Title

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Publication Date

2022-12-21

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December 21, 2022

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Acknowledgements

The author would like to gratefully acknowledge Dan Sperling, Julie Witcover, and Jin Wook Ro for their feedback on early drafts of this paper, as well as Alissa Kendall, for her help in developing some of the concepts that appear herein, and Seth Karten for assitance with copyediting and layout. Any errors or omissions that remain are solely the fault of the author.

This work was generously supported by funding from the Sustainable Transportation Energy Pathways (STEPS+) Energy Futures Research Center.

Acronyms

CI	carbon intensity
EV	electric vehicle
FD	Fractional Displacement
GHG	greenhouse gas
ICE	internal combustion engine
ICEV	internal combustion engine
LCA	life cycle analysis
LD	light-duty
LCFS	Low Carbon Fuel Standard
RNG	renewable natural gas
ZEV	zero-emission vehicle

Introduction

California has set ambitious targets for decarbonizing its transportation system and adopted a variety of programs to support the transition toward carbon-neutral vehicles and fuels.[1] The Low Carbon Fuel Standard (LCFS) is a critical element of the policy portfolio; it provides incentives for reducing the carbon intensity (CI, measured across a fuel's full life cycle) of transportation fuels, via the generation and trading of LCFS credits. Since its inception, the LCFS has successfully reduced greenhouse gas (GHG) emissions from transportation in the state and led to a doubling of the fraction of transportation energy coming from lower-carbon, non-petroleum sources.[2]

A core strength of the LCFS has been the way it correlates the amount of incentive offered to a given fuel with GHG reductions.[3] This allows the program to provide strong, focused support for innovative low-carbon technology.

Going forward, one concern is that the current method used to quantify LCFS credits in California as well as in similar policies in Oregon and Washington, relies on assumptions that reflect conditions in early phases of a transition from petroleum internal combustion engine vehicles (ICEVs) to alternative fuel vehicles, including zero-emission vehicles (ZEVs). But as ZEVs and other advanced technology vehicles saturate a market, these assumptions become increasingly flawed. In particular, the current LCFS approach embeds fixed assumptions about the amount of fuel displaced by advanced technology vehicles.[4] These assumptions tend to overestimate fuel displacement in middle and later years of the transition away from conventional vehicles; this overestimation could create LCFS credit market imbalances, drive down the LCFS credit price, or simply create a noticeable gap between GHG savings credited and those achieved.

This paper proposes an alternative approach to quantifying credit generation under the LCFS, called Fractional Displacement (FD) crediting. Fractional Displacement crediting is a minimally disruptive, technologically neutral modification to existing LCFS credit quantification methods. It allows the use of more appropriate assumptions about how much fuel is displaced by advanced technology vehicles. It maintains the core conceptual framework of the LCFS and improves the correlation between actual emissions reductions and crediting under the LCFS. The FD crediting approach can be adopted for virtually all LCFS technologies and pathways, and doing so would cause little, if any impact to credit generation under the LCFS for the next 5 years in all but one sector of California's transportation system. The only sector that could see near-term impacts would be electric forklifts (e-forklifts)**—**a market segment that has already largely converted from conventional ICEVs to ZEVs and one for which LCFS program staff sought input regarding options to phase down credit generation. As more sectors of the fleet move through their transition, a program-wide switch to FD crediting could prevent the emergence of future credit market imbalances, reduce the need for future rulemakings to correct such imbalances,

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[1] Muratsuchi, Bill Text - AB-1279 The California Climate Crisis Act.

[2] Mazzone, Witcover, and Murphy, "Multijurisdictional Status Review of Low Carbon Fuel Standards, 2010–2020 Q2."

[3] All references to LCFS-incentivized GHG reductions, emissions, and carbon intensities in what follows refer to carbon intensity scores reductions as assessed by the program's carbon intensity rating system.

[4] For the purposes of this paper, "advanced technology vehicles" are those with an energy economy ratio (EER) greater than 1. At present, all ZEVs, including electric and hydrogen fuel cell vehicles would meet this definition.

and preserve the LCFS' ability to support the transition to lower-carbon transportation technologies, in addition to improving the accuracy of quantified GHG reductions due to the program.

This concept is presented as the starting point for discussion, and feedback from the stakeholder community is welcomed.

Opportunities to Better Align Advanced Vehicle Technologies' LCFS Credit Generation with Emissions Impact

Quantitatively representing complex systems requires making a number of analytical assumptions that often do not have an objectively or empirically verifiable basis, that is to say, assumptions for which there is no single "correct" or "incorrect" choice. For example, life cycle analysis (LCA) of biofuel systems requires making numerous assumptions about system boundaries, coproduct allocation, and counterfactual outcomes, including indirect impacts like land use change. Quantifying life cycle impacts requires making these assumptions, and the analyst has no alternative other than to select one set of assumptions on an at least partially subjective basis, yet these assumptions can have a significant impact on the quantitative outcomes of the analysis in question.[5] In the absence of an objective basis for making these analytical assumptions, most scholarship (especially as it pertains to LCA) emphasizes transparency, the use of consensus-based standards, and aligning assumptions with the best possible understanding of the system being analyzed.[6] The core problem that FD crediting would solve is that the assumptions underpinning current LCFS quantification methods do not align with expected emissions impacts of advanced technology vehicles in the middle and later parts of a transition from conventional ICEVs to advanced technology vehicles, like ZEVs.

One of the strengths of the LCFS is the strong relationship between the amount of incentive received per unit of a given fuel, and its assessed GHG reductions. This relationship helps ensure that incentive revenue flows to fuels that provide the greatest emission reduction value to the program, and that producers have an incentive to continually seek opportunities for incremental reduction in carbon intensity of their fuels. Clearly, the assumptions made to allow quantitative analysis have the potential to substantially impact the amount of incentive received under the LCFS, and therefore, the ability of the program to achieve its goals. Ensuring that these assumptions match reality, to the greatest extent possible, is therefore critical to supporting the LCFS as it fills an important role in California's climate policy portfolio.

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[5] Murphy and Kendall, "Life Cycle Inventory Development for Corn and Stover Production Systems under Different Allocation Methods."

[6] ISO, *ISO 14040*; ISO, *14044 Environmental Management — Life Cycle Assessment — Requirements and Guidelines*; Ekvall and Finnveden, "Allocation in ISO 14041—a Critical Review."

Under the LCFS, the number of credits generated by each unit of fuel provided to the market is determined by the following formulas for most credit generating pathways:[7]

$$\boldsymbol{Credits_i^{XD}/Deficits_i^{XD}(MT) = \left(CI_{standard}^{XD} - CI_{reported}^{XD}\right) \times E_{displaced}^{XD} \times C}\ ,$$

*(**Equation 1**)*

$$\boldsymbol{E_{displaced}^{XD} = E_i \times EER^{XD}}\ ,$$

$$CI_{reported}^{XD} = \frac{CI_i}{EER^{XD}}\ ,$$

where $CI_{standard}^{XD}$ is the LCFS target for the fuel category, CI_i is the reported CI for a given fuel, E_i is the amount of fuel energy consumed by the advanced technology vehicle, EER^{XD} is the energy economy ratio, and *C* is a unit conversion factor, $10^{-6}\ tonnes/gram$. The *EER* is a dimensionless unit that reflects the relative efficiency of some powertrains compared to their closest internal combustion engine equivalent (gasoline, diesel, or jet fuel); this represents differences in fundamental efficiency of some powertrains as well as the effect of other efficiency-enhancing technologies like regenerative braking. For an advanced technology vehicle (with *EER* > 1), the *EER* reflects the emissions benefit provided by reducing the total amount of energy needed to provide mobility in that vehicle as compared to a conventional ICEV (Figure 1).

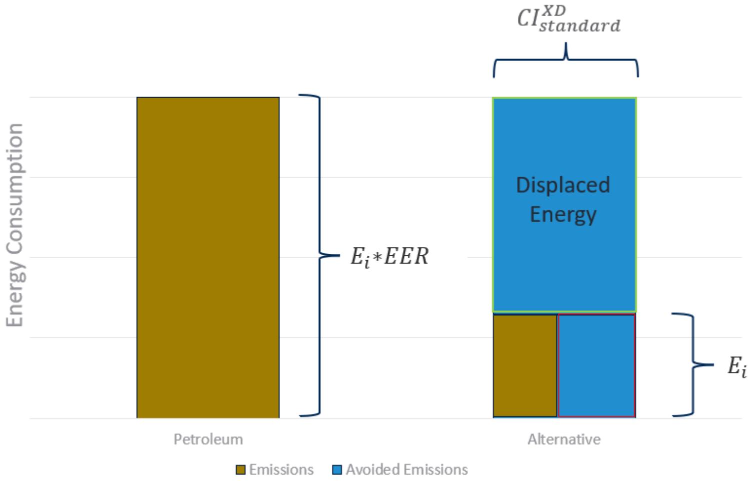

Figure 1. Illustration of energy consumed vs. energy displaced for the purposes of LCFS credit calculation. The height of the bar represents the amount of energy consumed, the width represents carbon intensity, meaning shaded areas represent emissions (brown) or avoided emissions (blue). Note: this figure omits petroleum emissions in excess of the CI standard. Without the displacement term, advanced technology vehicles would be credited only for the lower carbon intensity of the consumed energy but not for using less energy to accomplish the same transportation activity.[8]

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[7] Source: LCFS Regulation Order § 95486.1 (a) (1)

[8] For simplicity, this figure omits the effect of the changing LCFS carbon intensity target, effectively assuming that the target is equal to the carbon intensity of the "petroleum" bar. Note that the petroleum fuel's actual carbon intensity score lies above the standard for any CI reduction target by design; this gap is central to incentivizing the fuel mix change for compliance.

This approach to crediting under the LCFS functionally embeds two key assumptions into the calculation of LCFS credits for fuel displacement.

1. The fuel being displaced always has a carbon intensity equal to the LCFS target for the reference fuel, represented as $CI^{XD}_{standard}$ in § 95486.1 (a) (1).
2. The amount of fuel displaced by vehicles with an *EER* > 1 is a fixed multiple of their energy consumption, set by the *EER*, under all conditions.

The first assumption is appropriate, since the specific fuel being displaced in a given year is unknown and likely to change over time, as the transportation sector transitions toward carbon neutrality. Additionally, the LCFS structure focuses on crediting emissions relative to the declining program target. Maintaining this assumption for avoided emissions due to displacement is a consistent application of this policy design premise.

The second assumption structurally locks fuel displacement as a fixed multiple of the amount of energy used by the advanced technology vehicle. It implies that for every X units of energy used by an advanced vehicle, the alternative would have been to use $EER \times X$ units of energy in a conventional one. This functionally locks the displaced fuel assumption at its maximum theoretical value, under all market conditions. Early in transitions to a ZEV-dominated fleet, this assumption is reasonable; if the new technology vehicle were unavailable, the travel would likely have occurred in a conventional one. While the precise amount of displacement has been the subject of considerable study,[9] the assumption that electric vehicle (EV) travel activity (measured in vehicle miles traveled) displaces an equivalent amount of gasoline vehicle miles traveled provides a reasonable approximation in California's on-road vehicle market, given the amount of ZEV adoption to date.

As a jurisdiction transitions to a fleet increasingly dominated by ZEVs, this assumption regarding displaced energy loses its alignment with real-world impacts. ZEVs purchased by drivers who had previously driven ICEVs and would have otherwise continued doing so still displace significant amounts of petroleum. However, some fraction of ZEVs are likely purchased by drivers who would otherwise have owned a ZEV, e.g., replacement of a ZEV by a newer ZEV.[10] Early in the ZEV transition, it is reasonable to assume that EVs used in California would displace travel that would have otherwise occurred in an ICEV. During the middle and later phases of a multi-decade transition to ZEVs, however, this assumption does not universally hold true. Some more substantial proportion EVs purchased in the 2030s for example, will likely replace old EVs that are being scrapped, and perhaps a greater fraction of EVs sold in the state will move out of the state or be sold into other jurisdictions on the used vehicle market. A comprehensive quantification of the actual petroleum displacement by each new ZEV sold could be prohibitively complex, and dependent on numerous assumptions regarding the counterfactual being compared to. If one assumes that the total amount of travel across the entire economy is largely exogenous to decisions regarding fuel policy, then the fraction of conventional vehicles remaining in the fleet serves as a useful high-level approximation of displacement occurring. That is, if the fleet is 75% ICEVs and 25% ZEVs, then of the travel displaced by each additional ZEV, on average 75% of it would

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[9] Gohlke and Zhou, "Assessment of Light-Duty Plug-in Electric Vehicles in the United States, 2010 – 2019"; Davis, "How Much Are Electric Vehicles Driven?"

[10] Additionally, some fraction of ZEV purchases would be by owners who would have purchased the ZEV even without the incentive offered by the LCFS. While this would not meet most tests of additionality, it is prohibitively difficult to assess within a regulatory context, so the LCFS makes no attempt to do so.

otherwise have been done in an ICEV. There are alternative methods for estimating the amount of displaced petroleum that may offer improved accuracy or other advantages; some of these will be discussed later in this paper.

As the fraction of ZEVs in a fleet increases, the fraction of conventional vehicles decreases, meaning that over time, the average additional ZEV displaces a smaller proportion of ICEV travel and a greater proportion of travel that would have otherwise occurred in a ZEV. This means that as the fleet shifts from ICEV to ZEV, the underlying assumption of complete displacement of ICEV travel becomes an increasingly poorer approximation of real-world impacts. If the fleet is composed entirely of ZEVs, and all new vehicle sales are of ZEVs, it is hard to argue that new ZEVs displace any petroleum at all, however the current LCFS crediting method would assign credits as if each ZEV were still displacing the full theoretical amount of fuel used by conventional vehicles.

Improved Representations of Credit Generation Can Mitigate Future Market Imbalances

Close alignment between credit generation and emission reduction allows the technology-neutral, market-driven effect of the LCFS to maximally guide the flow of incentives to lower emitting technologies and reduces the need for regulatory intervention to correct imbalances in the market. At present, few vehicle classes have seen sufficient penetration of ZEVs to require regulatory intervention, however this is likely to occur more frequently as California progresses through its transition.

In a July 7, 2022 workshop, CARB staff identified electric forklifts (e-forklifts) as a vehicle class for which LCFS incentives may no longer be necessary to achieve state targets and solicited feedback regarding phase-down approaches.[11] The e-forklift fleet is over 50% electrified at present and, as a result, e-forklifts generate 27% of total EV credit under the LCFS, enough to cover around 7% of total deficit generation of the LCFS. This level of credit generation seemed disproportionate to the amount of energy use or emissions forklifts generate, and there were questions about whether the incentive revenue supporting e-forklifts might yield better results if redirected to other technologies.

E-forklifts represent the most immediate challenge that could be addressed by revising the assumptions around displacement for credit generation, but it is increasingly likely that this will apply to other fuel and technology pathways over time as well. For example, sometime in the mid-2030s, the number of ZEVs in California's on-road light duty vehicle fleet will exceed the number of conventional ones. While this is a necessary step towards a zero-emission future, it may make it difficult to balance the LCFS credit market. These risks are described in the Fuels section of the 2021 report *Driving California's Transportation Emissions to Zero by 2045*.[12] The LCFS credit generation by the ZEVs will require very rapid increases in the program target to keep pace and maintain a credit price sufficient to support the deployment of new technologies in difficult-to-electrify applications; such rapid increases would drive up conventional gasoline price impacts and increase the risk of credit shortfalls in future years. Balancing the need to support continued deployment against the risk of onerous fuel price impacts on remaining ICEV drivers could be challenging. As discussed in the previous section, current LCFS credit quantification methods tend to overstate fuel displacement effects for advanced vehicle technologies in

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[11] https://ww2.arb.ca.gov/sites/default/files/2022-07/LCFSWorkshop_Presentation.pdf

[12] Brown et al., "Driving California's Transportation Emissions to Zero."

the middle and later phases of a fleet transition; a more accurate representation of these effects better aligns credit generation with real-world emission impacts and reduces the potential market imbalance.

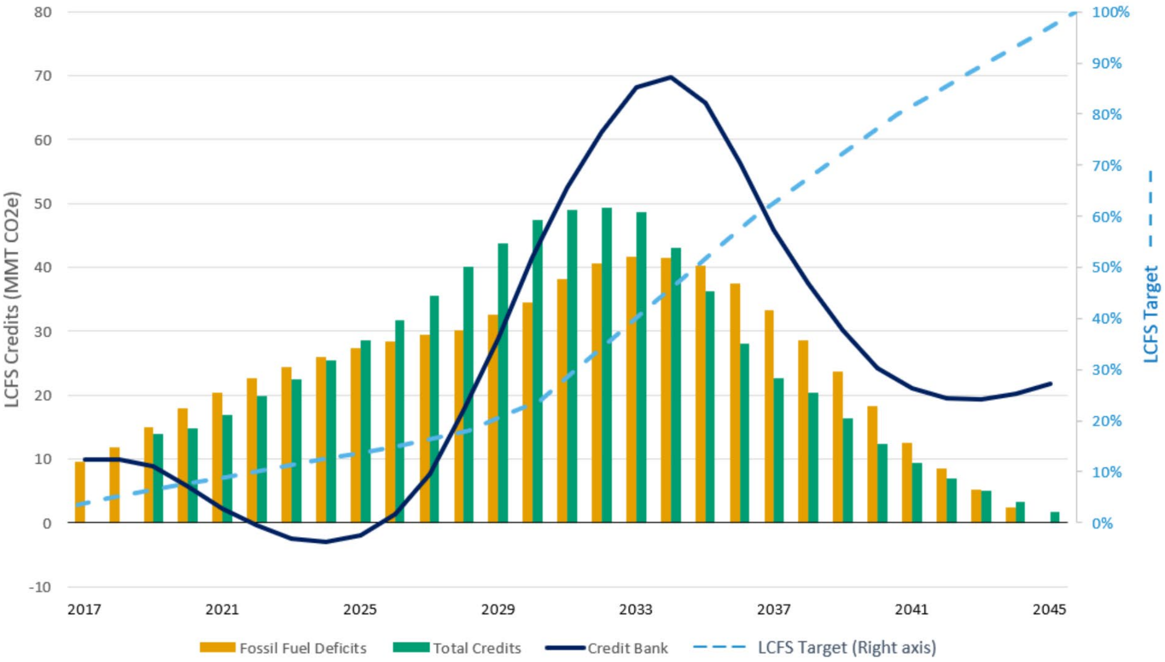

Figure 2. LCFS credits, deficits, aggregate bank and LCFS target (right axis) under the primary compliance scenario modeled in the *Driving to Zero* report. (Source: Brown, et al. 2021)

Figure 2 shows credit and deficit generation under the ZEV scenario (the one most closely aligned with ZEV deployment under the Advanced Clean Cars 2 rule) studied in *Driving California's Transportation Emissions to Zero*, and under the current LCFS 2030 target of 20% CI reduction from 2010 levels. Credit generation (green bars) rises quickly, predominantly driven by rapid light-duty EV credit growth. As a result, the credit bank (dark line) rapidly rises to 175% of yearly deficits and then rapidly falls again. While market response to those conditions is difficult to predict, this would likely lead to substantial downward pressure on LCFS credit prices. 2022 LCFS credit prices have declined by over 70% from their 2020 peak, due in part to the accumulation of a bank of credits in the range of 50-60% of prior year deficits, as well as anticipated credit growth from renewable diesel. The expectation of an even greater amount of growth in the bank of credits from light duty EVs would be expected to put similar, if not greater, downward pressure on LCFS credit prices. Any compensatory action by CARB to stabilize prices would risk creating uncertainty and price volatility in the credit market.

While LCFS targets in the mid-2030s must be increased to generate more deficits in any circumstance, compensating for the effect of current fuel displacement assumptions increases the magnitude of target correction needed. This has three key impacts. First, increasing the target to add additional deficits increases the price impact for consumers who still drive an ICEV. Since a significant fraction of the credits generated by advanced technology vehicles would have been issued on the basis of outdated assumptions regarding the magnitude of fuel displacement, that fraction of the incentive would not be effectively supporting California's effort to reduce GHG emissions. Essentially, it would require a higher impact on gasoline prices, without providing correspondingly higher emissions reductions. Second, the need to ramp up targets even more quickly, makes market balance in the mid to late 2030s even more difficult. There will be sectors of the transportation portfolio that will still be struggling to decarbonize, even as the light and medium duty on-road fleets transition to ZEVs. If the LCFS target must be high to compensate for inaccurate fuel displacement assumptions, this reduces the flexibility CARB will have to optimize LCFS target levels to support a transition in the hardest-to-decarbonize sectors of the fleet. Third, overstating emissions benefits from fuel displacement means that the LCFS will be delivering fewer actual emissions cuts than its nominal credit generation level would indicate. This could require additional emissions cuts in other areas of the transportation sector or the economy as a whole to make up the difference.

A more gradual escalation of credit growth in the 2030s, based on more accurate quantification of emissions impacts, would facilitate a more measured escalation in LCFS program targets and reduce the risk of another sustained period of depressed LCFS credit prices. A stable market, based on accurate quantification of emissions benefits, would reduce the need for regulator intervention and the volatility such intervention could introduce, and it would ensure that actual emissions reductions match what program data would nominally indicate.

Proposed Alternative: Fractional Displacement (FD) of Conventional Fuel

Currently, most LCFS credits are generated using fuel pathways according to the formulas presented in § 95486.1 (a) of the regulation and presented in *Equation 1* earlier in this paper.

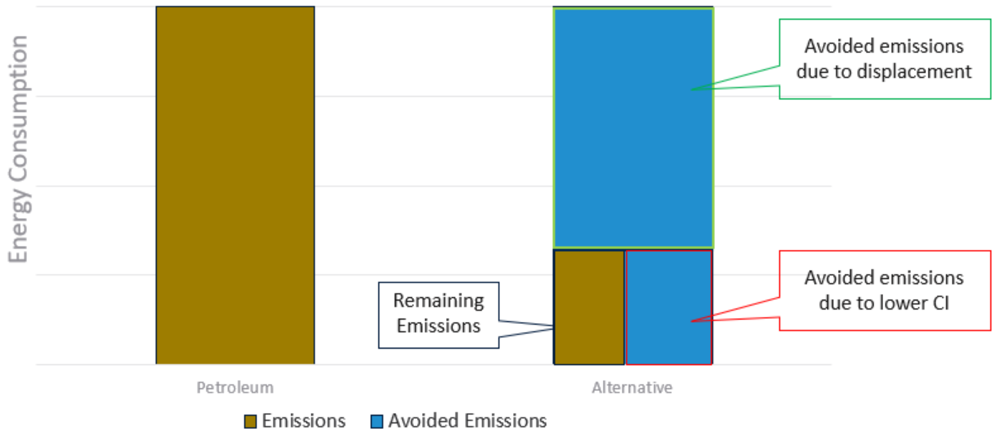

Figure 3. Representation of emissions from ICEV activity being displaced by an advanced technology vehicle (left) and the avoided emissions that will become the basis for credits under the LCFS. This representation includes two separate effects, avoided emissions due to displacement, and avoided emissions due to lower-CI of consumed fuel. The program currently represents these effects as a single equation, assuming fuel displacement is always present at the indicated level.

This equation attempts to mathematically represent two independent effects, reduced emissions due to lower carbon intensity fuel, and reduced fuel consumption due to switching to a more efficient power train (fuel displacement), illustrated in Figure 3.

The conceptual foundation of a Fractional Displacement is simple: change the mathematical representation of emissions under the LCFS to allow separate treatment of the lower-CI effects and the fuel displacement effects. This creates the opportunity to adjust the displacement credit of technologies to more accurately represent the actual displacement of the incumbent fuel by advanced technology vehicles (defined as those with an *EER* > 1). The adjustment factor for the displacement should match real-world displacement behavior as closely as possible. Since the displacement fraction may be difficult to precisely quantify, the fraction of the fleet still using the incumbent, higher-emission technology (typically petroleum) can serve as a useful approximation. (Alternative approaches to the displacement fraction will be discussed below, additional options may be forthcoming from the stakeholder community as well.) For example, if we base the displacement fraction on the fleet fraction of the incumbent technology, displacement credits in a sector that was evenly split between petroleum and ZEV technologies, would be multiplied by 50%. Credits generated due to the lower CI score of the consumed fuel would remain unchanged.

This approach builds on a conceptual understanding of displacement already reflected in the LCFS in its approach to credit quantification for e-forklifts and fixed-guideway vehicles (e.g., passenger rail and light rail). § 95486.1 (a) (4) distinguishes between equipment deployed prior to the implementation of the LCFS in 2011 as opposed to after. Pre-2011 deployments do not receive displacement credit, while post-2011 deployments do. The Fractional Displacement approach builds upon this by adding an additional layer of detail: recognizing that fuel displacement is not a binary effect, but rather scales in proportion to fleet composition and other factors.

Applying the FD approach would require some modest amendments to § 95486.1 to differentiate between credits generated from fuel displacement and those generated by lowering CI in consumed fuel. For example, changing § 95486.1 (a) (1)—as shown in *Equation 1*—for the purposes of credit generation to:

(Equation 2)

$$Credits_i^{XD}(MT) = \underbrace{\left(CI_{standard}^{XD} - CI_i\right) \times E_i \times C}_{\textit{CI Term}} + \underbrace{\left(EER^{XD} - 1\right) \times CI_{standard}^{XD} \times E_i \times F_{displaced}^{XD} \times C}_{\textit{Displacement Term}},$$

where $CI_{standard}^{XD}$, CI_i, E_i, EER^{XD}, and C are unchanged from their current definition and $F_{displaced}^{XD}$—"Displacement Fraction"—is the fraction of theoretical displacement to be credited under the given pathway. The fraction of the fleet still using the incumbent, higher-emitting technology (e.g., ICE) is a reasonable approximation here. For *EER*s < 1, $F_{displaced}^{XD}$ is always equal to 1; this exception will be discussed below.[13]

This alternative quantification method decomposes the credit generation from § 95486.1 (a) (1) into two terms, one quantifying emissions reduced due to lower CI fuel, and one quantifying emissions reduced by displacement of fuel due to higher efficiency.

For conventional vehicles, defined as those with an *EER* of 1, the displacement term is equal to zero and the CI term is equivalent to the current crediting equation described in § 95486.1 (a) (1). This is to say, when *EER* = 1, the FD approach makes no change to credit or deficit generation.

Under an FD approach, the CI term in *Equation 2* would not be affected by any changes in the displacement fraction; the credits generated for lower CI would continue to be generated as long as the

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[13] Omitting the displacement fraction term for *EER*s < 1 is mathematically equivalent to setting it equal to 1.

CI of the consumed fuel was lower than that year's target. Only the displacement term would change as the fleet converted from the incumbent technology to the new one.

Impacts on Credit Generation

The FD approach scales down displacement credits in proportion to the $F^{XD}_{displaced}$ term, leaving credits generated through lower CI fuels unchanged. This results in total credit generation that is identical to the current approach when $F^{XD}_{displaced} = 1$ but scales down to $1/EER^{XD}$ of current credit generation when $F^{XD}_{displaced} = 0$. Once the fleet has completely shifted to the advanced vehicle technology in question and no additional displacement occurs, the remaining CI term still provides credit generation, as long as the fuel consumed has a lower CI score than the target in a given year.

Table 1. Credit generation for 1 GJ of fuel under current LCFS method and with FD for a hypothetical EV with *EER* = 3.8, where the petroleum CI = 100 gCO2e/MJ and the electricity CI = 30 gCO2e/MJ. All numbers are author's assumptions, for illustrative purposes.

Year	**0**	**5**	**10**	**15**	**20**	**25**	**30**
LCFS Standard	0	10%	20%	30%	40%	50%	60%
Incumbent Fraction	100%	100%	80%	60%	40%	20%	0%
Credits with current method	0.38	0.342	0.304	0.266	0.228	0.19	0.152
Credits from CI	0.100	0.090	0.080	0.070	0.060	0.050	0.040
Max Potential Displacement	0.280	0.252	0.224	0.196	0.168	0.140	0.112
Total Credits w/FD	0.380	0.342	0.259	0.188	0.127	0.078	0.040
% of current	100%	100%	85%	71%	56%	41%	26%

Table 1 (above) shows the expected credit generation of an EV with an *EER* of 3.8 (the value currently assigned to E-forklifts). While the fleet is completely composed of incumbent vehicles, no change in displacement crediting occurs. As the fraction of incumbent vehicles decreases, so does the displacement term. The CI term declines due to the increasing LCFS target, which is the same as in the current approach. At the end of the transitional period (assumed to be 30 years in this case), only the CI term produces credits, equal to $1/EER^{XD}$, or 26%, of what would have been generated by the status quo method.

Fractional Displacement Crediting Impacts for Vehicles with *EER* < 1

FD crediting resolves issues related to fuel displacement assumptions that will be increasingly out of date as the market progresses through its transition to ZEVs and other advanced technology vehicles (those with *EER* > 1). The method has less effect on quantification of emissions in vehicles with *EER* < 1 (such as spark-ignition natural gas engines substituting for diesels), though the impacts it has generally improve the accuracy of crediting relative to real-world emission impacts and reduce potential market volatility.

While *EER*s reflect a fundamental relationship between the relative efficiency of two powertrains regardless of their assessed value, *EER*s < 1 represent a very different mechanism of impact on aggregate fuel consumption than *EER*s > 1. As discussed above, an *EER* > 1 represents the use of fuel in a more efficient powertrain, and therefore less aggregate fuel consumption required for an equivalent amount of vehicle activity. The precise amount of fuel displaced is not known with high precision or confidence, and the FD approach seeks to better accommodate this uncertainty. An *EER* < 1 represents a powertrain that is less efficient than the reference one. In this case, additional energy is required to accomplish the same amount of vehicle travel or work. The key difference between *EER*s above and below 1 is that in almost every case for an *EER* < 1, the quantity of additional energy being consumed is known with relatively high confidence and precision. When a diesel truck is displaced by a renewable natural gas (RNG) truck with *EER* 0.9, the RNG truck consumes more energy in the form of RNG to do the same work, with the additional energy consumption following the ratio of $(1\ /\ EER)$. The additional energy needed by a vehicle with *EER* < 1 does not vary depending on the technologies used by other vehicles in the fleet around it or on any factors other than the relative efficiency of the two powertrains. As such, $F_{displaced}^{XD}$ should be omitted or set equal to 1 for *EER*s > 1.

When applying the fractional displacement approach to vehicles with an *EER* < 1, the standard assumption of the displaced fuel having CI equal to $CI_{standard}^{XD}$ would remain appropriate, however given the fact that the fuel being used to make up for the lower efficiency of the powertrain is known with high certainty in most cases, substituting CI_i for $CI_{standard}^{XD}$ in the displacement term could be appropriate as well. In this instance, the displacement term represents the additional fuel required due to the use of a lower-efficiency powertrain and becomes a penalty, reducing the credits that would otherwise be generated by a lower-CI fuel.

FD crediting also provides for more accurate representation of complex fuel systems that create fuels with a negative CI score, such as those from electricity generated by the combustion of carbon-negative RNG. At present, the LCFS recognizes and credits avoided fugitive methane emissions from the installation of anaerobic digesters when there is no regulatory requirement to do so. In some situations, the avoided methane emission is substantial, yielding a fuel that achieves a negative CI score, implying that every unit of consumed fuel results in an absolute reduction of GHGs from the atmosphere. The LCFS also recognizes pathways in which RNG with a negative CI score is combusted to generate electricity, and that electricity is used to charge EVs. This means that the multiplier effect from the *EER* is applied to the negative CI score, implying that more methane is avoided by the use of RNG-derived electricity in an EV than if the RNG had been directly used as vehicle fuel. In truth, the quantity of avoided methane is a function of the amount of RNG produced and has no relation to the efficiency of the vehicle in which the RNG is consumed. FD crediting effectively prevents this erroneous representation from occurring. The negative CI of the RNG is fully reflected in the CI term of the *Equation 2*. Emissions benefits from displacement are quantified using $CI_{standard}^{XD}$, which would not be carbon-negative under any foreseeable circumstance, meaning that the counterintuitive multiplication of avoided methane credit by *EER* would no longer be possible under the FD crediting approach.

Alternative Methods to Estimate the Displacement Fraction

The core change the FD approach makes to the current LCFS crediting method is to decompose the equation currently used by credit generating pathways, represented in *Equation 1* above, into CI and Displacement components, so that the Displacement component can be scaled to better match actual fuel displacement. This functionally liberates LCFS credit generation from the assumption that every advanced technology vehicle displaces the maximum theoretical potential amount of fuel possible for a given *EER* under all market conditions. This allows more precise assumptions, incorporating a wider variety of policy considerations to provide a better reflection of real-world vehicle market and activity dynamics.

Setting $F_{displaced}^{XD}$ to equal the fraction of the fleet using the incumbent technology, typically petroleum-fueled ICEVs, is a useful high-level approximation that better represents actual fuel displacement. It assumes that if a fleet is 50% ICEV and 50% ZEV, then on average, 50% of the travel that ZEV displaces would have been done by an ICEV and 50% by another ZEV. In this case, regulatory staff would establish the value of $F_{displaced}^{XD}$ on a regular basis, as they do annually for the average CI of the California electricity grid.

The suggested approximation, where $F_{displaced}^{XD}$ is equal to the fraction of the fleet using the incumbent technology is admittedly imperfect. During the transition from conventional to advanced technologies, the age of incumbent technology vehicles would, on average, be greater than that of the advanced technology ones replacing them. This implies that incumbent technology vehicles would be somewhat more likely to be retired out of service in any given year than advanced ones, meaning that each additional advanced technology vehicle would be expected to displace slightly more of the incumbent fuel use than would be expected by simply relying on the fleet fraction. To be clear, approximating $F_{displaced}^{XD}$ as the incumbent technology fleet fraction yields displacement credits that much more closely align with real-world behavior across the full temporal scope of a fleet transition than the binary approach used in the status quo, but further improvements are possible.

If research or modeling on fleet turnover behavior provides a superior alternative value of $F_{displaced}^{XD}$, one that better matches real-world fuel displacement, such a value can be used while still aligning with the underlying logical and quantitative representation described in the FD approach.

For example, if research and/or modeling were available to more precisely quantify marginal displacement rates for advanced technology vehicles, those rates could be substituted for $F_{displaced}^{XD}$ and result in a representation of displaced emissions that would support even closer alignment with real-world performance.

Alternatively, $F_{displaced}^{XD}$ can be set to equal the incumbent fleet fraction with a lag of one or more years. This provides an imprecise but directionally correct accommodation for the tendency of the incumbent fleet fraction to slightly underestimate likely real-world fuel displacement.

All approaches that base $F_{displaced}^{XD}$ on the incumbent fleet fraction require the regulator to know with reasonable precision what the incumbent fleet fraction actually is. For vehicle types that are regularly surveyed, or require registration with a regulatory body, this data should be available (though there may be a significant delay before they are collected, verified, and made available to regulators). There may be vehicle classes for which the incumbent fleet fraction cannot be known with acceptable accuracy, such as where a significant fraction of the fleet consuming fuels that are subject to credit or deficit generation under the LCFS are based and registered outside the regulating jurisdiction, or where no good survey data exist upon which to base an estimate. In these cases, a number of less precise alternatives would still be expected to better represent displacement credit effects than the current approach, such as assuming the fleet transition happens over a predetermined number of years, and setting $F_{displaced}^{XD}$ according to that assumption; e.g., if the transition from conventional to advanced technology vehicles were expected to take 20 years, $F_{displaced}^{XD}$ could be approximated by starting at 1 in year zero and declining by five percentage points per year. Alternatively, if the jurisdiction has established policy requiring sales of vehicles with the incumbent technology to discontinue by a given point in time, the incumbent fleet fraction could be estimated using models of vehicle retirement and replacement, based on the targets set in regulation.

The value of $F^{XD}_{displaced}$ can be modified to reduce administrative burden and increase predictability by specifying trajectories or values over certain time periods or setting a maximum year-to-year change in $F^{XD}_{displaced}$. One such approach would be to establish a significance threshold before Fractional Displacement crediting is applied, which could help ensure that advanced technologies are more firmly established in their market before their credit generation starts to degrade as well as reduce the administrative burden associated with quantifying fleet composition during very early phases of a technological transition. For example, specifying that FD crediting does not begin until a given advanced vehicle technology makes up 25% of the fleet would preserve near-term support for the technology, and spare program staff the need to accurately quantify very small changes in fleet composition. Similarly, specifying a trajectory for $F^{XD}_{displaced}$ during the final years of a transition can accomplish the same goals, e.g., once the incumbent fraction in a given fleet is less than 10%, $F^{XD}_{displaced}$ could be set to decline to zero over a specified number of years.

Most of the examples discussed in this paper have focused on situations where only two technology classes are present in a market. There may, however, be situations where more than two technology types each make up significant fractions of a given market segment. The FD crediting approach is still applicable in these cases. Basing $F^{XD}_{displaced}$ on the incumbent fraction means that each vehicle will only be credited for displacing the incumbent fuel, not fuel used by vehicles with *EER* > 1. This may slightly underestimate real-world displacement, such as if heavy duty EVs with an *EER* of 5 entered a market with a significant proportion of heavy-duty hydrogen fuel cell vehicles, with an *EER* of 2.1, displacing some of them as well as incumbent ICEVs. Under most plausible market conditions, this underestimate would be relatively small due to the broad decrementing of displacement credits overall. Moreover, if this did occur, an appropriate adjustment factor could be added to the $F^{XD}_{displaced}$ term for each technology type.

In all cases, careful modeling should be performed to fully understand the implications of any decision and to ensure an appropriate balance between maximizing the accuracy of LCFS displacement credit representation, minimizing administrative burden, and sending appropriate and effective market signals.

Deficit Generation Under a FD Approach

The current equation in § 95486.1 (a) (1), reported as *Equation 1* in this paper, applies to both credit and deficit generation in the LCFS, with deficits resulting when $CI^{XD}_{standard} < CI^{XD}_{reported}$. For fuels with *EER* = 1, the displacement term drops out of the FD crediting method presented in, leaving it equal to the current approach, as shown in *Equation 1*. For *EER*s other than 1, the FD approach improves the representation of deficit generation relative to the current practice.

Deficit generation via pathways with *EER* > 1 could occur if, for example, an EV consumes electricity with CI higher than that year's LCFS target or a hydrogen FCEV consumes hydrogen made from fossil sources. Both of these conditions, and others like them, are extremely unlikely given expected market, technology, and policy dynamics, as well as the availability of book-and-claim accounting to purchase environmental attributes of low-carbon energy.

In those cases, however, the FD approach would continue to more accurately represent the real-world emission impact of such occurrences. The current approach obtains $CI^{XD}_{reported}$ by dividing the CI of the fuel used in a given pathway, CI_i, by the appropriate *EER*. This is required by the current quantification equation, which simultaneously estimates the CI and Displacement terms in one step. For the unusual case of *EER* > 1 and $CI^{XD}_{standard} < CI^{XD}_{reported}$, dividing CI_i by the *EER* will tend to mute the effect of excess emissions caused by the use of above-target fuel in a high-*EER* pathway. Table 2 describes a hypothetical example of this occurrence, building on the same general market dynamics as in Table 1, but with more ambitious targets at the end year, and electricity with a hypothetical grid electricity CI around that of California's in 2010. In this case, the EV pathway shifts from credit to deficit generation earlier than under the current approach, to a more accurate representation of the actual emissions impact from displaced fuel in such vehicles. If the electricity used as vehicle fuel could not reduce its emissions beyond 2010 levels, then it would be unsuitable as a fuel in a carbon-neutral transportation system. The fact that the fuel shifts from credit generation to deficit generation earlier in the transition under FD crediting represents improved alignment between LCFS crediting and overall program goals, in the unusual case of deficit generation in high-*EER* vehicles.

Table 2. Credit generation for 1 GJ of fuel under current LCFS method and with FD for a hypothetical EV with *EER* = 3.8, but in which electricity had CI = 80 g CO2e/MJ through the entire period. Petroleum CI – 100 g CO2e/MJ. FD crediting provides earlier and stronger push-back against fuels with higher carbon than the given year's target. All numbers are illustrative.

Year	0	5	10	15	20	2S	30
LCFS Standard	0	10%	20%	50%	60%	70%	80%
Incumbent Fraction	100%	100%	80%	60%	40%	20%	0%
Credits with current method	0.3	0.262	0.224	0.11	0.072	0.034	-0.004
Credits from CI	0.020	0.010	0.000	-0.030	-0.040	-0.050	-0.060
Max Potential Displacement	0.280	0.252	0.224	0.140	0.112	0.084	0.056
Total Credits w/ FD	0.300	0.262	0.179	0.054	0.005	-0.033	-0.060
% of current	100%	100%	80%	49%	7%	-98%	1500%

In the case of *EER* < 1, which is a more likely condition for deficit-generating pathways, much of the same logic holds true. With $CI^{XD}_{standard} < CI^{XD}_{reported}$, the CI term of the credit generation under the FD approach will invariably be negative, as will the displacement term due to the *EER* < 1. The current LCFS practice of obtaining $CI^{XD}_{reported}$ by dividing CI_i, by the relevant *EER* may slightly overstate the excess emissions - which are the basis of deficits - in vehicles with *EER* < 1, which implies that the FD approach slightly improves the correlation between actual emissions and deficit generation in these cases.

FD Impacts on e-Forklift Credit Generation

At the July 7th, 2022, workshop, LCFS staff asked for input regarding possible phase-down approaches for e-forklifts. This class of vehicles is already well-advanced in its transition from ICEVs to ZEVs, and future CARB rulemaking will likely set a date after which all new forklifts in California must be ZEVs.[14] In

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[14] At the time of writing, data on the size and composition of the CA forklift fleet were not available. These data appear to have been collected by CARB as part of ongoing rulemaking and vehicle survey activity, but multiple requests for access to this data did not receive a response.

2021, e-forklifts generated almost 1.3 million credits, accounting for 7% of total LCFS credit generation, despite making up a smaller share of the total fleet, or transportation energy consumption. This outsized credit generation is likely due to the overestimation of displaced fuel by advanced technology vehicles that occurs under the current LCFS approach. Each e-forklift is assumed to displace one conventional forklift's worth of energy, under all conditions, even when the market has predominantly switched to ZEV technology already. While the precise composition of the California forklift fleet was unavailable at the time of writing, conversations with stakeholders in this space indicate that the overwhelming majority of sales of forklifts at present are for e-forklifts, and the fleet as a whole is more than half electric. E-forklifts are, as mentioned above, the only vehicle class for which switching to the FD crediting method and using the incumbent fraction to approximate $F_{displaced}^{XD}$ would result in significant and immediate changes in credit generation (Table 3).

Table 3. LCFS credit generation for e-forklifts under current, FD, and a "gradual catch-up" approach. *EER* is 3.8 for e-forklifts, and total fuel consumption by this class is assumed to grow at 3% per year from 2021 data. Incumbent fractions are the author's estimates.

	2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Incumbent Fraction	40%	35%	30%	25%	20%	18%	15%	13%	10%	8%	6%	4%	2%	0%
LCFS Target	90.4	89.1	86.4	84.4	82.4	79.4	76.3	73.3	70.3	65.3	60.3	55.2	50.2	45.2
Grid CI	72.7	69.6	66.4	63.3	60.1	56.9	53.8	50.6	47.4	44.3	41.1	38.0	34.8	31.6
e-Fork fuel consumed (million GGE)	42	44	45	46	48	49	50	52	54	55	57	58	60	62
e-Fork Credits (Current method)	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.2	1.1	1.0
e-Fork Credits w/FD (million)	0.60	0.56	0.50	0.44	0.39	0.36	0.33	0.30	0.27	0.23	0.20	0.16	0.13	0.10
% of base	42%	38%	35%	31%	27%	25%	23%	21%	19%	17%	16%	14%	12%	10%
Difference in credits (million)	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	0.9
Gradual Catch-Up method														
F_displaced value	100%	100%	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	2%	0%
e-Fork Credits - Gradual Catch-up (millions)	1.4	1.4	1.4	1.3	1.2	1.0	0.9	0.8	0.7	0.5	0.4	0.2	0.1	0.1
% of base	95%	96%	100%	91%	82%	73%	64%	55%	46%	37%	28%	19%	12%	10%
Difference in credits (millions)	0.1	0.1	0.0	0.1	0.3	0.4	0.5	0.6	0.8	0.8	0.9	1.0	1.0	0.9

Based on the assumption of a 40% incumbent fraction, immediate application of FD crediting would result in a precipitous drop in LCFS credit generation from this category, compared to the current method. While this would more accurately reflect anticipated emissions benefits, it could have a disruptive effect on the progress of this sector toward carbon neutrality. To mitigate this, a gradual catch-up approach that limited the maximum rate of change for the $F^{XD}_{displaced}$ term to no more than 10% per year was adopted. This guaranteed a phase-down period for credits from fuel displacement of no less than 10 years (Figure 4). The gradual catch-up approach brings e-forklift credit generation into line with the default FD approach shortly before the fleet completes its transition, in this hypothetical example.[15]

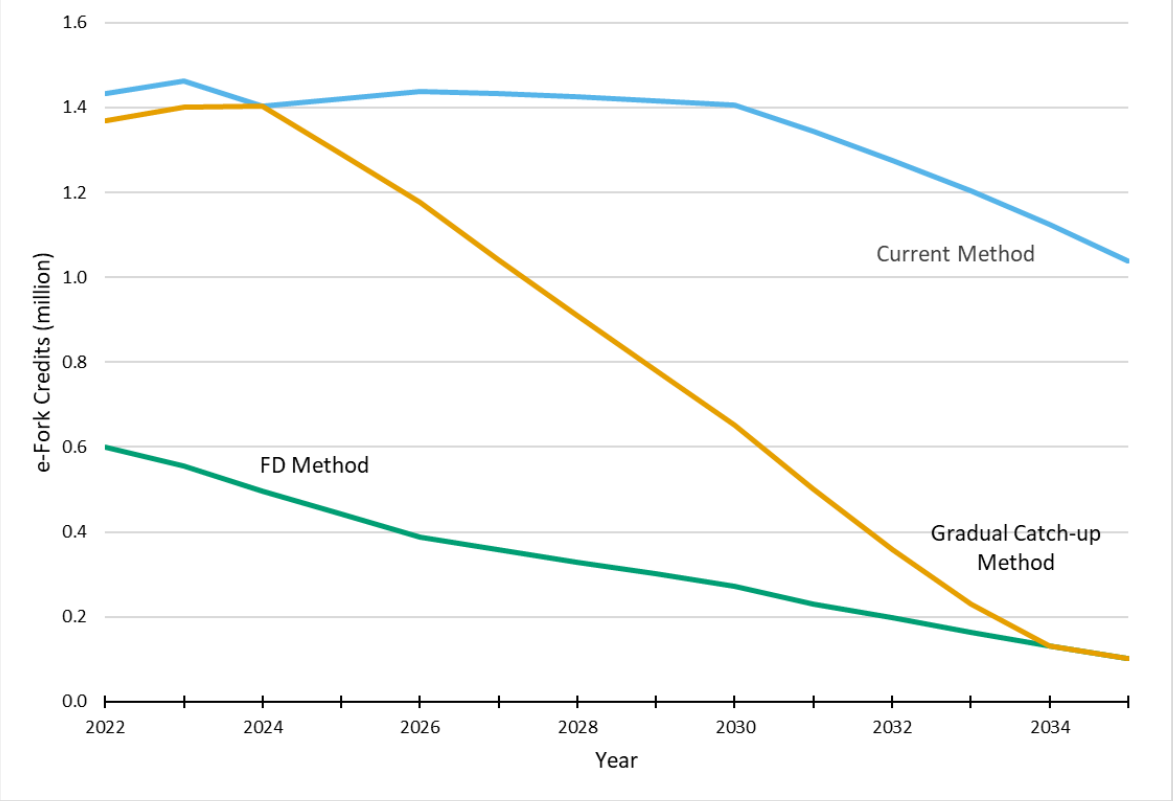

Figure 4. Credit generation by e-forklifts under current, FD crediting, and "Gradual Catch-up" methods. Data taken from Table 3.

FD Impacts on Light-Duty EV Credit Generation

The FD crediting approach is suitable for application across all credit generation pathways that currently use the equation § 95486.1 (a) (1) (reported as *Equation 1* in this paper). At present, only e-forklifts would see a significant change in credit generation under this approach, though as more fleets transition from ICE to ZEV, the effect of FD crediting would become more widespread. Light-duty EVs, specifically

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[15] The current approach to LCFS credit generation may need to be retained for LCFS credit pathways that have already been granted. This paper takes no position on legal or contractual limitations or expectations implied by the LCFS and does not suggest any action that would violate existing law, policy, or contracts.

battery-electric vehicles, would be the technology class in which the greatest impact would ultimately be felt by the change to FD crediting. As reported in *Driving California's Transportation Emissions to Zero by 2045*, and discussed above, the massive amount of credits expected from light-duty EVs in the mid-late 2030s may make it difficult to maintain LCFS credit prices high enough to support needed fuel deployment in difficult-to-decarbonize sectors of the economy. Scaling down credits to light-duty EVs could not only improve alignment between credit generation and emission reductions but also promote more stable LCFS credit market and pricing behavior, and it could ensure that LCFS credit revenue would support measures that continue to reduce fleet-wide emissions during the middle and later phases of the transition to ZEVs.

Table 4 and Figure 5 show three potential scenarios for application of the FD crediting approach to light-duty EVs. The incumbent fraction was projected based on fleet composition, specifically ICE and non-plugin hybrid electric vehicle components of the car and light truck fleet in the ZEV scenario from the *Driving to Zero* report. Grid electricity CI was interpolated from present values to an assumed 0 CI in 2045, and the *EER* was assumed to remain at 3.4 for the full period.

The "LD [light-duty] EV Credits w/FD" line represents application of the FD approach using the incumbent fraction for the given year; it is, in essence, the most direct and straightforward application of the FD crediting approach. "LD EV Credits w/ lag-2" adopts FD crediting, with the displacement fraction based on the incumbent fraction in the fleet, lagged 2 years. This delays the impact of FD crediting slightly and helps compensate for the slight mismatch between the incumbent fraction and theoretical displacement behavior due to the relative age of ICEVs during middle and later years of the transition to zero emissions. The "Threshold approach" delays implementation of FD crediting, by setting $F_{displaced}^{XD}$=1 until EVs represent 10% of the fleet, then applying a 2% per year catch-up factor until the $F_{displaced}^{XD}$ equals what it would be under the 2-year lag approach. This threshold crediting approach holds displacement credits stable until the advanced technology vehicle fleet is sufficiently large to ensure it has a market foothold (sales rates would have to be well in excess of 10% before the fleet fraction reaches that level) before starting to decrement displacement credits. As discussed above, the threshold approach can also be applied to the final years of a fleet's transition to ZEVs, however, in this case the transition to ZEVs was still far from complete in 2045, so no end-year transition strategy was applied.

Table 4. Credit generation from light-duty (LD) EVs under current LCFS methods and three different approaches to FD crediting. LCFS targets are 30% in 2030, and 90% in 2045, with the incumbent vehicle fraction taken from the ZEV scenario of *Driving California's Transportation Emissions to Zero by 2045*. (The highlighted colors of the rows correspond to the colors of the curves in Figure 5.)

	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045
Incumbent Fraction	96%	95%	95%	94%	93%	91%	88%	86%	82%	79%	75%	70%	65%	60%	55%	50%	46%	42%	37%	34%	30%	27%	24%	21%
LCFS Target	89.5	88.3	85.5	83.5	81.5	78.6	75.6	72.6	69.6	64.6	59.7	54.7	49.7	44.7	41.3	37.8	34.3	30.8	27.3	23.9	20.4	16.9	13.4	9.9
Grid CI	72.7	69.6	66.4	63.3	60.1	56.9	53.8	50.6	47.4	44.3	41.1	38.0	34.8	31.6	28.5	25.3	22.1	19.0	15.8	12.7	9.5	6.3	3.2	0.0
LD EV fuel consump (million GGE)	130	157	185	232	298	381	478	590	708	835	969	1110	1256	1390	1512	1625	1727	1821	1903	1975	2036	2088	2131	2166
LD EV Credits (Current method)	3.6	4.3	5.0	6.1	7.7	9.6	11.6	13.8	16.0	17.5	18.7	19.6	20.2	20.0	20.2	20.0	19.5	18.7	17.6	16.2	14.6	12.8	10.8	8.8
LD EV Credits w/FD (million)	3.48	4.13	4.72	5.78	7.22	8.77	10.41	12.05	13.50	14.19	14.51	14.42	13.95	12.92	12.21	11.32	10.32	9.27	8.21	7.19	6.22	5.34	4.56	3.87
% of base	96%	96%	95%	94%	93%	92%	90%	87%	84%	81%	77%	73%	69%	65%	60%	56%	53%	50%	47%	44%	43%	42%	42%	44%
Difference in credits (million)	0.1	0.2	0.2	0.3	0.5	0.8	1.2	1.8	2.5	3.3	4.2	5.2	6.2	7.1	8.0	8.7	9.2	9.4	9.3	9.0	8.3	7.4	6.3	4.9
LD EV credits w/ Lag-2 (million)	3.53	4.19	4.78	5.87	7.37	9.04	10.85	12.69	14.37	15.27	15.79	15.90	15.60	14.69	14.01	13.03	11.90	10.71	9.48	8.27	7.11	6.04	5.08	4.22
% of base	98%	97%	97%	96%	95%	95%	93%	92%	90%	87%	84%	81%	77%	73%	69%	65%	61%	57%	54%	51%	49%	47%	47%	48%
Difference in credits (million)	0.1	0.1	0.2	0.3	0.4	0.5	0.8	1.1	1.6	2.2	2.9	3.7	4.6	5.3	6.2	7.0	7.6	8.0	8.1	7.9	7.5	6.7	5.7	4.5
Threshold approach F_frac value	100%	100%	100%	100%	100%	100%	100%	100%	97%	91%	85%	79%	72%	65%	58%	51%	46%	42%	37%	34%	30%	27%	24%	21%
LD EV Credits - Threshold & Lag (millions)	3.6	4.3	5.0	6.1	7.7	9.6	11.6	13.8	15.6	16.2	16.3	15.9	15.2	13.8	12.7	11.4	10.3	9.3	8.2	7.2	6.2	5.3	4.6	3.9
% of base	100%	100%	100%	100%	100%	100%	100%	100%	97%	92%	87%	81%	75%	69%	63%	57%	53%	50%	47%	44%	43%	42%	42%	44%
Difference in credits (millions)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.3	2.4	3.7	5.0	6.3	7.5	8.6	9.2	9.4	9.3	9.0	8.3	7.4	6.3	4.9

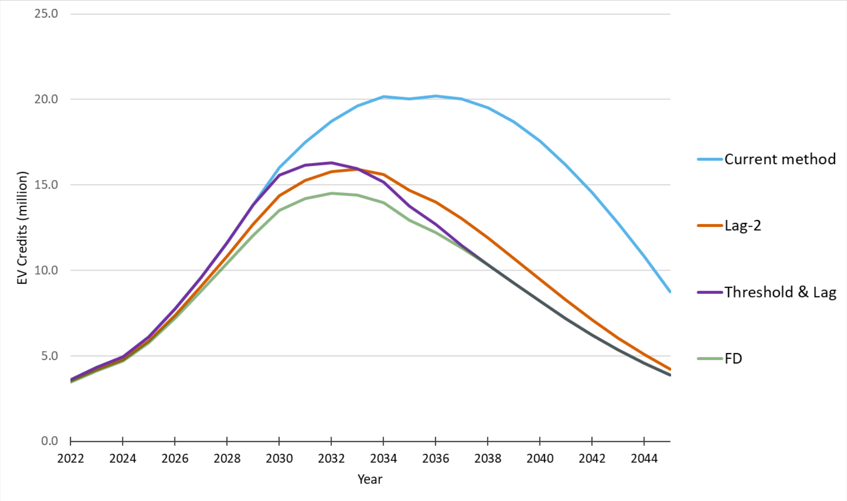

Figure 5. Light-duty EV credit generation under the current LCFS approach (blue line) as well as the FD crediting approaches laid out in Table 4.

Figure 5 presents these effects graphically, showing a lower peak credit generation potential from light-duty EVs, as well as the peak being attained earlier. Given the expectation that most light-duty EVs will be price-competitive with ICEVs by the early 2030s, beginning to decrement LCFS credit support at that point may allow better alignment of program incentives with its underlying intent. While EVs will continue to receive LCFS credits as long as the electricity they are charged with has lower CI than the program target, phasing down credits starting in the early 2030s shifts the program's focus to fuel pathways that may still be struggling to achieve commercial scale deployment.

Adopting the FD credit approach will reduce aggregate credit generation from advanced technology vehicles, which may require the LCFS program target to be set lower than it would be under the current crediting approach. While this may make the pace of decarbonization seem nominally slower than if the current approach were maintained, the difference between the two approaches is that FD crediting better reflects the emissions impact of fuels used in advanced technology vehicles. Meeting a nominally higher LCFS target with credits reflecting overstated estimates of fuel displacement does not mean GHG emissions are actually reduced. Lower LCFS targets in the 2030s and early 2040s reduce the price impact on consumers still using gasoline and allow a more gradual LCFS target trajectory, which will contribute to a stable LCFS credit market.

Conclusion

Current mathematical representations of fuel displacement under the LCFS embed the assumption that advanced technology vehicles, those with $EER > 1$, always displace fuel at their maximum theoretical level, no matter the market conditions. This assumption means that for the purposes of LCFS crediting the first advanced technology vehicle sold into a market displaces precisely as much as the one-millionth such vehicle, or the one that replaces the final incumbent vehicle. Under the present method, credits would be generated for fuel displacement even after a fleet had completely shifted to ZEV technology. This assumption of complete displacement reasonably approximates real-world behavior during the early phases of a vehicle transition but would likely lead to significant overestimation of displacement as the fleet converts to new, more advanced technologies.

The Fractional Displacement crediting approach resolves this overestimation by disaggregating the current credit quantification equation into two components, one that reflects credits from lower-CI fuel on an equal-energy basis, and one that reflects displacement of additional fuel due to higher efficiency powertrains. The displacement component can then be reduced over time, such as in proportion to the fraction of vehicles using the incumbent technology that remain in the fleet. This change is technology-neutral and is built on the same conceptual and mathematical foundation as the current quantification method.

The FD approach offers the opportunity to more accurately represent credits generated by advanced technology vehicles as they become more prevalent in the fleet, which would strengthen the connection between actual emissions benefits and the amount of incentive. This connection has been a strength of the LCFS to date, and reinforcing it helps support effective program function moving forward. The FD approach would also reduce the potential for future destabilization of the LCFS credit price by large-scale fleet turnover to advanced technology vehicles, such as is expected to happen in the 2030s as the on-road LD vehicle fleet transitions to EVs. Switching to FD crediting would mitigate the risk of downward price pressure on LCFS credits and reduce the need for regulatory intervention as technologies mature. The FD approach never completely cuts a technology out of the LCFS; if the fuel consumed by a vehicle has a lower CI than the target for a year, it will receive appropriate credit. While

FD crediting can be adopted piece-meal, comprehensive adoption would create a stronger and more durable foundation for the LCFS and reduce the risk of market disruptions in the future.

Works Cited

Brown, Austin L., Daniel Sperling, Bernadette Austin, J. R. DeShazo, Lew Fulton, Timothy Lipman, Colin Murphy, et al. “Driving California’s Transportation Emissions to Zero,” April 1, 2021. https://doi.org/10.7922/G2MC8X9X.

Davis, Lucas W. “How Much Are Electric Vehicles Driven?” *Applied Economics Letters* 26, no. 18 (October 24, 2019): 1497–1502. https://doi.org/10.1080/13504851.2019.1582847.

Ekvall, Tomas, and Göran Finnveden. “Allocation in ISO 14041—a Critical Review.” *Journal of Cleaner Production* 9 (2001): 197–208. https://doi.org/10.1016/S0959-6526(00)00052-4.

Gohlke, David, and Yan Zhou. “Assessment of Light-Duty Plug-in Electric Vehicles in the United States, 2010 – 2019.” Argonne National Lab. (ANL), Argonne, IL (United States), June 1, 2020. https://doi.org/10.2172/1642115.

ISO. *14044 Environmental Management — Life Cycle Assessment — Requirements and Guidelines*. Geneva, SW: International Standards Organization, 2006.

———. *ISO 14040*. Vol. 2006. Geneva, SW: International Standards Organization, 2006.

Mazzone, Daniel, Julie Witcover, and Colin Murphy. “Multijurisdictional Status Review of Low Carbon Fuel Standards, 2010–2020 Q2: California, Oregon, and British Columbia,” July 1, 2021. https://doi.org/10.7922/G2SN0771.

Muratsuchi, Al. Bill Text - AB-1279 The California Climate Crisis Act., Pub. L. No. AB 1279. Accessed November 3, 2022. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1279.

Murphy, Colin W, and Alissa Kendall. “Life Cycle Inventory Development for Corn and Stover Production Systems under Different Allocation Methods.” *Biomass and Bioenergy* 58 (November 2013): 67–75. https://doi.org/10.1016/j.biombioe.2013.08.008.