The End of Neutrality?
Fuel Standards, Technology Neutrality, and Stimulating the EV Market

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Abstract

Widespread electrification of the transportation sector is a key component of most strategies for deep decarbonization of the U.S. economy. While the acceptance of EVs has grown dramatically over the last decade, much of this growth has been spurred by substantial support from public funds and other related policies. Major electrification on the time scales supported in many climate policy plans will require substantial investment spurred by policy. In this paper we discuss the policy options for expanding the EV market. Our particular focus is on the potential role that a Clean Fuel Standard (CFS) can play in supporting electrification. These standards, like California's LCFS, are typically positioned as "technology neutral," and the LCFS itself relies upon a dense set of calculations and assumptions to rate a wide variety of fuels based upon their life-cycle carbon intensity (CI). However, it is likely that for a CFS to support the kinds of investments on a magnitude likely necessary to reach electrification goals, it may have to be altered in such fundamental ways as to no longer really function as either technology-neutral or a purely fuels-based standard.

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1 Introduction

A key element of most visions for achieving climate stabilization involves the widespread transition of the transportation sector to electricity via the adoption of electric vehicles (EVs). Governments around the world have set ambitious targets for EV adoption or set goals to phase out the sale of EVs entirely, often supporting these objectives with policies designed to encourage adoption. While the growth of the EV market over the last decade has been spectacular in percentage terms, EVs still remain a modest fraction of overall passenger vehicles.

One policy tool for supporting EV growth that has drawn interest in several regions is the clean fuel standard (CFS), such as the Federal Renewable Fuel Standard and California's Low Carbon Fuel Standard (LCFS). A CFS allows suppliers of low carbon transportation energy to earn credits that are sold to producers of higher-carbon transportation fuels. They have traditionally been positioned as "technology-neutral" standards that scores, or bins, a broad set of fuels based upon their life-cycle carbon intensity. A CFS is designed to promote clean or renewable transportation in a way that is most easily applied to blends of lower-carbon fuel used in similar (internal combustion engine) vehicles. Adapting a CFS to promote specific and dramatically different transportation technologies, such as hydrogen or electricity, has therefore necessitated adopting a series of complex and arguably dubious assumptions. If taken to a large scale, these assumptions fundamentally reshape and redefine the nature and function of a CFS. To the extent that these assumptions create favorable conditions for specific fuels, the standard loses one of its main initial benefits: technological neutrality. To the extent it increasingly focuses on vehicle purchases and infrastructure, it is no longer a "fuel" standard.

In this paper we discuss the policy challenges presented by a goal of rapid large-scale expansion of EVs. We focus on the market for passenger vehicles, which constitutes almost all of the EV industry for which there is currently useful empirical evidence. There are three channels in which EV adoption can be supported: operational (fuel) costs, up-front (vehicle) costs, and operational convenience. In each dimension the policy challenge is to establish or expand an advantage (or minimize a disadvantage) of EVs relative to conventional internal combustion engine (ICE) vehicles.

We then survey the standard policy options available for promoting the expansion of EVs, including carbon pricing, intensity standards (such as the LCFS), and subsidies provided by either general public funds or utility ratepayers. Each option has its particular advantages and disadvantages with regards to economic efficiency, transparency, and broad public appeal. Regulators in multiple jurisdictions are now assessing how a CFS could be deployed to promote EV adoption. Many are looking to the experience in California with its LCFS as a model.

The California experience illustrates how much a desire to promote EV's can fundamentally reshape CFS design. As implemented in California, the LCFS has not affected the electricity price for EV users. In contrast, the LCFS in California has added several elements designed to reduce vehicle costs by directing a large proportion of residential charging value to a statewide point-of-purchase rebate for EVS, and to promote the provision of services that increase charging convenience by allowing credit generation for unused fueling capacity for zero emission vehicles (ZEVs), namely EVs and hydrogen. While these measures arguably increase the appeal of EVs and ZEVs more generally, they also alter the nature of the LCFS in ways that carry unpredictable implications for the production of other types of low carbon fuels. For example, there are no specific rewards available for the sale of flex-fuel cars that would be analogous to those available for EVs, or for "blender" pumps that could facilitate more large scale usage of biofuels. Any LCFS credit revenue directed toward these is completely at the discretion of the credit seller. Thus, where more distribution channels have opened for non-ZEV fuels, as in the case of renewable diesel, it has been on the strength of the LCFS incentive on the flow of fuels.

If EVs are to be supported either through vehicle subsidies or through promoting convenience and accessibility through measures such as expanded charging networks, this leaves policy makers with one of two choices. Support for vehicle costs and charging networks could either be provided via policies specifically designed and directed for those purposes, or such support could be added to a CFS at a magnitude and in a fashion that so alters the nature of that regulation that it no longer resembles or operates as an actual fuel standard.

2 EVs and Intensity Standards

A wide set of factors, including financial considerations and personal preferences, influence electric vehicle adoption. Yet government policies focus three margins of the consumer's decision. First and foremost, government policy targets the purchase price of the vehicle. Even with the reduction in battery prices over the past decade, EVs remain more costly to build and purchase than conventional vehicles. Second, government policy directly and indirectly influences vehicle operational costs, which also affects consumer purchase decisions.[1] Reflective of higher power-train efficiency, electric vehicles tend to be less costly to operate than conventional counterparts. But, fuel taxes and state regulation of electric utilities influence the magnitude of the potential savings. Operational cost savings offered by an EV vary from 15 - 30 percent in states with high electricity prices to over 70 percent in the Pacific Northwest (Muehlegger and Rapson (2023)). Lastly, policies aim to make electric vehicle ownership more convenient, targeting non-pecuniary obstacles to purchase, such as incentive or mandates to increase the density of the charging station network or policies that offer "conveniences" to EV drivers, from "HOV" lane access to reduced parking and registration fees.

Empirical research has attempted to measure the importance of each of these three margins. Early evidence indicates that purchase subsidies are an effective but costly way to increase demand for alternative-fuel vehicles. Evidence from hybrid cars show large effects,[2] but estimates of the response to EV subsidies are substantially lower.[3] Evidence also shows that consumers do incorporate future fuel costs in their car choices,[4] although Bushnell et al. (2022) find that the salience of gasoline price is much stronger than that of electricity price in making an EV purchase decision. Finally, a recent literature on charging infrastructure in the U.S. implies that investments in charging are more cost-effective at stimulating EV adoption than EV purchase

[1]Busse et al. (2013), Allcott and Wozny (2014), and Sallee et al. (2016) document that future gasoline costs are largely incorporated into purchase decisions, yet evidence from Bushnell et al. (2022) suggests that electricity prices influence EV purchases considerably less than commensurate changes in gasoline prices.

[2]Gallagher and Muehlegger (2011) and Chandra et al. (2010) estimate that a $1000 tax incentive (3-4 percent of the purchase price) was associated with 31 to 38 percent increase in hybrid vehicle adoption

[3]A 10 percent subsidy-induced decrease in EV purchase price leads to a roughly 10-35 percent increase in EV adoption in the U.S.Li et al. (2017), Li (2017), and Springel (2021)) estimate demand elasticities for early EV adopters in the range of 1-2. Clinton and Steinberg (2019) place the elasticity even higher, around 3.0. Muehlegger and Rapson (2022) focus on low- and middle-income EV demand. They find a 33 percent increase in demand from a 10 percent subsidy.

[4]Four recent papers find that consumers are willing to pay between $70 and $100 more for a car today if it saves them $100 in (present value of) future fuel expenses, where $100 is referred to as 'full valuation'. Busse et al. (2013) find full valuation in the new and used car markets in the U.S.; using different data and methodology, Sallee et al. (2016) find full valuation in the used car market; Grigolon et al. (2018) find nearly full valuation ($91) in the European new car market; and Allcott and Wozny (2014) estimate that car buyers are willing to pay $76 at purchase for $100 in future savings.

subsidies,[5] although in a survey of European countries with more and higher EV incentives and EV penetration than in the U.S. (Norway and the Netherlands), Baldursson et al. (2021) note that "infrastructure has tended to follow the development of EVs."[6]

A CFS is structured as an intensity standard designed to address the second of these margins by increasing the operational costs of driving a conventional vehicle relative to an electric (or alternative) vehicle. Conceptually, the objective of an intensity standard is to create a wedge between the cost to use dirty and clean inputs. Applied to pollution, an intensity standard sets a target emissions intensity within a particular segment (e.g., transportation fuels), ($\bar{X}$). Each firm's emissions intensity is benchmarked relative to this standard. Firms generating less emissions than the standard receive credits, while firms generating more pollution incur a compliance deficit, which must be met by purchasing credits from less polluting firms.[7] The number of firms in- and out-of-compliance determines the price at which the credits trade. Specifically, the equilibrium price of credits adjusts, so as to create a sufficient subsidy to balance supply and demand of compliance credits at the target intensity standard.

Ideally designed, an intensity standard offers two attractive features. First, the intensity standard, by construction, sets a binding emissions intensity that can be made more stringent over time. Furthermore, the tradability of compliance credits (assuming low transaction costs) ensures that compliance will occur in an efficient (i.e., least-cost) manner. Second, intensity standards are "technologically-neutral," only favor or disfavor a firm or technology based on measurable performance relative to the emissions standard. Formally, if a firm emits X units of pollution per unit of production relative to the target emissions intensity, $\bar{X}$, and the equilibrium price for credits is given by P_c, a firm faces an effective per-unit tax equal to $P_c * (X - \bar{X})$, representing the cost of the compliance credits they need to purchase for each unit of production. Where a firm's emissions intensity (X) exceeds the target ($\bar{X}$), the intensity standard acts as an implicit tax.

It is instructive to consider the advantages and disadvantages of clean fuel standards relative to two other policy approaches: (1) market-based approaches such as carbon taxes, and (2) direct subsidies of green goods. Relative to a carbon tax, an intensity standard creates a

[5]See Li (2017), Springel (2021), and Li et al. (2017)

[6]Empirically it is extremely challenging to determine the direction of causation. Does a neighborhood have lots of charging stations because it has lots of EVs, or was it the presence of the charging stations that induced high EVs demand in the first place? Unfortunately, the ideal empirical setting for answering this question has been elusive, see Muehlegger and Rapson (2023)

[7]Many "mandates", such as California's Zero Emission Vehicle (ZEV) mandate, are functionally equivalent to intensity standards. Tesla (and other companies) that sell a high proportion of ZEVs generate compliance credits which are then sold to companies out-of-compliance with the ZEV mandate.

similar wedge between the price of dirty and clean goods as does an emissions tax, if set at a similar level of stringency. This creates similar incentives for producers and consumers to shift away from dirty goods to clean goods. But notably (and in contrast to an emissions tax), an intensity standard does this by *taxing* heavily-polluting goods while *subsidizing* cleaner, but still polluting goods with pollution intensities below the standard. Thus, intensity standards impose smaller impacts on prices than an emissions tax, potentially reducing the political costs of implementation at the cost of reducing the degree to which consumers have an incentive reduce demand. Second, although tradability ensures that intensity standards can meet an emissions intensity threshold within the regulated segment in a least-cost manner, a *fuel* standard generally limits its focus to intensity of fuels, rather than travel in general. In this way a CFS ignores margins for CO2 reductions, such as improved vehicle efficiency and alternative modes of travel, that can be influenced by a more broadly applied carbon tax.

Relative to subsidies, fuel standards offer two potential advantages. First, an intensity standard does not compete for public funds like a pure subsidy, as the "taxes" paid by firms out-of-compliance fund the "subsidies" paid to compliant firms. Second, the "technological-neutrality" of fuel standards evaluates the merits of different goods or technologies solely on their performance relative to the emissions standard, whereas green subsidies require policy-makers to pick which technology to favor. Yet, the discretion offered by green subsidies can be attractive to policy-makers attempting to satisfy multiple objectives when setting EV policy. For instance, policymakers guided by environmental justice considerations may hope to target the benefits of policy towards disadvantaged socioeconomic groups or limit eligibility for high-income applicants. Real-world examples include means-testing of the Clean Vehicle Rebate Project and Clean Cars 4 All. One last feature of subsidies, that could be viewed as a strength or a vulnerability, is that they can be directed at almost any aspect of travel, from vehicle costs, to operational costs, to charging costs and infrastructure, without resorting to the kinds of programatic changes described below that are required to direct funds through a more technology neutral policy such as a CFS.

3 Clean Fuel Standards and EVs

In this section we review experiences with CFS programs, and their efforts to promote EVs. California first implemented its LCFS in 2011, and has a goal to reduce the carbon intensity (CI) of fuels by 20% by 2030, with an update to increase stringency to 30% by 2030 underway. The Federal Renewable Fuels Standard (RFS) was created in 2005 and expanded in 2007. While not strictly a CFS, the RFS targets both environmental and energy security goals, and uses fuel CI reduction as an eligibility requirement in its mandates of different "bins" of renewable fuels. Both Oregon and Washington have adopted a CFS in the last decade. Other jurisdictions with a CFS program include British Columbia, Canada, and Brazil. Several U.S. states have seen a CFS enter the policy discussion without yet having been adopted, including Colorado, New Mexico, New York, and Minnesota.

A CFS is built around a paradigm of reducing the carbon content of transportation fuels compared to reference fuels such as gasoline or diesel. As such, CFS programs as initially designed did not direct incentives beyond the fuel itself. This approach is not easily adapted to alternative fuels, such as electricity and hydrogen, that require new infrastructure and vehicles and are less easily comparable to petroleum fuel. California has expanded its LCFS extensively to support these alternative fuels and in this section we describe the methodology and implications of California's approach.

3.1 The California LCFS

The California Low Carbon Fuel Standard was initially implemented in 2011, amended in 2013, re-adopted in 2015, and extended in 2019 to set targets through 2030. The LCFS sets a CI standard percentage reduction from the petroleum-based reference fuel; the CI target decreases each year. Implementation involves classifying fuel volumes into pools defined by the reference fuel used or displaced (diesel, E10 gasoline, and, from 2019, jet fuel) and setting a nominal CI standard for each fuel pool.[8] The LCFS falls within a general regulatory framework known as intensity standards. It regulates the CI (e.g., gCO2e per megajoule) of transportation fuels, rather than the total amount of CO2 released through fuels.

As with all fuel standards, the LCFS implicitly subsidizes the sales of fuels that are "cleaner," that is, rated lower in CI, than the standard, and pays for the subsidy through charges imposed on fuel that is "dirtier" than the standard (CI rating above the standard). Sales of individual fuels rated at a CI below/above the standard generate credits/deficits in amounts proportionate to volumes on emissions relative to the standard. LCFS compliance requires all incurred deficits each year be met by credits generated by production of low-carbon fuels or purchased from others. LCFS credits can be banked without limit, allowing over-compliance under less stringent standards to help cover increased obligations as the standard grows more stringent, and they are fungible — meaning credits generated in any fuel pool are treated equivalently.

[8] Alternative jet fuel can count toward meeting the target, but petroleum jet fuel is not charged against it. Alternative jet thus provides a means for offsetting on-road petroleum use.

Policies like the LCFS are attractive to the policy community partly because the subsidies and charges can partially offset; this, plus the fact that the charge or subsidy falls only on emissions relative to the standard, dilutes the pass-through of the implied carbon cost to retail fuel prices. For example, in 2020 California LCFS credits were valued at a little under $200/ton of CO2e, while allowances under California's cap-and-trade program were valued at a little under $20/ton. Despite the LCFS carbon price being an order of magnitude larger than the price in the cap-and-trade program, the two charges had similar impacts on retail fuel prices for conventional gasoline (about 18 cents per gallon). Environmental economists note that this carbon cost dilution of the LCFS encourages more fuel consumption than would arise under alternative instruments such as a carbon tax set at similar stringency. [9]

EVs, as we shall see, have a lower CI score than the standard, which translates into revenue — the policy's implicit subsidy — when LCFS credits from EV charging are sold regulated parties holding deficits.

3.1.1 Carbon Intensity: The Foundational Metric

Calculating the carbon intensity (CI) score for each fuel, a foundational element of the LCFS, is complicated. The scoring includes GHG emissions from as much of the "lifecycle" of a fuel's production as possible, partly due to a feature of the biofuels widely used for compliance. Biofuel tailpipe GHG emissions do not differ much those of petroleum-based fuels; any GHG benefit from biofuel use requires considering carbon captured while growing feedstock crops.[10] Along with crop production, other aspects of the lifecycle ranging from emissions from feedstock and fuel transportation, to fuels burned in the refining process, to "indirect land use change" (ILUC) such as deforestation stimulated by higher demand for croplands, were also included.

Within an LCFS, CI scores must be able to be linked to an emissions metric (tons of CO2e) directly comparable across fuels. However, GHG impacts can vary with fuel/vehicle/condition combinations. A "low carbon" fuel in a fuel inefficient vehicle could still produce a relatively large amount of GHG. The LCFS uses assumptions about aspects of fuel use such as the average mileage (joules/mile) of vehicle types using a specific fuel, to formulate the comparisons.

[9] In an extreme case, the "cleaner" fuel subsidy could spur consumption growth to overwhelm the reduction in the fuel's CI and carbon emissions can increase. With conventional fuels, this extreme case is unlikely as it would require extremely price-elastic fuel demand. The overall point that, relative to other regulations, the LCFS can encourage consumption of fuels, remains.

[10] Carbon cap-and-trade programs, which often encompass a broader set of carbon emissions than transportation, usually treat biofuel emissions as zero-carbon, essentially assigning zero emissions to their production. A carbon tax or carbon cap system could use lifecycle accounting, but to date have not.

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For EVs, the subsidy effect is linked to how much conventional travel, and therefore fuel consumption, is assumed displaced by the induced EV vehicle miles travelled (eVMT). At one extreme, if EV subsidies induce eVMT from a household that previously relied exclusively on mass transit, the GHG savings are negative. At the other extreme, if every mile driven in an EV displaces a mile in an ICE vehicle, the GHG savings depend on the relative fuel carbon intensities and technology efficiencies. The LCFS framework adopts this latter approach, assuming that each eVMT offsets an amount of petroleum blend fuel used in a representative conventional vehicle to go one mile.

3.1.2 Setting Carbon Intensity Scores for EVs

For EVs, calculating LCFS credits produced through the electricity's sale and consumption for transport thus requires:

(i) the amount of electricity used for vehicle charging;

(ii) the CI score of the electricity used for vehicle charging;

(iii) the amount of electricity required to produce a unit of travel (e.g., eVMT) and the amount of carbon (gasoline) displaced by that eVMT.

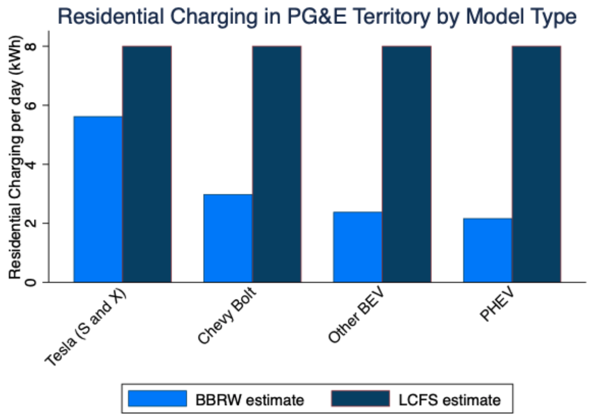
There is little direct measurement of any of these factors. In most cases the California Air Resources Board, the implementing agency, applies an administrative value based on analysis and assumptions. Below, assumptions for each factor and resulting values assigned for generating LCFS credits are briefly summarized.

i *Quantity of Electricity used for Charging*.

It may be surprising that the *amount* of electricity going into vehicles is usually not currently directly measured. Most households do not meter the electricity going into vehicles separately from that going toward other household uses. In recent LCFS figures, unmetered home charging accounted for roughly 85% of all passenger vehicle EV credits. Through 2022, home charging amounts were estimated based upon the observed charging of the small sample of households with separate EV charging meters; all other homes with EVs were assumed to

[11] The complexity of assessment process is reflected in CI scores awarded to biomethane, from such sources as animal-waste ponds at farms, that can otherwise emit methane directly to the atmosphere. Under the LCFS, if methane release is unregulated, biomethane capture is credited with emissions savings, alongside emissions from its production. A resulting biomethane CI score can be negative (e.g., consuming the fuel in a vehicle creates climate benefits). Moreover, because most natural gas-powered vehicles are assessed as *less* efficient than their conventional counterparts, and so "sequester" more carbon per mile, biomethane sellers also benefit from the inefficiency.

Figure 1: Comparison of Residential Charging Load Estimates



charge at the average level for the metered households within a same utility area (or a statewide average, when utility-specific data aren't available). There are strong reasons to believe that this is a highly biased sample of EV charging. Recent estimates from Burlig et al. (2021) indicate that actual home charging may be less than half as much as the values recently assigned to EV-owning households, at least for some utility areas (Figure 1).

Figure 1 highlights another shortcoming of the current estimation approach - it makes no accounting for the model or type of EV, including distinguishing between all-electric and plug-in hybrid vehicles, and assumes all vehicles charge equally. If the estimates above are correct and same gap applies in other utility regions, LCFS credits recently awarded for EV charging may be close to twice the amount warranted by actual EV usage.[12] If the share of unmetered charging used in the estimates decreases going forward, estimates would improve. The implication of the research cited above is that EVs are likely being driven far less, at least on home-charging and perhaps in total, than the LCFS assumes. In addition, some surveys of transportation usage (Davis (2019)) imply that the average EV is driven considerably fewer miles than the average conventional vehicle, and therefore displaces less conventional fuel than the regulation credits. If EVs are not being driven less, the finding raises the question of where they are being charged, if not at home. The LCFS as it has been structured appears to over-compensate for residential charging. If the LCFS assumptions about *total* charging are correct then credits for non-residential charging are massively under-represented. The Air Resources Board is planning to update the method used to estimate for statewide residential EV charging starting in

[12]The original regulation foresaw an unmetered residential EV charging credit phaseout; regulatory amendments removed that stipulation. The regulation also indicates use of the best available information to estimate unmetered charging. In late 2021, CARB started providing data on quarterly numbers of EVs and statewide charging averages per quarter used for LCFS crediting.

2023. The new method draws on a broader range of residential EV charging data already reported under the LCFS program (to earn credits for electricity "cleaner" – with a lower CI score – than the grid), and should improve the accuracy of the estimates.

ii *Carbon Intensity Score of the Electricity.*

The California ARB uses two types of values for electricity's CI score; a default and incremental value. As a default, the ARB uses an annually updated estimate of the average CI of all electricity consumed in California (82.92 gCO2e/MJ in 2020) to calculate electricity charging credits. Using the average overlooks that the marginal electricity associated with the charging may have a higher (or lower) carbon intensity than the average, and be more reflective of actual emissions associated with the event.

The ARB also allows entities to use a different electricity CI score that reflects actual or "booked" electricity associated with charging. An entity can claim incremental credits with an electricity CI value lower than the grid average (often zero) if book-and-claim accounting establishes a contract for electricity of the appropriate CI score to match vehicle electricity charging amounts.[13] Below grid-CI scores could reward timing of charging to match lower marginal emissions on the grid, but, because of the ease of book and claim, more likely lead to firms that sell power for vehicles, or — in the case where onboard telematics are used to measure charging — firms that sell vehicles themselves, to procure zero or other low carbon electricity.[14]

While the low-CI electricity initiative unlocked access to more EV credit value for firms in the EV supply chain, the logic applied to account for the carbon savings is questionable. For renewable electricity to be the marginal source of electricity in EV charging, said charging would have to occur simultaneously (and geographically co-located) with the curtailment of renewable energy sources due to "over-generation." Even in California, such curtailments are relatively minimal. Moreover, with the advent of booked low-CI electricity, the incentive to claim time-of-use more reflective of marginal emissions diminishes considerably.

iii *Electricity used and Gasoline displaced per travel mile*

The LCFS subsidizes the sale and usage of certain fuels justified by their displacing of "dirtier" fuel. As discussed above, in the LCFS each eVMT is assumed to displace a conventional ICE VMT, which necessitates assuming an efficiency for a representative EV relative to a rep-

[13]Contracted low-CI electricity must be generated within the California Balancing Authority or meet CPUC REC deliverability requirements (ARB 2019). In the case of zero-CI electricity, the source must be renewable, excluding biomass, biomethane, geothermal, and municipal solid waste.

[14]Recent amendments allow automakers, utilities, or other involved entities to earn credits on the increment of CI savings below the grid average for home charging.

resentative ICE vehicle. This value, called the *Energy Economy Ratio* (EER), is set at 3.4 for light-duty electric vehicles.[15] In other words, a joule of electricity used for transportation is assumed to be consumed in a vehicle that is 3.4 times as efficient (in joules/mile) as the ICE vehicle whose VMT is assumed displaced.

The EER, as a ratio, is dimensionless. In the calculation of LCFS credits, it is used alongside the common energy unit (converted from e.g., kWh of electricity, gallons of gasoline, mcf of methaneusing an administratively determined *Energy Density* (ED) of each type of fuel —- 3.6 megajoules per kWh for electricity. Combined with the CI score for the fuel, the EER and ED produce the following credit "obligation" formula for kWh (and other) sales (in grams of CO2e):

$$(\frac{\mathrm{CI}_{ev}}{EER_{ev}} - \mathrm{CI}_{standard}) x ED_{ev} x EER_{ev}$$

Since the CI score of electricity is below the standard, this "obligation" is negative, and the above formula reflects credits earned for each kWh estimated to go into an EV. With a zero CI classification, credits generated would equal the CI of the standard times the ED of electricity and the EER of 3.4. This was .00113 tons/kWh in 2021, and at the then-credit price of about $200/ton was valued at about 22 cents/kWh, above the electricity wholesale cost of roughly 5 cents/kWh and the California retail price of about 20 cents/kWh (Borenstein and Bushnell (2022)).

3.1.3 Infrastructure Credits

In 2018, the LCFS was amended to allow for credit generation from zero emission vehicle fueling infrastructure, namely hydrogen refueling stations for fuel cell vehicles and DC fast chargers for EVs put into public service in or after 2019. ZEV infrastructure crediting, crafted to respond to an Executive Order instructing ARB to recommend ways to use the LCFS to assist ZEV infrastructure build-out, was the first LCFS credit generation not directly tied to actual low carbon fuel use. EV fast charging and hydrogen infrastructure credits are each limited to 2.5% of deficit generation from the prior quarter, and are based on what would have been earned had unused charging capacity been in use. Infrastructure credits awarded at a facility decline as operating capacity - and LCFS credit generation for actual fuel flows – increases, and ARB sets a limit on potential credit generation per charger to try to stay within installation

[15] The detailed regulation is described in https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf

costs. Thus stations supporting little charging earn more infrastructure credits than those with high volumes. Applications for EV fast charging infrastructure credits are open until 2025.

3.1.4 Disposition of LCFS Credits for Electricity Sales

Who earns electricity credits and how the credit revenue is spent have evolved under the LCFS to reduce the chances for electricity use to go uncredited while expanding the list of who can earn electricity credits,[16] and adding additional restrictions to credit revenue use. Electricity, in part due to its regulated nature, is the only fuel with such restrictions.

Initially, electric service providers — utilities or providers of electric charging infrastructure — earned the credits absent explicit to credit transfer agreements. ARB imposed no restrictions on how LCFS EV credit revenue was used. This system resulted in a patchwork of programs statewide to spend LCFS EV credit value. Utilities regulated by the CPUC needed approval for expenditure programs. One utility, SDG&E, used EV revenue from 2017-2019 for an annual rebate to registered EV owners in its utility area. Others (PG&E and SCE) instituted post-purchase EV rebates.[17] More recent LCFS amendments created a framework to shift most EV credit revenue toward a single statewide point-of-purchase rebate program. Residential "base credits" — awarded for the gap between grid-average CI scores and the standard — provide the funding for the statewide point-of-purchase rebate program, called the *California Clean Fuel Reward*, via 67% of residential base credit revenue for investor-owned utilities and lower percentage contributions for others varying by utility size that edge up in 2023. The maximum rebate increases with EV battery size, and began in 2020 at $1500 per vehicle.[18]

Amendments in 2020 added an equity dimension to EV credit disposition. Starting in 2022, utilities must earmark a proportion of the remainder of the EV base credit value (called "hold-back credits") for use in projects that support transport electrification targeting disadvantaged or low-income communities, rural areas, and/or low-income individuals. The rest of the revenue from EV credits — including incremental credits earned for low-CI electricity used at residences (based on the gap between the grid-average CI and the charging electricity CI) [19] — is subject to the same spending restrictions as before.

[16]Electricity is an opt-in fuel in the LCFS, meaning it is not explicitly regulated because its CI score was deemed to meet last-year targets from the outset.

[17]For SDG&E, annual per vehicle rebates for EV owners were $200, $500, and $850 for 2017-2019, respectively. One-time post-purchase rebates for the others were $450 to $1000. In the case of SMUD, the EV owner could opt for a one-time $599 cash incentive or a Level 2 charger.

[18]https://ww2.arb.ca.gov/news/carb-and-california-electric-utilities-partner-offer-consumers-1500-electric-cars.

[19]Note non-residential low CI electricity credits do not have these categories.

3.2 Other CFS Programs and EVs

California's treatment of EVs in its LCFS has repercussions beyond the state. The U.S. EPA recently proposed a method under its RFS that would allow EVs using biogas as a source for the electricity to generate credits, held off its inclusion in its 2023 rulemaking, but indicated it would continue to explore EV credit generation can be implemented. The proposal would have made the RFS more LCFS-like by expanding the pool of credit generation fuels to electricity, setting a precedent to also include hydrogen sourced from biomass as an end-use fuel. Key distinctions between the two programs, such as the fact that the RFS has no incentive for incremental CI reduction and is limiting EV electricity sourcing to renewable biomass (excluding lower CI sources like wind and solar), will remain even if the EPA eventually implements a similar provision. With the exception of Brazil, jurisdictions with CFS programs look to EVs as a critical element that the program can support via credit revenue, and as key to setting ambitious fuel carbon intensity standard targets. Recent expanded and more stringent targets set in Oregon (37% CI reduction by 2035 from 2015 levels) and Washington (20% by 2034 and 2038 from 2018 levels) rely on robust EV rollout displacing petroleum fuels. Because of the low CI score associated with EVs, successful EV rollout makes more stringent targets more feasible. CFS programs in other jurisdictions have followed California's lead regarding some if not all EV-related provisions.

CFS jurisdictions outside California have used similar or identical energy economy ratios as California to account for efficiency of electric drivetrains, which have a big impact on credit generation. Oregon followed California's lead in allowing book-and-claim accounting for low- and zero-CI score electricity charging credits. Oregon also echoed California in allowing borrowing (advancing) of electricity credits, although not, as in California, to backstop the credit price ceiling. Instead, Oregon electricity credits can be advanced for entities to help finance the transition to EV fleets, with those credits paid back over time as the charging occurs. The CFS program in Washington state includes ZEV infrastructure capacity credits similar to those in use in California, by statute. Most jurisdictions also direct some portion of electricity revenue towards addressing environmental justice and equity concerns, as does California. In short, the portfolio of assumptions and provisions that California has applied to EVs has been taken up elsewhere, with some tailoring to specific jurisdiction circumstances, broadening the implications of findings of actions California takes with respect to EVs. In this vein, a recent study examined the extent to which an LCFS program might be maximally leveraged to support EV adoption, focusing especially on the role of ZEV infrastructure capacity credits (Kelly and Pavlenko (2020)).

4 Conclusion

The electrification of transportation constitutes a transition of immense scale. In this paper we have summarized and discussed the three channels that policies typically influence: vehicle cost, operating (or fuel) costs, and infrastructure support. To date, the most substantial policy support of EV adoption has been directed at vehicle costs through tax credits and a variety of other direct and indirect subsidies such as a ZEV mandate operating in several states.

The policy resources needed to expand the share EVs in line with goals to fully electrify may be enormous. The research described here estimates that a 10% decrease in the purchase price increases EV sales by 10% to 35%. Adoption can be accelerated by improving the value proposition to buyers, as has already occurred via a proliferation of models, longer driving range, and more charging stations. But governments consistently reveal a belief that substantial support for the industry remains necessary. Where will the funds for this support come from?

Broadly speaking there are two options: from general tax funds or from the petroleum based transportation sector. Subsidies and tax-credits drawn from general public funds could continue to fund both infrastructure investment and vehicle purchases. A gasoline or carbon tax can provide support in one or two ways. Such a tax (or carbon price) would make conventional vehicles more expensive relative to EVs by raising their costs. If the funds raised through the tax are further directed to EV subsidies it can further influence adoption. While carbon taxes have been rare, at least in the U.S., the indirect taxation of petroleum fuels via clean fuel standards has been more common.

In many ways, the differences between an emissions tax and a fuel standard are differences of optics and priorities. With a carbon tax, the main point is to set a price on carbon and let firms and consumers decide how to change their behavior in response. The funds raised is a secondary effect. With a CFS the point is to explicitly mandate lower carbon or renewable fuels, and the mechanism that achieves the mandate is an implicit tax on higher carbon sources that in turn funds the lower-carbon technologies. The differences between "taxes" and "standards" is therefore sometimes overblown. Fundamentally both act as taxes - either implicitly or explicitly - on dirty inputs. The main difference is that a standard pre-commits the funds collected via the tax to a set of offsetting green inputs.

What both approaches do share are elements of technology neutrality. The value of technology neutrality is largest when there is large uncertainty about the ultimate identity and mix of fuels and technological solutions that can best achieve policy goals. Such policies reward compliance based upon estimates of how much carbon savings they provide, rather than by how they provide it.

This paper has focused on the potential for a CFS to significantly boost EV adoption. There is a paradox inherent in relying upon a technology-neutral standard as a prominent source of funds for advancing a specific technology, EVs. For a CFS to direct sufficient revenues to channels that promote substantial EV adoption, it needs to changed in such a fundamental way as to no longer be a technology-neutral, or a purely fuel-based standard.

One potentially important factor through which a CFS could provide support is through the price of electricity itself. Somewhat ironically, high electricity prices are a both barrier that a CFS in its "pure" form would be well positioned to address and the one aspect of electrification that has not benefited from California's LCFS to date. While research on California has indicated that electricity prices have less salience than gasoline prices for purchasers of EVs, this may be short-lived. The price of electricity does have an impact and there is reason to believe that EV drivers will become aware of it over time.

The importance of electricity prices could also be larger outside of California, for two reasons. First, electricity prices are considerably less complex in most US states than in California; and, second, *if* the assumptions supporting the credit values of electricity in California are taken at face value, the carbon savings from using electricity in an EV should be enough to offset the complete cost of electricity. A zero-cost fuel could have considerable salience in promoting the attractiveness of EVs. Therefore one role for a CFS that has been largely untapped may be to deploy it in the way it was originally designed, as means for subsidizing the price of low-carbon fuel.

California's LCFS has taken a different path by both awarding credits for activities other than selling low-carbon fuels (such as installing charging stations) and by directing revenues from electricity sales toward vehicle rebates, rather than lowering the electricity price paid for charging vehicles. By contrast, the program contains no analogous incentives for biofuels infrastructure, such as the installation of e85 pumps. The resources directed to light duty EVs amounted to just under 20% of the roughly $3.3 billion in credit value generated in 2022 by California's LCFS, under a series of extremely generous administrative rules and assumptions that favor EVs. In so doing, policymakers have begun setting the policy on a path different from the science-based, technology-neutral fuel standard it was originally positioned to be.

For supporters of EVs, this transformation of the CFS may be considered a feature rather than a bug. California leadership has decided upon EVs as the policy priority and is working to steer its existing climate policies toward that goal. The complicated and subtle ways in which the LCFS now raises funds and directs them may in the end make it a more durable and acceptable policy tool than one that works in a more explicit and transparent fashion. In the process, however, it will reduce (in expectation) the rewards for innovation in other solutions. This, in turn, may constrain the set of viable technologies to support transportation decarbonization in the future, both in the light duty sector and beyond.

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