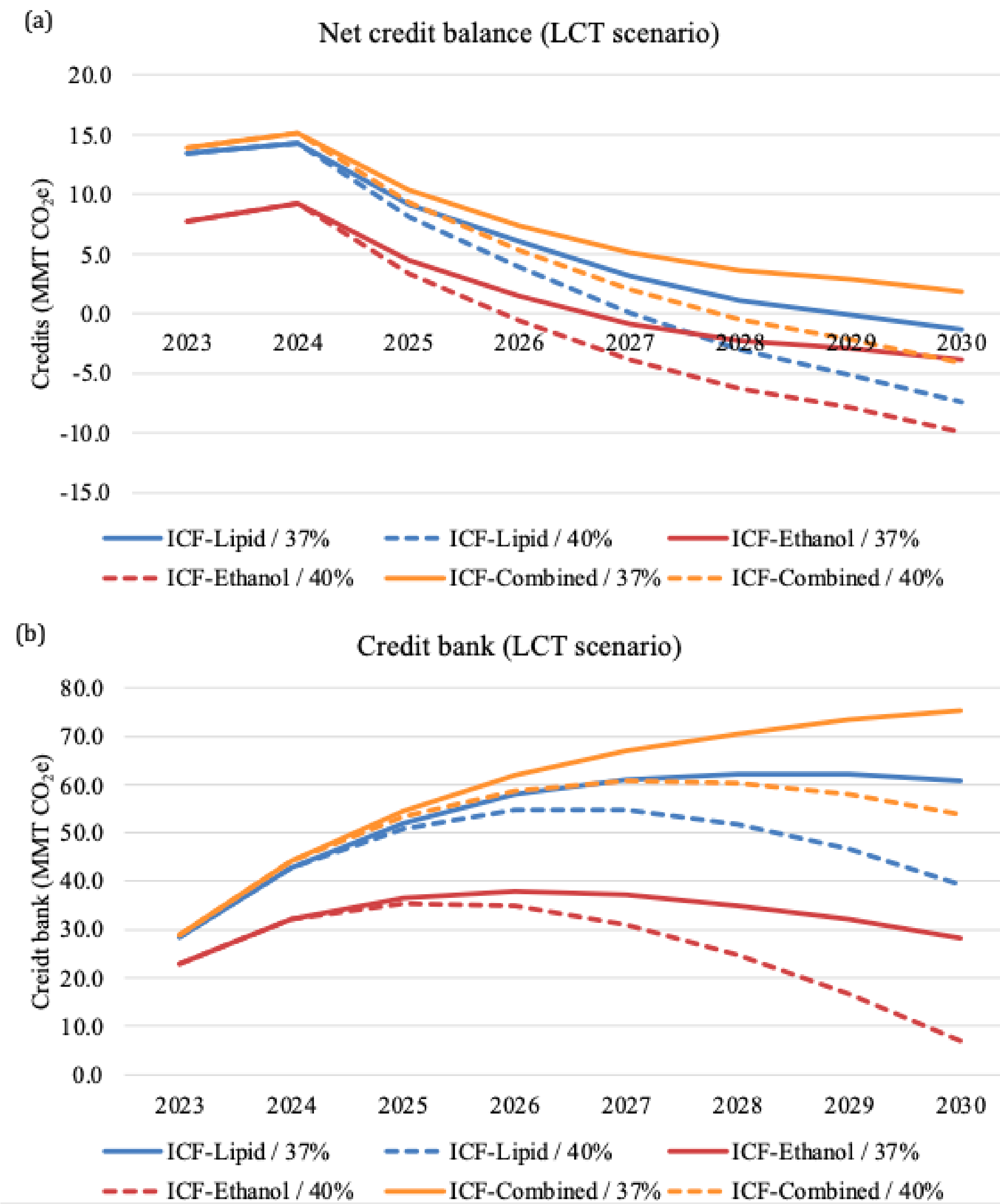


Figure 10. Net credit balance (a) and cumulative credit bank (b) with the adjusted parameters for LCT scenario.

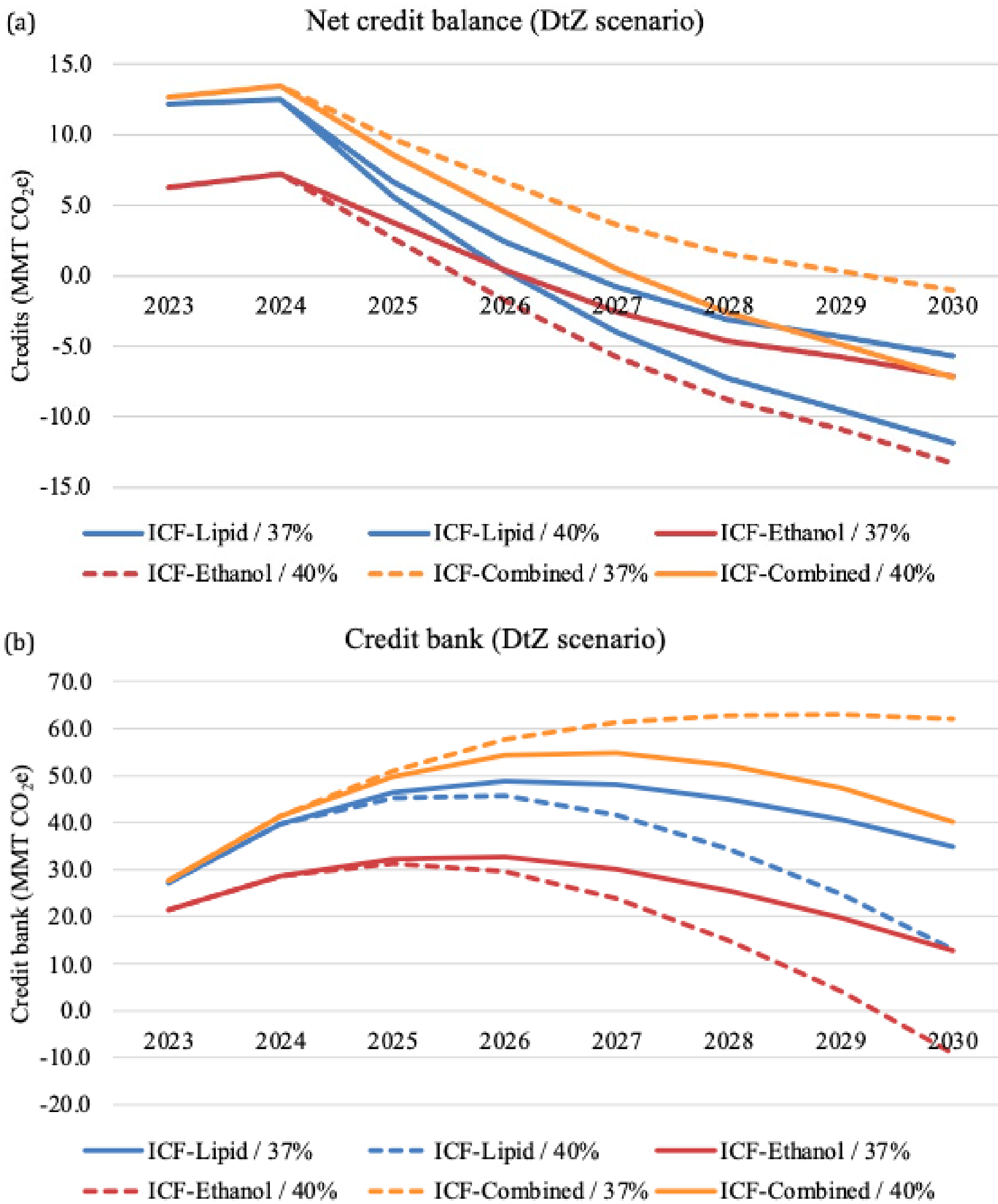


Figure 11. Net credit balance (a) and cumulative credit bank (b) with the adjusted parameters for DtZ scenario.

Impacts of Target Reduction Schedule

The LCFS sets year-by-year targets used for compliance. This allows a significant degree of flexibility for determining the compliance schedule under any given future long-term target. To explore these relationships, we evaluated three target trajectories for reaching a 30% target by 2030 using the FPSM. These include two 30% target trajectories described above (Table 3) and one trajectory from the California Transportation Supply (CATS) model developed by CARB, which will be discussed in Section 3.6 (Table 7).

The post-2030 trajectory from the CATS model was slightly modified to align with the other trajectories, which is an annual increase of the target by 6%, instead of its original value of 4.5%, after 2030. The front-loaded version more rapidly increases ambition in the mid-2020s but has more gentle increases in the latter part of the decade than the regular 30% target. The CATS model trajectory increases ambition in the early years even more than the front-loaded version. The results of this comparison for the LCT and DtZ scenarios are shown (Figure 12).

Despite the identical 2030 target of 30%, the CATS trajectory significantly reduces the surplus of credits through the mid-2020s, resulting in approximately 21 million and 10 million fewer banked credits than the 30% and front-loaded 30% trajectories by 2030 respectively. This is despite the fact that the maximum difference between the CATS and 30% targets is 3.25 percentage points, 18.75% versus 15.5% in 2025. Under the DtZ scenario, the 30%F and CATS trajectories drop the LCFS market into net deficit generation for four and five years, respectively.

Table 7. Target trajectories for testing the impacts of target reduction schedule.

By 2030	2023	2024	2025	2026	2027	2028	2029	2030
30%	11.25%	12.50%	15.50%	18.50%	21.00%	24.00%	27.00%	30.00%
30% F	11.25%	12.50%	16.50%	20.00%	22.50%	25.00%	27.50%	30.00%
CATS	11.25%	12.50%	18.75%	21.00%	23.25%	25.50%	27.75%	30.00%

Under both LCT and DtZ fuel demand scenarios, the CATS target trajectory results in net deficit generation for a period, as does the frontloaded 30% target scenario. Under all combinations of fuel demand scenarios and target trajectories, the credit bank remains net positive through 2030, though the CATS target trajectory under the DtZ scenario draws it down to around 13 million credits in 2030, as compared to approximately 41 million projected annual deficits.

Taken together, these results indicate that a rapid near-term increase in LCFS target, such as the 16.5% 2025 target from the frontloaded 30% target trajectory or the 18.75% target from the CATS target trajectory, are unlikely to result in the depletion of the credit bank by 2030. Under the LCT demand scenario, all target trajectories resulted in a gradually increasing credit bank. Under the DtZ demand scenario, the credit bank remained stable or declined.

Banked LCFS credits serve a variety of useful roles, including hedging against unfavorable or volatile future market conditions and creating liquidity for credit trades. Drawing the bank down to zero (or nearly so) is therefore inadvisable. The significant decline in LCFS credit prices in 2021 and 2022 suggest that the current bank—approximately 15 million credits in 2022 as compared to approximately 20 million deficits—may be above the optimal size for a stable LCFS credit market capable of supporting the necessary transition to very low carbon transportation.

Given the relative novelty of carbon instrument markets, there is no clearly established standard for the size of an adequate aggregate level of banked credits, and suggesting one is outside the scope of this report. Additional research is required to better understand the impact of aggregate banked credit volumes on LCFS market dynamics. It is also important to note that changes to LCFS program parameters not discussed in this report would also impact net credit balances. Additional scenario analysis of any proposed target trajectories or program changes is recommended.

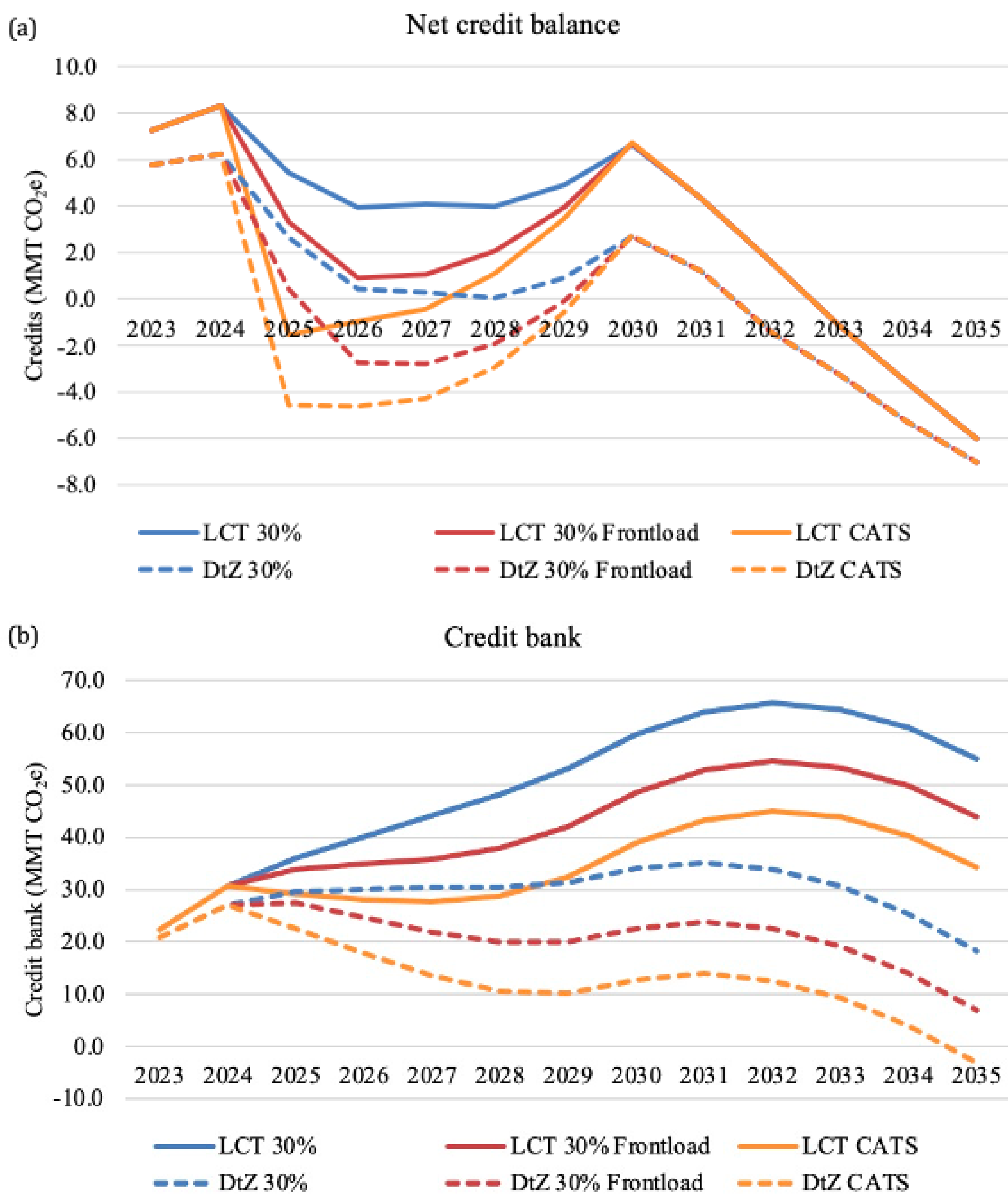


Figure 12. Net credit balance (a) and Cumulative credit bank (b) with the 30% and the front-load version of 30% targets for the LCT and DtZ scenarios.

Post-2030 Targets

While the current rule-making process focuses largely on the 2030 reduction target, California's climate goals function over a longer timeframe. The 2030 target must establish a trajectory that can achieve carbon neutrality by 2045. It is therefore important to consider how 2030 targets affect post-2030 GHG emissions and future policy.

Selecting post-2030 targets is complicated by expected changes in California's vehicle fleet due to policies like ACC2, ACT, and ACF. As California approaches the 2035 ACC2 deadline—after which, no new ICE vehicles will be registered—EV sales shares are expected to rise rapidly and approach 100%. This means that, as older ICE vehicles retire, they will be replaced by ZEVs, leading to a period of rapid change in the composition of the LDV fleet. California's annual new car sales are typically in the 1.5-to-2-million-unit range, which sets a *de facto* maximum rate at which new EVs can enter the fleet. With around 29 million LDVs total, this implies fleet turnover rates that could get as high as 5-7% per year. Replacing an ICE LDV with an EV reduces the number of deficits generated from the consumption of gasoline and increases credit generation from the additional charging by the new vehicle. The combination of these effects results in rapid changes in the net balance of LCFS credits and deficits. The program's target must increase more rapidly than it did in the in the early- to mid-2020s (or before) in order to keep deficit generation approximately in balance with credit generation.

To analyze the impacts of different incremental targets after 2030, different sets of target trajectories were tested for the LCT and DtZ scenarios. Differences in LCFS target acceleration schedule post-2030 arise when comparing target increases of five and six percentage points per year from 2031-2035 (Figure 13 and Figure 14). Both the LCT and DtZ scenarios show net positive credit balances in 2030 at a 30% target. Different rates of target acceleration in the 2020s mean that the bank of credits in 2030 can range from 12 to 60 million credits, depending on how quickly targets accelerated in the 2020s (See Figure 12), A larger bank in 2030 means that more ambitious post-2030 targets can be achieved without risk of bank depletion and excessively high credit prices. A smaller bank implies less flexibility to accommodate higher targets.

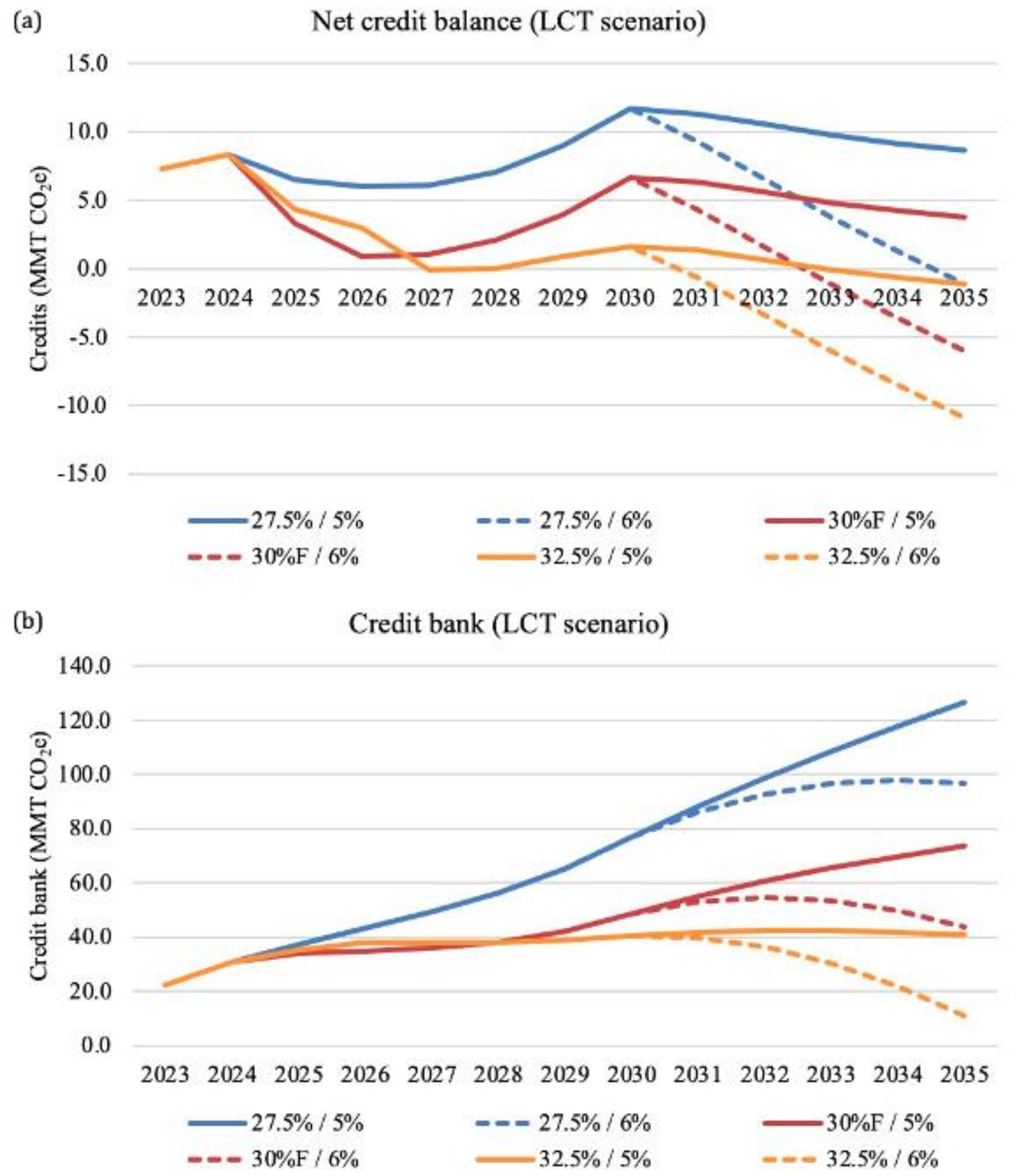


Figure 13. Net credit balance (a) and Cumulative credit bank (b) with different post-2030 incremental percentage points of the reduction target for the LCT scenario.

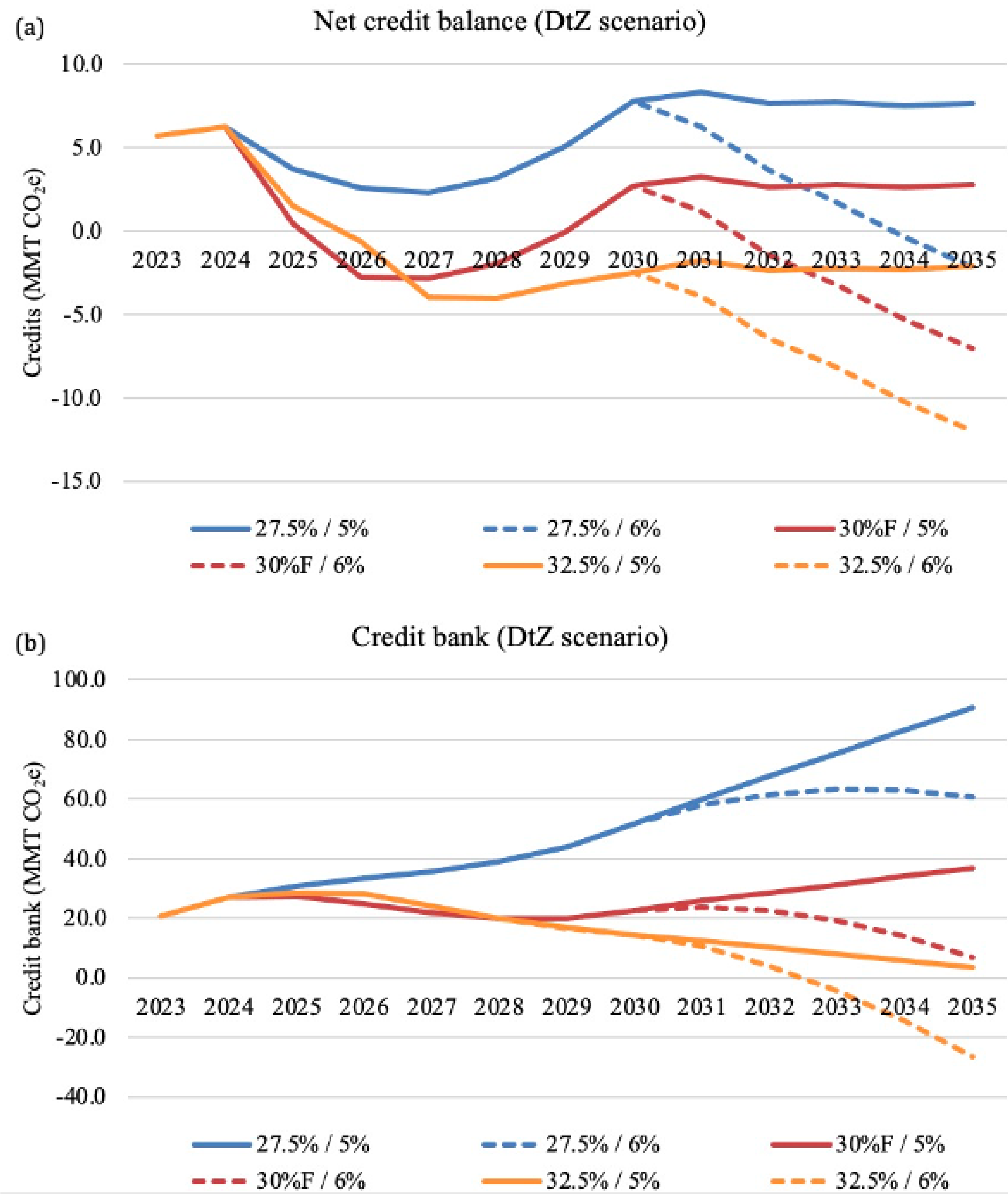


Figure 14. Net credit balance (a) and Cumulative credit bank (b) with different post-2030 incremental percentage points of the reduction target for the DtZ scenario.

Under both DtZ and LCT demand scenarios, six percentage point annual target increases resulted in decreasing annual credit balances, sometimes to the point of net deficits. Five percentage point annual target increases resulted in constant or very gradually declining annual credit balances (Figure 13 and Figure 14). Notably, under a more ambitious 32.5% 2030 target scenario the declining credit balance caused by 6% annual target increases led to credit bank depletion by 2033 in the DtZ scenario, and near-depletion in the LCT scenario with about 11 million credits remaining, against 41 million annual deficits. Lower 2030 targets did not come so close to depleting the credit bank.

These figures demonstrate the critical relationship between pre-2030 and post-2030 target ambition. Higher levels of pre-2030 target ambition make it harder to support higher levels of post-2030 target ambition and vice versa[6]. Policy makers will need to decide how best to schedule LCFS target acceleration. Early ambition typically has better climate impacts than later due to the temporal dependence of GHG emissions (30).

Delaying target increases would be expected to reduce cost impacts on consumers. This is especially relevant given the expected vehicle fleet in the early 2030s. TTM modeling projects the California vehicle fleet composition reaching 50% ZEV around 2035. Prior to that point, most drivers in California will still be driving an ICE vehicle, typically fueled by petroleum. As targets exceed 30% and continue to climb, the per-gallon price impacts on retail gasoline would be expected to rise as well. Given the expectation that the transition to EVs will generally occur most rapidly among higher-income drivers, this implies that lower-income drivers may be disproportionately exposed to the retail fuel price increases caused by the LCFS. Delaying the onset of higher targets provides more time for lower-income drivers to transition into EVs; policies focused on equity and improving access to electrified transportation can assist in this effort. Even where significant retail gasoline price impacts occur, they are likely to be less than the social cost of carbon applied to the CO_2 emitted from combustion of gasoline, and the value of air quality benefits from of reducing vehicle combustion. Lower-income and disadvantaged communities are typically at greater risk from both climate and air quality related pollution impacts, so even with anticipated fuel price impacts, the net effect of the LCFS is likely to be positive for most parties. The distributional parameters of these impacts should not be overlooked, however, and further study of this topic is recommended (31,32).

Delaying the maximum ambition of LCFS targets to a level sufficient for the state to meet long-term climate goals but not higher could help achieve a balance between the aggregate benefit of reduced emissions, as well as the net positive impact on disadvantaged communities.

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[6] This conclusion is, in part, a result of the static nature of the FPSM model. Higher early targets would be expected to bring additional supplies of low-carbon fuel into the market, allowing higher post-2030 ambition. This impact is likely to be muted, however, because the primary driver of LCFS credit generation in the early 2030s is the transition to ZEVs, especially EVs. That transition is driven primarily by policies like the ACC2 rule. The amount of credit generated per LDV is generally seen as too small to significantly affect vehicle purchase decisions for most LDV purchasers, and revenue from LDV charging credits typically goes to utilities or vehicle charging service providers who have little impact on LDV purchase decisions. As such, higher LCFS targets or credit prices are unlikely to affect the rate of LD EV deployment, and the treatment of LD EV deployment as exogenous to credit market parameters is a reasonable reflection of expected behavior.

Comparison with the CATS Model

The CATS optimization model has been developed by CARB to determine fuel portfolios likely to be available for California. It addresses the problem of minimizing the cost of fuel supply while meeting the fuel demand. The August 2023 workshop by CARB provided an updated version of the CATS model with a new scenario. To simulate a similar scenario to the CATS model in the FPSM, a scenario called "CATS" was developed by adjusting fuel demand, control parameter scheme, and reduction target trajectory to match those presented in the CATS Example Input file presented at that workshop, to the greatest degree possible.

The CATS fuel demand output is used in a similar way to the TTM results. The output provides an estimate of total fuel demand within aggregated categories. While the total gasoline pool demand projections are close to each other, the CATS scenario presented by CARB projects significantly greater diesel demand than TTM. In the LCT scenario, the demand for petroleum diesel and liquid diesel substitutes diminished more rapidly than in the CATS scenario. The LCT scenario also assumed more transitions to hydrogen fuel cell technology than the CATS scenario.

The CATS control parameter scheme was developed in the FPSM to implement assumptions from the CATS model. For example, instead of using FPSM default CI improvement rates, CI values of fuel each year were imported from the CATS model assumptions and credits from off-road and projects were estimated based on the values from the CATS model. The CI values for ethanol, BD, and RD and SAF over time are shown in Figure 15. The CATS model assumes relatively higher CI values for lipid-based fuels such as BD and RD and SAF, and relatively steady CI values for ethanol. The FPSM by default, assumed a decreasing trend for CI of ethanol. In addition, renewable gasoline was assumed to be less than 20 million gasoline gallon equivalent (mm GGE), and SAF was assumed to be 266 million diesel gallon equivalent (mm DGE) by 2030 with a maximum distillate capacity of 2,060 mm DGE. Blend rates of biodiesel and ethanol into respective counterparts were also adjusted to 17% and 12% respectively. Because of these different assumptions on the blend rates, application of the CATS control parameter scheme to the CATS fuel demand changes the composition of fuel portfolio while keeping the total fuel pool at the same level. Gasoline and diesel pool demand projections with the CATS fuel demand and the CATS control parameter scheme (Figure 16 and Figure 17) are compared with the LCT scenario with the default control parameter scheme.

The most notable difference between CATS and FPSM is in the trajectory of diesel demand. FPSM projects a significant decline in diesel demand due to a broad transition towards ZEVs in most segments of the MD and HD fleets. CATS projects a more modest transition to ZEVs in this space. The differences through 2030, however, are relatively modest and have a limited impact on the capacity of California's fuel system to meet the LCFS targets by 2030. Further research and modeling is warranted to better understand long-run transition dynamics in the MD and HD vehicle space, as well as their impacts on fuel policy.

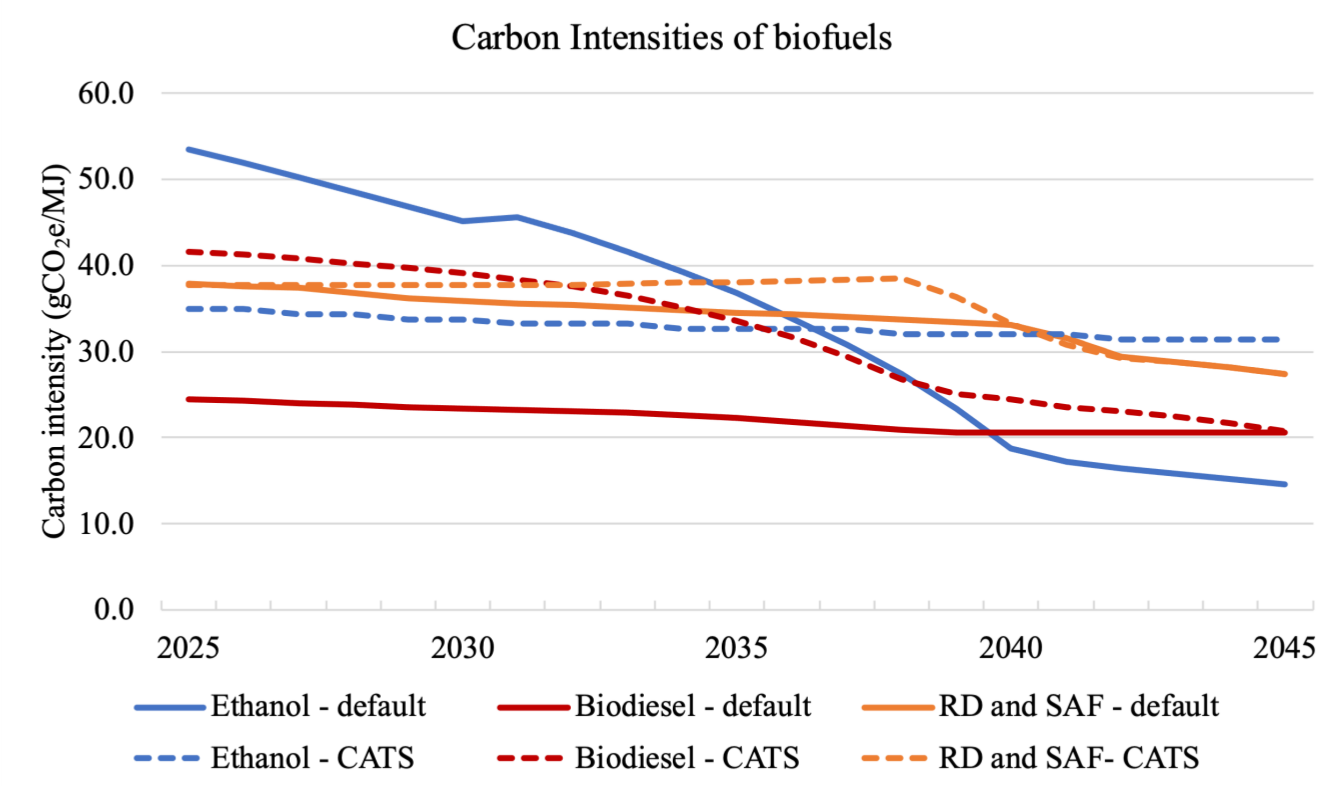

Figure 15. Carbon intensities of biofuels including ethanol, biodiesel, and weight-averaged renewable diesel and sustainable aviation fuel.

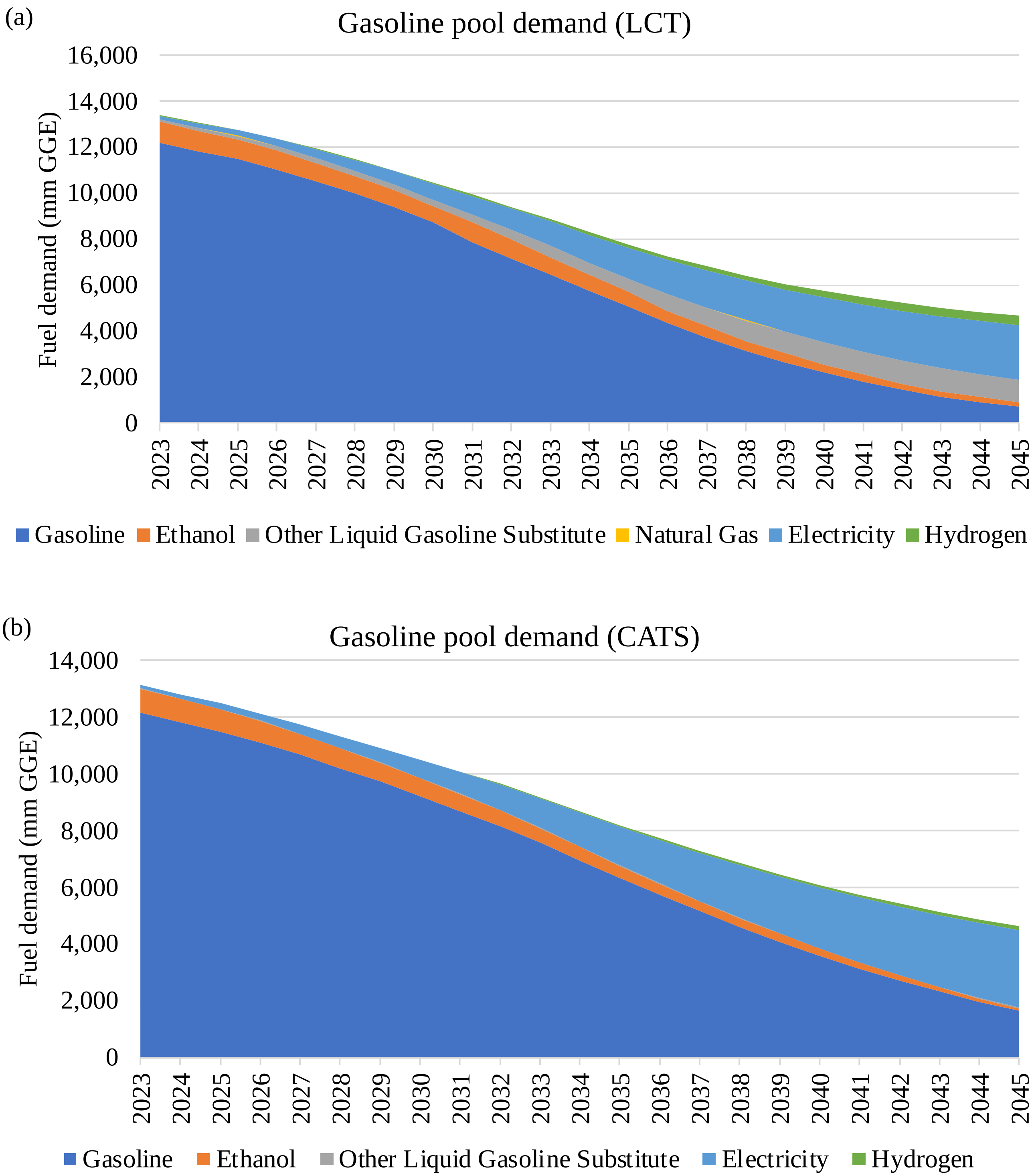

Figure 16. Gasoline pool demand projections for (a) LCT scenario with the default control parameters in the FPSM and (b) CATS scenario with the CATS control parameters.

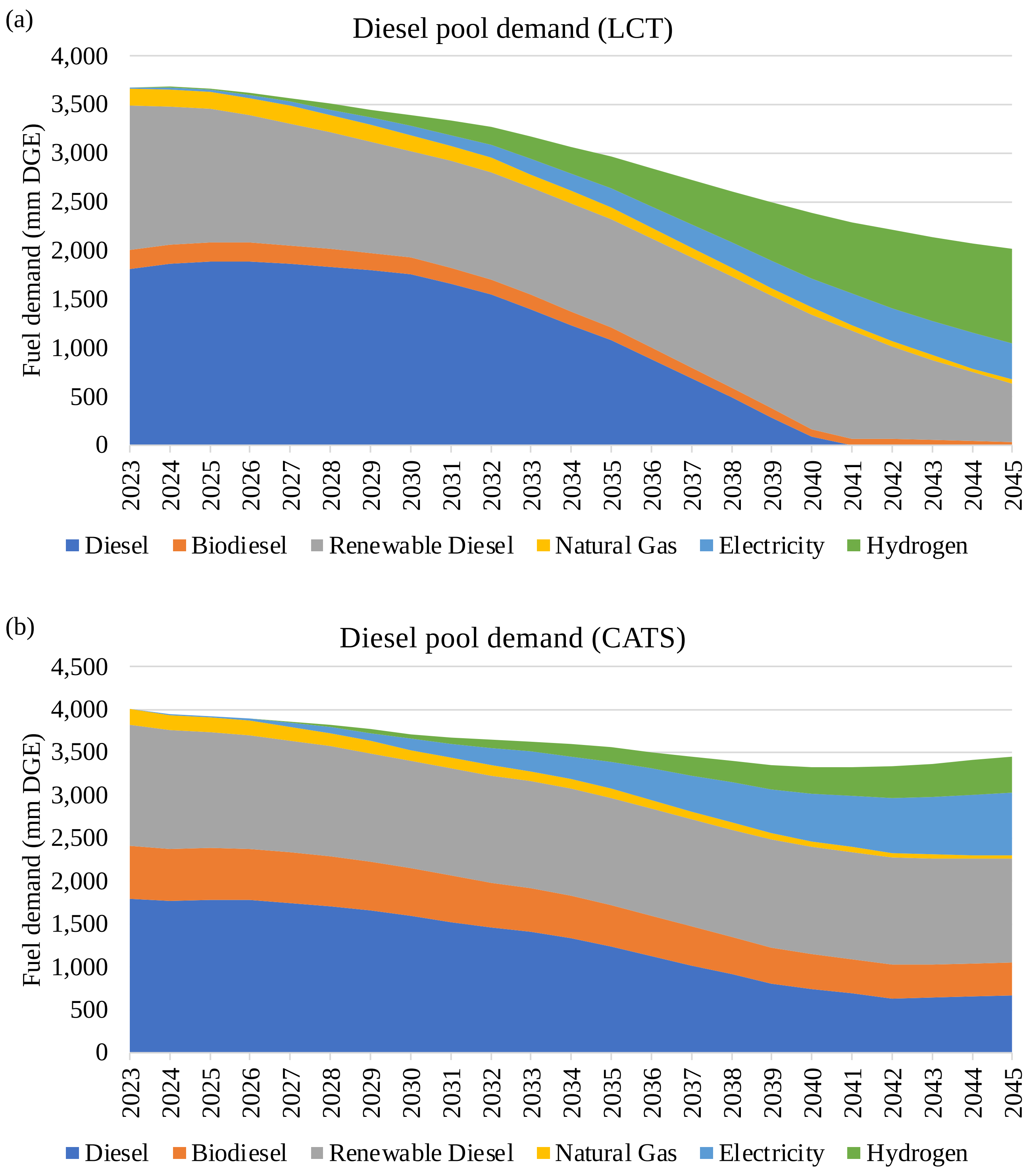

Figure 17. Diesel pool demand projections for (a) LCT scenario with the default control parameters in the FPSM and (b) CATS scenario with the CATS control parameters.

The CATS reduction target is 30% by 2030. The reduction target trajectories for the 30% target in this study and in the CATS model are shown in Table 8. The impact of the CATS target trajectory is discussed in more depth in Section 3.4. In this section, post-2030 target increases for the LCT and DtZ scenarios are set to match the CATS assumption of 4.5 percentage points per year, to facilitate comparison between the two models.

Table 8. Reduction target trajectories for the comparison between this study and the CATS model for the primary 30% target described in this report, the front-loaded 30% target (30% F) and the 30% target trajectory presented in CATS modeling results.

Scenario	2024	2025	2026	2027	2028	2029	2030	2031
30%	12.5	15.5	18.5	21	24	27	30	34.5
30% F	12.5	16.5	20	22.5	25	27.5	30	34.5
CATS	12.5	18.75	21	23.25	25.5	27.75	30	34.5

Based on scenarios and assumptions for the CATS model, net credit balance and credit bank were calculated using the FPSM. Under all target trajectories, the results with the default assumptions showed less net credit balance and thus faster depletion of the credit bank. This is largely due to higher volumes of BD and RD and lower volumes of petroleum diesel with the CATS assumptions. Except for the case with the CATS assumptions and regular 30% target, other cases drop the LCFS market into net deficit generation in the late-2020s. The results with the CATS fuel demand scenario using the CATS control parameter scheme and the results using the default scheme (Table 4) are shown in Figure 18.

These results, considered in context with those presented in sections 3.2 and 3.5, indicate that the combination of modeling assumptions and target trajectory reflected in the CATS model may represent the maximum, or near-maximum limit of ambition for LCFS target increases through 2030. The CATS scenario and modeling assumptions draw down the bank of LCFS credits significantly by 2035 under both the underlying model assumptions from CATS as well as FPSM defaults. While the bank remains positive through 2030, even a relatively gradual post-2030 target acceleration schedule draws the bank down to zero in the early- to mid-2030s. This follows the relationship between pre- and post-2030 target ambition discussed in Section 3.6.

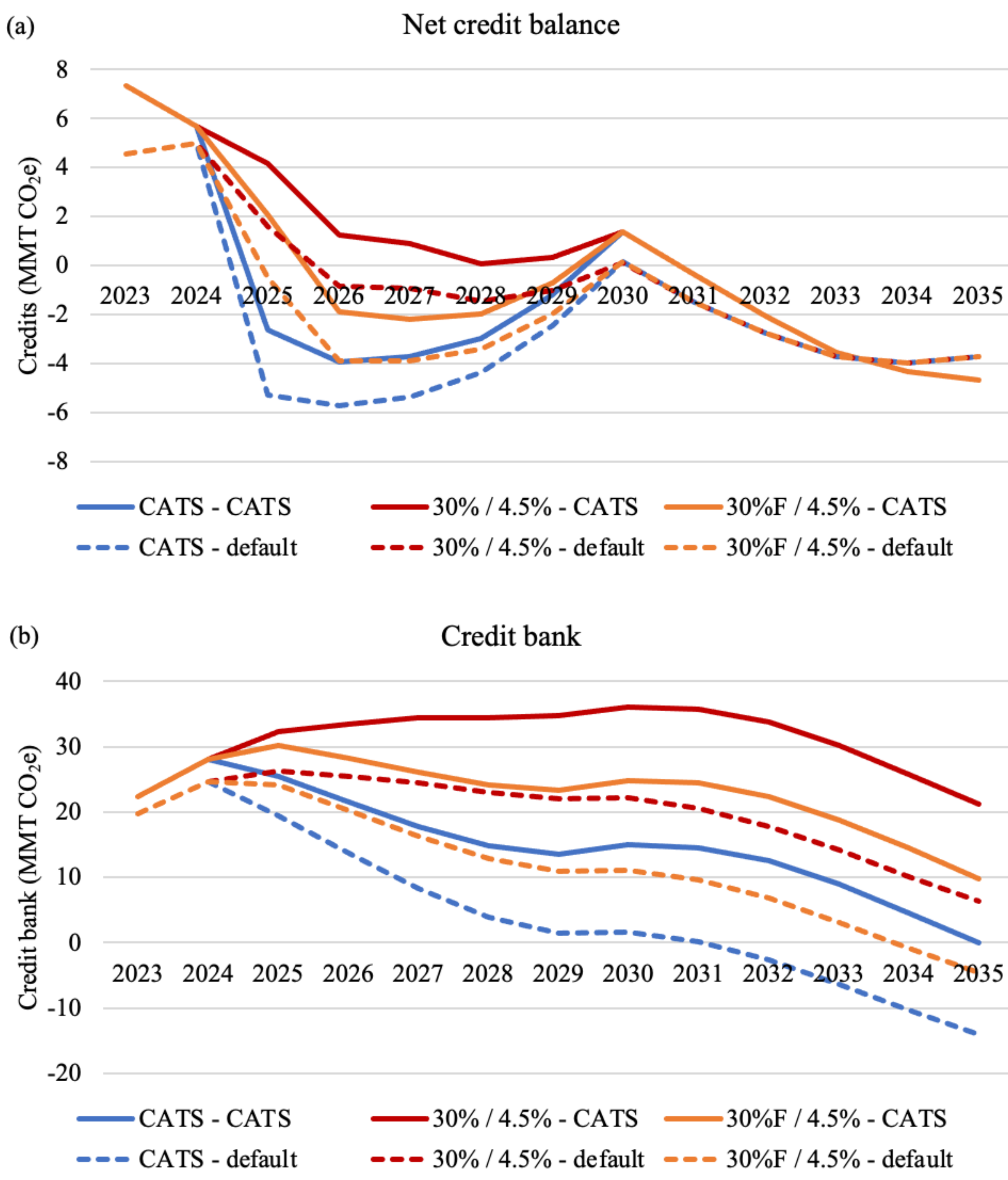

Figure 18. Net credit balance (a) and credit bank (b) for the CATS fuel demand scenario using the CATS control parameter scheme and the default control parameter scheme as shown in Table 4.

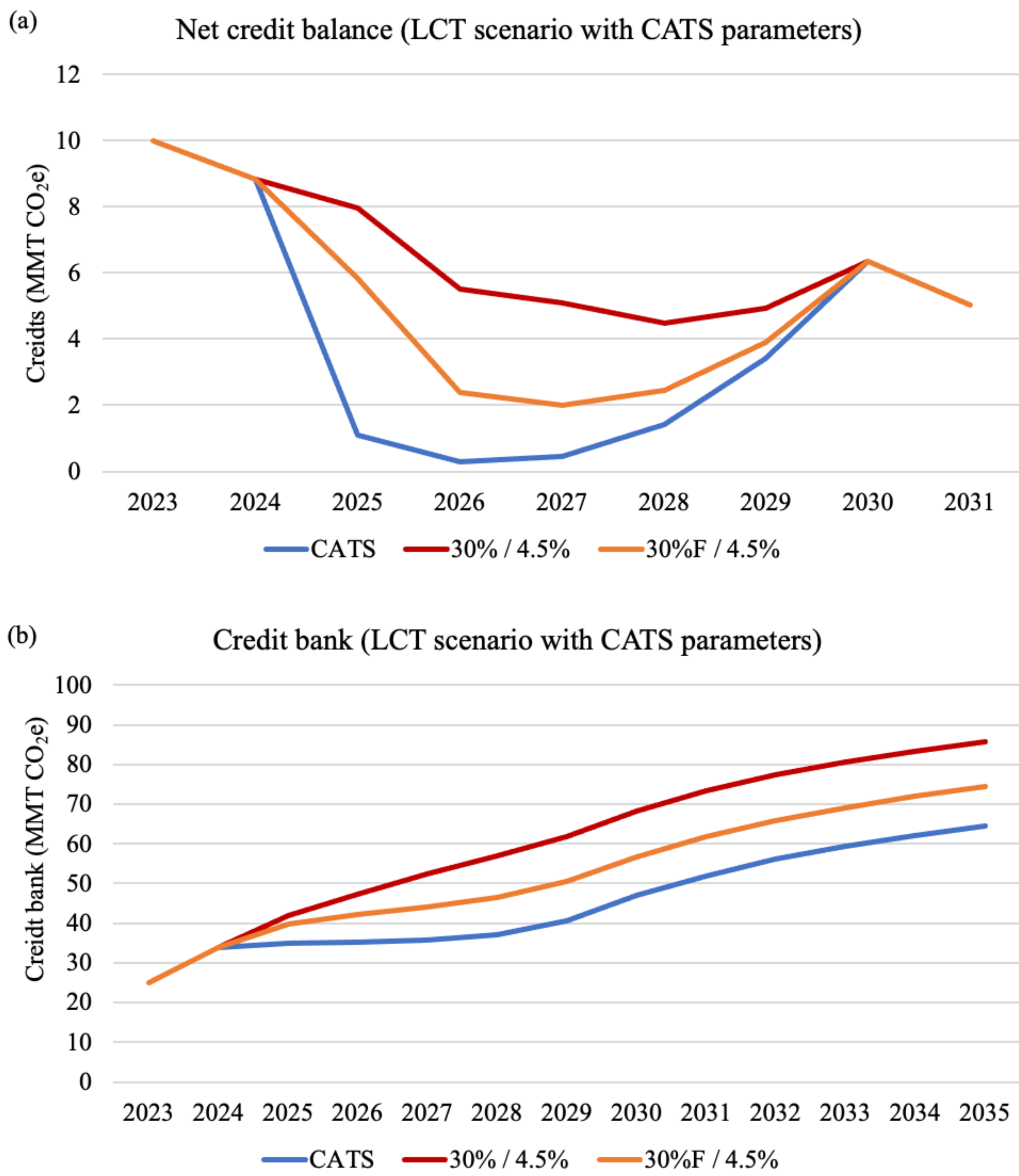

Figure 19. Net credit balance (a) and credit bank (b) for the LCT scenario using the CATS control parameter scheme.

Conclusions

Results of FPSM modeling of several target scenarios under consideration for California's LCFS in a rulemaking anticipated in late 2023 show that the current 20% target is unlikely to support a balanced supply and demand for LCFS credits and that the 30% target proposed by CARB is likely to yield a more balanced market. Targets significantly above 30% risk drawing down the credit bank and leading to growing net deficits. Targets significantly below 30% may not adequately address the existing oversupply of credits. It is important to note that program parameters other than the top-level program target may be changed during the anticipated rulemaking. These changes were not modeled in the work presented here and they would likely have a significant impact on credit supply and demand. Future work is recommended to confirm the approximate balance between credit supply and demand under a wider range of technology, economic, or policy scenarios. This report demonstrates the capacity of FPSM to explore a wide range of policy-relevant scenarios to inform policy development.

The modeling presented here considers two primary scenarios: Low Carbon Transportation (LCT) and Driving to Zero (DtZ), each based on similar assumptions but notably different in the amount of petroleum gasoline consumptions they project. The DtZ scenario assumes significantly more gasoline consumption than LCT. Comparing results from both scenarios offers a sense of the sensitivity of different parameters to assumptions about gasoline demand. The magnitude of this difference was approximately 750 million gallons of gasoline in the mid-2020s and declines slightly over time as fleets shift to EVs. The lower gasoline demand of LCT reduced deficit generation and allowed targets to be around 2-3% higher than DtZ scenarios with comparable credit balance and bank trajectories. This shows the critical importance of accurately projecting gasoline demand as part of fuel portfolio modeling exercises like this. The gap between LCT and DtZ gasoline demand projections is largely due to assumptions about the rebound in post-COVID driving behavior. DtZ assumes a full rebound to pre-COVID driving behavior, LCT assumes that 2022 data reflect the beginning of a new long-term trend; the truth is likely to lie somewhere in between these two points, however they still serve as useful high- and low-demand bounding cases for this analysis. As such, neither should be taken as independently indicative of future behavior.

Another notable finding is the need for rapid target acceleration post-2030. The current target trajectory calls for 1.25% per year annual target increases, and even under a 30% 2030 target, the average annual target increases through the mid-to-late 2020s would average around 3% per year. Given the rapid transition to very high EV sales fractions, however, target increases of 5-6% per year are required to avoid a rapid accumulation of credits that would likely lead to low credit prices. This implies a 55-60% 2035 target following a 30% 2030 target. The rapid acceleration of target levels highlights the need for careful modeling to align expected credit supply and demand to prevent future market imbalances. The FPSM can contribute to this work.

The FPSM modeling presented here also evaluates the impact of different target trajectories to a 30% target. The transition from current target levels to a higher 2030 target can follow a number of different trajectories.

Comparison of several of these, including the default target trajectory from recently released CATS modeling demonstrates that there is considerable flexibility to change the rate at which the target increases during the 2020s without risking credit bank depletion. Even the most front-loaded target trajectory, the one presented in CATS modeling, still maintains a credit bank over 10 million in 2030. Comparison of post-2030 targets, however, shows that the smaller 2030 credit banks associated with higher early ambition reduce the capacity of the LCFS market to support higher post-2030 ambition. In short, this means that there may be a trade-off between pre-2030 ambition and post-2030 ambition. This trade off may have important impacts on the process of transition in California's fuel markets, as well as on the magnitude and distribution of price impacts resulting from higher LCFS targets. The FPSM allows for rapid adjustment of target trajectories for comparative analysis. Further evaluation of such trajectories can help inform decision making.

Evaluation of high-biofuel sensitivity scenarios demonstrate that targets significantly above 30% require assumed ethanol CI increases significantly above historical trends, as well as the consumption of nearly 3 billion gallons per year of lipid-based fuels like renewable diesel, biodiesel, and hydrotreated SAF. While it may be nominally possible for the LCFS program to attain a 40% target in 2030, significant concerns about the sustainability and land use change impacts of that level of biofuel consumption must be addressed. Lower targets would likely support continued modest growth of lipid-based fuels, while relying more on ZEVs to provide the bulk of compliance credit.

The work presented in this paper describes the use of the FPSM model to inform policy making by evaluating policy scenarios that are highly relevant to imminent policy actions. By using models like FPSM, policy makers can design and implement effective fuel decarbonization policies and support the LCFS continued role as part of California's GHG reduction portfolio.

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