

Assessing the potential for low-carbon fuel standards as a mode of electric vehicle support

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Keywords: Zero-emission vehicles; regulatory design; Low-carbon fuels; California Low-Carbon Fuel Standard

Introduction

Transportation emissions now comprise the largest source of U.S. greenhouse gas (GHG) emissions, with nearly 20% of total emissions coming from the light-duty vehicle fleet alone.¹ Electric vehicles (EVs) offer significant GHG savings relative to conventional, internal combustion engine (ICE) vehicles, but as of 2019 only comprise 0.6% of the U.S. light-duty fleet.² On the federal level, EV adoption has been encouraged through federal tax credits and broader emissions standards for cars. However, several jurisdictions in North America are going further by regulating transportation fuel carbon intensity, which can be a method of incentivizing electric vehicle charging, through the implementation of low-carbon fuel standards (LCFS).

Governments have adopted low-carbon fuel regulations, which set targets for transport fuel GHG emissions, across Canada, Europe, and the United States to help meet goals for climate change mitigation. In North America, the policies have largely been adopted at the state and provincial level. The Renewable Fuels Standard (RFS) in the United States aims to accomplish similar goals, but it has thus far been limited by its exclusion of some alternative fuels, notably electricity and hydrogen produced from non-biogenic sources such as wind and solar. Furthermore, the RFS has struggled to drive innovation and investment in the advanced biofuels that offer the greatest carbon reductions. Due in part to these failings, a national-level U.S. low-carbon fuel regulation has been considered by academic institutions such as Institute for Transportation Studies at

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1 U.S. EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018," (August 2020), <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018>

2 Energy Information Administration, "Annual Energy Outlook 2020," (2020), <https://www.eia.gov/outlooks/aeo/data/browser/#/?id=22-AEO2020&cases=ref2020&sourcekey=0>

Acknowledgements: Thanks to Nic Lutsey and Michael Nicholas of the ICCT, Jeremy Martin of the Union of Concerned Scientists, Julie Witcover of the UC Davis Institute of Transportation Studies and Simon Mui of the Natural Resources Defense Council for helpful reviews.

the University of California, Davis,³ and proposed by the U.S. House Select Committee on the Climate Crisis.⁴ Key questions regarding LCFS programs include the balance of compliance pathways used to meet the program targets and the associated costs of compliance. As electrification is increasingly used to meet LCFS targets, further research is necessary to understand the economic proposition for EV drivers and EV infrastructure providers, as well as what policy design features most effectively accelerate electrification.

An LCFS program can provide a long-term, durable funding source for EV infrastructure and EV purchasing incentives as other policies such as rebates expire or are phased-down. Low-carbon fuel standards utilize a technology-neutral structure to establish a declining sector-wide carbon intensity (CI) target for fuels, measured in grams of carbon dioxide equivalents per megajoule of fuel (gCO₂e/MJ), expressing the total GHG impact per unit of energy delivered. Fuel providers are required to reduce their overall carbon intensity relative to the standard, or by purchasing credits from other companies representing fuels sold that are below the carbon intensity standard. Electricity, which benefits from both low carbon emissions and high-efficiency EV powertrains, is one of the lowest-emitting sources of transportation energy within LCFS programs.

This study evaluates LCFS policies, with a specific focus on California, to assess the role that a national LCFS program can play in accelerating the rate of light-duty passenger EV deployment. We first present an overview of EV inclusion in different LCFS policies in North America and identify California-specific structures by which electricity is supported as a transport fuel. We then evaluate the credit generation and carbon savings from using electricity for transport within the California LCFS and a prospective national LCFS context to estimate the potential revenue generation that could be used to support EV uptake through rebates over the next 5 years. Next, we assess the overall cost of carbon abatement from EVs compared to other transport decarbonization options within a LCFS. Lastly, we assess the cost-effectiveness of charging infrastructure investments as an LCFS compliance strategy for obligated parties.

Background on electricity crediting in LCFS programs

Several jurisdictions in North America have introduced LCFS programs. California's LCFS has a 20% CI reduction in transportation fuels by 2030 relative to 2010.⁵ Oregon's Clean Fuels Program (CFP) targets the emissions intensity reduction of its transport fuels mix by 10% below 2015 levels by 2025, 20% by 2030, and 25% by 2035.⁶ British Columbia set a target of 20% below 2010 levels for liquid fuels by 2030.⁷ In addition, several other U.S. states and regions are developing or considering their own fuels emissions

3 Julia Witcover, "Status Review of California's LCFS, 2011-2018 Q1," (Research Report - UCD-ITS-RR-18-25, Institute for Transportation Studies, University of California, Davis, 2018), <https://its.ucdavis.edu/research/californias-low-carbon-fuel-standard/>

4 House Select Committee on the Climate Crisis, "Solving the Climate Crisis: The Congressional Action Plan for a Clean Energy Economy and a Healthy, Resilient, and Just America," (2020), <https://climatecrisis.house.gov/sites/climatecrisis.house.gov/files/Climate%20Crisis%20Action%20Plan.pdf>

5 Low Carbon Fuel Standard Regulation, California Air Resources Board, 17 CCR, January 4, 2019, https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf

6 Executive Order, Office of the Governor of Oregon, No. 20-04, March 10, 2020, https://www.oregon.gov/gov/Documents/executive_orders/eo_20-04.pdf

7 Government of British Columbia, BC-LCFS Requirements, August 2020, <https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/renewable-low-carbon-fuels/fuel-supplier-compliance-50005>

standards, including in the Midwestern U.S., Washington, Colorado, and New York.⁸ Canada has proposed a similar policy, the Clean Fuel Standard, intended to decarbonize its overall fuel mix, including transport fuels.⁹ The European Union's Fuel Quality Directive has set a 6% greenhouse gas reduction for all energy used in transport in 2020 relative to 2010 that each member state must transpose into law.¹⁰ Brazil's RenovaBio policy set a 10% carbon intensity reduction target for the entire transport fuel mix for 2028 relative to 2017.¹¹

While transportation fuel policies have primarily driven transitions within liquid fuel markets, they are now impacting the use of electricity for transportation. Obligated parties such as fuel importers and refiners generate deficits, measured in metric tonnes of carbon dioxide equivalents (MTCO₂e), for fuel sold with a CI above the standard within each fuel class, i.e. gasoline or diesel. Those deficits must be covered through the generation or purchase of credits, valued in terms of \$/MTCO₂e, which are created predominantly through the utilization of alternative fuels with a CI lower than the standard. The market value of these credits fluctuates based on demand but have an imposed price cap to control the marginal compliance costs. In California, the cap was set at \$200/ MTCO₂e in 2016 and is adjusted annually for inflation according to the Consumer Price Index.¹² Each fuel type, feedstock, and emission-reduction technology combination is assigned a CI, so that the value of a given alternative fuel or technology within the policy is proportional to its GHG reductions compared to the standard fuel it replaces. Credit generators may submit applications to verify a lower CI rating for unique pathways that would result in greater potential GHG reductions.

Electric vehicles offer some of the greatest potential carbon reductions for light-duty vehicles due to existing electricity decarbonization policies in conjunction with high vehicle efficiency. The carbon savings from electricity are estimated according to the life-cycle emissions from grid-average electricity generation, which differs across jurisdiction from 19.73 gCO₂e/MJ in British Columbia, to 82.92 gCO₂e/MJ in California, and 107.92 gCO₂e/MJ in Oregon¹³ for 2020. Complementary electricity decarbonization policies in each jurisdiction include ambitious renewable energy targets that further reduce the carbon intensity of electricity over time, thereby increasing the credit generating potential from electricity. In addition, EVs benefit from a more efficient power train than internal combustion engines, which leads to a greater quantity of energy displaced relative to liquid fuels. Low-carbon fuel policies account for this disparity between energy supplied to drivetrains with different efficiencies through

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- 8 Godwin, Jordan, "Groups Exploring Potential Midwest LCFS Collaborative," (*Governors' Biofuel Coalition*, February 15, 2019), <https://www.governorsbiofuelscoalition.org/groups-exploring-potential-midwest-lcfs-collaborative/>; Puget Sound Air Agency, "Considering a Regional Clean Fuel Standard," Puget Sound Air Agency, (April 6, 2020), <https://pscleanair.gov/528/Clean-Fuel-Standard>; Erin Voegele, "Colorado to evaluate feasibility of an LCFS program," *Biomass Magazine*, September 12, 2019, <http://biomassmagazine.com/articles/16462/colorado-to-evaluate-feasibility-of-an-lcfs-program>; Low Carbon Fuel Standard, New York Senate, S4003A, February 25, 2019, <https://www.nysenate.gov/legislation/bills/2019/s4003/amendment/a>
- 9 Environment and Climate Change Canada, "Clean Fuel Standard: Proposed Regulatory Approach," (2019), <https://www.canada.ca/en/environment-climate-change/services/managing-pollution/energy-production/fuel-regulations/clean-fuel-standard/regulatory-approach.html>
- 10 European Commission, Fuel Quality, (April 23, 2009), https://ec.europa.eu/clima/policies/transport/fuel_en
- 11 Nikita Pavlenko & Carmen Arujo, *Opportunities and risks for continued biofuel expansion in Brazil*, (ICCT: Washington, DC, 2019), https://theicct.org/sites/default/files/publications/ICCT_Brazil_lowcarbon_fuel_opp_20190726.pdf
- 12 California Air Resources Board, "LCFS Credit Clearance Market," accessed October 16, 2020, <https://ww2.arb.ca.gov/resources/documents/lcfs-credit-clearance-market>
- 13 Renewable and Low Carbon Fuel Requirements Regulation, British Columbia, Reg. 394/2008, July 13, 2020, http://www.bclaws.ca/civix/document/id/complete/statreg/394_2008; Low Carbon Fuel Standard Regulation, California Air Resources Board, 17 CCR, January 4, 2019; Fuel Pathways - Carbon Intensity Values (Current list of carbon intensity values updated May 15, 2020), <https://www.oregon.gov/deq/aa/programs/Pages/Clean-Fuel-Pathways.aspx>

an energy-economy ratio (EER), which reflects the difference in distance travelled between an EV and a conventional vehicle per unit of energy supplied. The EER used for electricity supplied to light-duty vehicles is 3.4 in British Columbia, California, and Oregon.¹⁴ Compared with the 2020 gasoline CI in each jurisdiction, EV charging offers carbon reductions of from 67 to 92%. The deep carbon reductions from electric vehicle charging, in addition to increases EV market share, have contributed to their rising share of total credit generation to 18% and 8% for California and Oregon, respectively, in 2019 representing avoided emissions of 2.7 million tonnes CO₂e in California and over 100,000 tonnes CO₂e in Oregon.¹⁵

Figure 1 summarizes the credit generation opportunities in the LCFS from electricity pathways and across multiple sub-sectors. California's LCFS allows for electricity credits to be generated from both residential and non-residential electric vehicle charging. For residential charging, both "base" and "incremental" credits can be generated. The base credits, which can only be generated by electric utilities, are assessed according to the difference between the carbon intensity standard and grid-average electricity (accounting for the EER). Residential charging can be tracked directly via charger metering and through non-metered crediting, wherein a service area estimate is based on average charging behavior and the number of EV's registered. Electric utilities that generate these base credits are required to reinvest a minimum percentage of their revenue from base credits into the Clean Fuel Reward Program that funds a statewide point-of-sale rebate for electric vehicles, as further described and discussed below. Starting in 2022, half of the remaining base credits, called "holdback" credits, must be used to support broader transportation electrification projects in rural and disadvantaged communities.¹⁶ Incremental credits incentivize the use of low-CI electricity and can be generated by other entities, including load-serving entities, original equipment manufacturers (i.e., automakers using vehicle telemetry to measure charging), and others. The value of incremental credits is assessed based on the difference between the CI of the electricity and the grid average; Low-CI electricity pathways include zero-CI electricity from renewable sources such as solar and wind electricity, non-zero CI electricity from sources such as renewable natural gas, or the Smart Charging electricity pathway.¹⁷

14 Renewable and Low Carbon Fuel Requirements Regulation. British Columbia, Reg. 394/2008, July 13, 2020, http://www.bclaws.ca/civix/document/id/complete/statreg/394_2008; Low Carbon Fuel Standard Regulation, California Air Resources Board, 17 CCR, July 1, 2020, https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf; Final Report – Oregon Low Carbon Fuel Standard, Oregon Department of Environmental, January 25, 2011, <https://www.oregon.gov/deq/FilterDocs/CFPFinalReport.pdf>

15 California Air Resources Board, "Low Carbon Fuel Standard Data Dashboard," (July 31, 2020), <https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm>; Data for the Clean Fuels Program (Electric Vehicles in Oregon, December 2019), <https://www.oregon.gov/deq/air/programs/Pages/Clean-Fuels-Data.aspx>

16 California Air Resources Board, "LCFS Electricity and Hydrogen Provisions," accessed August 2020, <https://ww2.arb.ca.gov/resources/documents/lcfs-electricity-and-hydrogen-provisions>

17 The Smart Charging pathway allows entities to generate LCFS credits based on the difference between the supplied electricity's CI and the grid average, based on the hour of electricity it was supplied. This encourages charging during less carbon-intensive times of day, e.g. overnight.

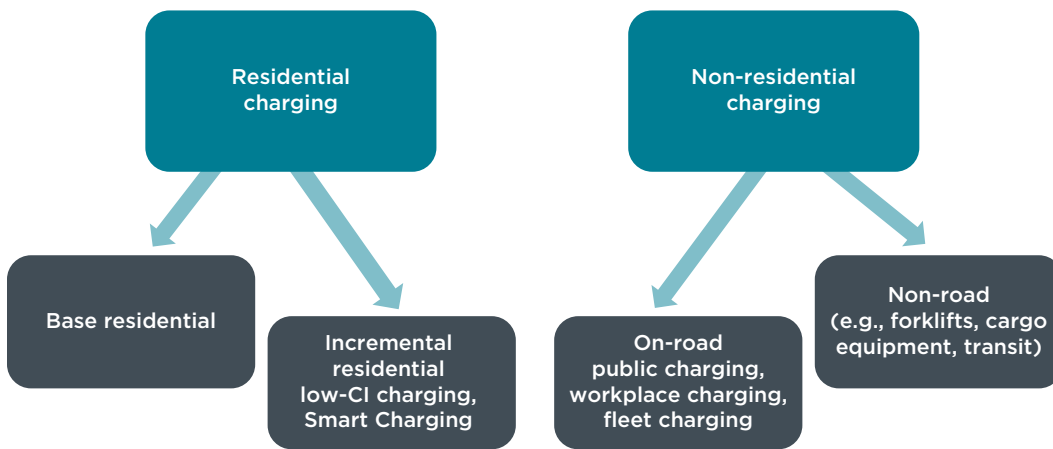


Figure 1. Summary of credit generation options for dispensing electricity to transport in the California LCFS. Adapted from “LCFS Electricity and Hydrogen Provisions,” California Air Resources Board, accessed August 2020, <https://ww2.arb.ca.gov/resources/documents/lcfs-electricity-and-hydrogen-provisions>.

In addition to residential charging, LCFS credits can be generated from non-residential EV charging, including public and private fleet charging. As with residential charging, non-residential charging can also generate incremental credits for the use of low or zero-CI electricity. Load-serving entities and automakers have the first opportunity to claim incremental credits; if they aren’t claimed, then charging network operators are eligible to claim them. Non-residential charging also includes electricity dispensed to vehicle fleets such as those used by local governments or private companies with a dedicated charger, which can include heavy-duty vehicles. Additionally, non-road equipment, including electrified forklifts, cargo equipment, public transit, and shore-side marine vessel power can all generate LCFS credits, though these vehicles have different EERs than those established for light-duty vehicles.¹⁸ While the use of electricity to charge heavy-duty vehicles and non-road vehicles is important for overall transport decarbonization, here we focus on the opportunities from residential charging and public charging for light-duty passenger vehicles.

California’s LCFS was amended in 2018 to expand the credit generation opportunities for electricity by including zero-emission vehicle (ZEV) infrastructure crediting, also known as capacity credits, to support deployment of direct current (DC) fast charging infrastructure.¹⁹ These projects can generate infrastructure credits based on their potential capacity in addition to their dispensed electricity. The updated regulation limits the scope of this provision to only publicly accessible DC fast chargers built or expanded after 2019 and will not accept additional applications once potential credits from this pathway exceed an allowed threshold. Infrastructure capacity credit generation is based on the total available capacity at a given site, estimated in kilowatt hours per day (kWh/day), minus the quantity of electricity dispensed, measured in kilowatt hours (kWh); therefore, heavily-trafficked DC fast chargers with high utilization, measured in kWh dispensed, will receive fewer infrastructure credits from this pathway than those with low utilization. Capacity credits help to improve the immediate financial prospects for charging sites with low or uncertain utilization; however, this pathway

¹⁸ California Air Resources Board, “LCFS Electricity and Hydrogen Provisions,” accessed August 2020, <https://ww2.arb.ca.gov/resources/documents/lcfs-electricity-and-hydrogen-provisions>.

¹⁹ California Air Resources Board, “LCFS ZEV Infrastructure Crediting,” (August 21, 2020), <https://ww2.arb.ca.gov/resources/documents/lcfs-zev-infrastructure-crediting>.

avoids creating a perverse incentive as the value of credit generation from the marginal unit of dispensed electricity will always exceed that from capacity credits. As of 2020 California has over 1,000 DC fast charging stations of which 484 chargers at 55 stations generate infrastructure credits.²⁰ The infrastructure pathway is intended to accelerate the deployment of DC fast charging infrastructure in the next five years, it will no longer accept applications credits after 2025. However, credit generation will continue until approved sites exhaust their 5 years of capacity credit generation. Therefore, applications approved in 2025 can generate LCFS credits through 2029.

It is difficult to assess the contribution of LCFS credits to the uptake of EVs in these jurisdictions; however, we note that jurisdictions with LCFS programs in place contain several of the metropolitan areas with the highest EV deployment in North America. Annual EV registrations grew from 2,565 to 32,253 through 2019 in Oregon since 2013 from 62,217 in 2015 to 145,864 through 2019 in California; and from 2,017 in 2011 to 14,100 through August of 2020 in British Columbia.²¹ A growing EV market share is not solely attributable to LCFS credit values; in many cases, EV uptake is driven by a mix of vehicle regulations, incentives, and growing charging infrastructure.²² The incentives in particular draw from various revenue streams, are allocated through different mechanisms, and do not necessarily adapt as EV uptake increases. These policies also have different qualifying customers and vehicles, and their varying expiration dates can impact their long-term influence on EV deployment. The uncertainty surrounding the medium and long-term availability of the current patchwork of regional electric vehicle incentives can be mitigated through the durable support offered through a potential National LCFS program.

Methodology

This study evaluates the cost-effectiveness of electrification and the revenue generation potential from EVs and chargers within a LCFS framework. Credit generation is estimated on a per-EV level, as well as the aggregate revenue to be made available for point-of-sale rebates in California and nationwide. This analysis combines a total cost of ownership (TCO) approach for battery electric vehicles (BEV) with estimates of per-BEV charging infrastructure deployment costs to estimate the levelized cost of BEV deployment. We assess the levelized cost of a BEV with a 250-mile range (BEV-250) and its estimated carbon savings over a five-year period relative to a comparable ICE vehicle to estimate the cost of carbon reductions from electrification. We utilize a five-year TCO in order to present a conservative comparison of the near-term costs and emissions savings from transitioning to EVs from conventional, ICE vehicles; however, we note that operating costs and emissions savings can continue long beyond five years. Finally, we compare the levelized cost of credit generation via the installation of charging infrastructure with the cost of blending biofuels to assess their relative costs as a method of LCFS compliance.

20 Alternative Fuels Data Center, Electric Vehicle Charging Station Locations, accessed August 3rd, 2020, https://afdc.energy.gov/fuels/electricity_locations.html#/analyze?fuel=ELEC&country=US®ion=US-CA; LCFS; California Air Resources Board, "ZEV Infrastructure Crediting," (August 21, 2020), <https://ww2.arb.ca.gov/resources/documents/lcfs-zev-infrastructure-crediting>

21 Data for the Clean Fuels Program (Electric Vehicles in Oregon, December 2019), <https://www.oregon.gov/deq/air/programs/Pages/Clean-Fuels-Data.aspx>; California New Car Dealers Association, "California Auto Outlook," (February 2020), <https://www.cncda.org/wp-content/uploads/Cal-Covering-4Q-19.pdf>; Table 20-10-0021-01 (New motor vehicle registrations, August 26, 2020), <https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2010002101>

22 Anh Bui, Peter Slowik, and Nic Lutsey. *Update on electric vehicle adoption across U.S. cities*, (ICCT: Washington, DC, 2020) <https://theicct.org/sites/default/files/publications/EV-cities-update-aug2020.pdf>

Electric vehicle credit generation and rebate value potential

The net carbon reductions from electricity supplied to transportation varies according to the CI of the generation resources on the electrical grid, the efficiency of BEVs, and the CI of liquid fuel that the electricity displaces. To estimate electricity emissions, we utilize EIA's 2020 forecasts²³ of the electricity generation mix in conjunction with emission factors for electricity generation from the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model developed by Argonne National Laboratory²⁴ to project electricity grid carbon composition from 2020 onward for both California and the U.S. The EIA forecast incorporates state-level renewable energy targets, such as California's 33% of retail sales by 2020 and 60% of retail sales by 2030, in their state and national-level forecast. The U.S. grid average CI for each year reflects the weighted average emissions, based on generation mix, from the total net generation of the electrical grid. California's grid average CI reflects the emissions from in-state generation resources as well as emissions from international and interregional electricity imports. The composition of California's imported electricity is not projected in EIA's forecast, so we use the U.S. average grid CI as a proxy for the imported share of electricity.

We compare the emissions from electricity to the regulatory value established by the California Air Resources Board as the standard for California reformulated gasoline blendstock for oxygenate blending to estimate carbon savings. To estimate future LCFS credit generation, we compare the electricity CI to the CI for gasoline within the LCFS. Figure 2 illustrates our estimated change in CI for grid electricity over time compared to the CI for gasoline and the declining CI target. We adjust the CI for electricity using the EER of 3.4 for light-duty vehicles. From 2020 to 2030, we estimate that California's EER-adjusted grid average CI declines from 24.4 gCO₂e/MJ to 17.3 gCO₂e/MJ, while the U.S. EER-adjusted grid average declines from 31.2 gCO₂e/MJ to 26.4 gCO₂e/MJ.

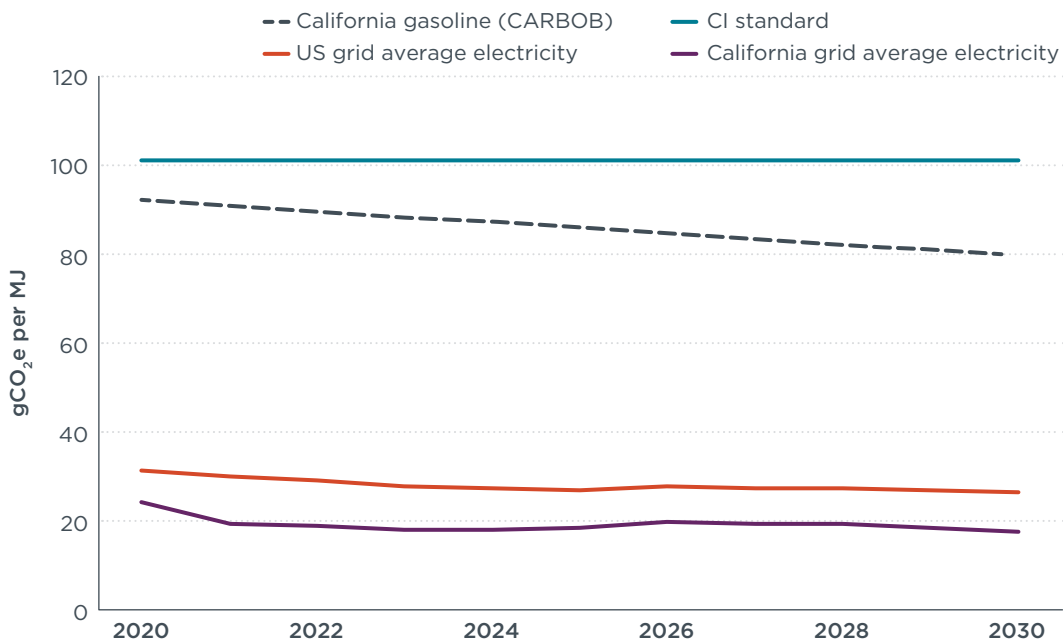


Figure 2: EER-adjusted life-cycle emissions for U.S. grid average and California grid electricity relative to gasoline and California LCFS target over time.

²³ Energy Information Administration, "Annual Energy Outlook 2020," (2020), <https://www.eia.gov/outlooks/aeo/data/browser/#/?id=22-AEO2020&cases=ref2020&sourcekey=0>

²⁴ Argonne National Laboratory, The Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model, (October 4, 2019), <https://greet.es.anl.gov/>

While the majority of EV charging comes from unmetered residential charging, various submetering programs are being introduced to better track charging activity and incentivize vehicle owners to utilize time-of-use charging rates.²⁵ We estimate the credit generation from electric vehicles for each year of operation using Equation 1 below.²⁶ First, the EER- adjusted carbon intensity from electricity ($CI_{\text{electricity}}$) is subtracted from the carbon intensity standard for a given year (CI_{standard}). The emissions savings are then multiplied by a vehicle's electricity consumption in a given year (E_i) and the EER, and then converted into tonnes of CO₂e. The E_i is based on the annual vehicle miles travelled (VMT) of that vehicle and its efficiency for that model year. The total credits are cumulative over five years of operation.

$$\text{Credits (tonnes)} = \left(CI_{\text{standard}} - \left(\frac{CI_{\text{electricity}}}{EER} \right) \right) \times (E_i \times EER) \times \left(1 \times 10^{-6} \frac{\text{tonnes CO}_2\text{e}}{\text{grams CO}_2\text{e}} \right)$$

Equation 1: Calculation for credit generation for BEV Charging

Base credit reinvestment requirements

California's LCFS stipulates that a minimum portion of the net value of LCFS credits generated from residential EV charging starting in 2019 is directed into the Clean Fuel Reward Program, a statewide point-of-purchase rebate fund for EVs. The proportion of revenue from LCFS credits that electric distribution utilities must contribute depends on whether they are investor-owned or publicly-owned, and on the volume of electricity they sell annually. Table 1 summarizes the minimum share of base credits, or net base credit revenues, that must be contributed by each electric utility participating in the LCFS. Large investor-owned utilities must use the highest quantity of their base credit revenue for the Clean Fuel Rewards program, at 67%, whereas publicly-owned and smaller utilities have lower obligations that increase after 2022. We also assume that 10% of utilities' base credit contribution for the Clean Fuel Reward Program is earmarked for program administration, in accordance with LCFS regulatory guidance.

Table 1: The minimum percent contribution of base credits or net base credit revenues from each participating utility into the Clean Fuel Rewards Program.

Electric distribution utility category	Clean Fuel Reward contribution in years 2019 through 2022	Clean Fuel Reward contribution in years 2023 and beyond
Large investor-owned utility	67%	67%
Large publicly-owned utility	35%	45%
Medium investor-owned and publicly-owned utilities	20%	25%
Small investor-owned and publicly-owned utilities	0%	2%

We utilize California's Clean Vehicle Rebate program registration data through 2020 to estimate the distribution of EV's in each utility category.²⁷ Overall, approximately 80% of California EVs that received a Clean Vehicle Rebate are serviced by large

25 Mike Nicholas, *Ensuring driving on electricity is cheaper than driving on gasoline*, (ICCT: Washington, DC, 2018), https://theicct.org/sites/default/files/publications/Driving-on-electricity-versus-gasoline_ICCT-Briefing_26022018_vF.pdf

26 Low Carbon Fuel Standard Regulation, California Air Resources Board, 17 CCR, July 1, 2020, https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf

27 Clean Vehicle Rebate Statistics, (August 6, 2020), <https://cleanvehiclerebate.org/eng/rebate-statistics>

investor-owned utilities, the category with the highest Clean Fuel Reward Program reinvestment requirement. Approximately 12% of recipients are serviced by large publicly-owned utilities, while a smaller percentage of recipients are serviced by medium or small publicly-owned utilities. We assume that these registration trends stay constant through 2030, adjusting the proportion of the Clean Fuel Reward Program reinvestment requirements after 2022 per LCFS guidelines. Additional assumptions on vehicle efficiency, vehicle miles travelled, and charging behavior match those outlined in the total cost of operation methodology below.

To assess the quantity of vehicles generating credits and the subset of new sales for rebates annually, we utilize a business-as-usual scenario of EV sales for California. Annual EV sales, including both BEVs and plug-in hybrid vehicles (PHEVs), are projected to grow from around 198,000 in 2020 to over 365,000 in 2025.²⁸ Beyond 2020, we assume the California EV fleet grows based on annual sales, and then allocate the annual Clean Fuel Reward Program funding by the quantity of BEVs and PHEVs sold, adjusting the PHEV credit generation and rebate value for an assumed average PHEV battery size of 8 kWh. This EV sales projection does not reflect federal or state policy changes which could either increase or decrease the rate of EV deployment. For example, the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule, if upheld, could constrain the rate of EV deployment. In contrast, political changes at the federal level or expanded state and local initiatives could accelerate the pace of EV deployment in California.

To assess the potential EV rebates available for a hypothetical National LCFS, we utilize several different assumptions from the California example. First, we assume that the carbon savings from EV charging will be assessed based on the U.S. average electricity grid emissions relative to California's existing carbon intensity standard, as shown in Figure 2. While California uses reinvestment requirements for utilities to calculate the share of LCFS credit revenue suitable for a point-of-sale rebate, a national program may not necessarily take the same approach. We first estimate the total aggregate revenue from residential charging and then assume a 50% spending requirement for rebates. Based on EIA data, we estimate that 72% of customers are served by investor-owned utilities and approximately 16% served by publicly-owned utilities.²⁹ We assume that credits are generated by an EV fleet of BEVs and PHEVs consistent with national sales projections of approximately 860,000 PHEVs and BEVs sold annually in 2025.³⁰

Total cost of operation of an electric vehicle vs. internal combustion engine vehicle

The five-year TCO of vehicles in this analysis includes upfront purchase costs, ongoing maintenance costs, fueling costs, and charging infrastructure. We compare the five-year TCO of a BEV-250 to a comparable ICE vehicle, estimating the net difference in costs between the two vehicles. Table 2 displays our assumptions for vehicle cost components, efficiency, and VMT for model years 2020 and 2030. We utilize a recent review³¹ of BEV component costs that incorporates battery pack price data and forecasts through

28 Michael Nicholas, Dale Hall, and Nic Lutsey, *Quantifying the Electric Vehicle Charging Infrastructure Gap Across U.S. Markets*, (ICCT: Washington, DC, 2019), https://theicct.org/sites/default/files/publications/US_charging_Gap_20190124.pdf

29 Energy Information Administration, "Investor-owned utilities served 72% of U.S. electricity customers in 2017," (2019), <https://www.eia.gov/todayinenergy/detail.php?id=40913#>

30 Michael Nicholas, Dale Hall, and Nic Lutsey, *Quantifying the Electric Vehicle Charging Infrastructure Gap Across U.S. Markets*.

31 Nic Lutsey and Michael Nicholas, *Update on electric vehicle costs in the United States through 2030*, (ICCT: Washington, DC, 2019) https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

2030.³² Based on that analysis, we utilize a declining BEV-250 purchase price through 2030 as the cost of batteries falls to \$104/kWh in 2025 and \$72/kWh in 2030. We assume an annual cost increase of 1.5% for ICE vehicles to reflect the compliance costs of meeting increasing fuel efficiency standards. We apply a 7.5% sales tax to the price of both ICE and BEV-250 vehicles. To present the five-year TCO without the impact of any complementary policies, we do not include any outside incentives such as tax credits or point-of-purchase rebates.

Table 2: Assumptions for total cost of operation calculations for BEV-250 and ICE

	BEV-250		ICE	
Model year	2020	2030	2020	2030
Purchase cost	\$31,483	\$23,320	\$19,190	\$21,308
Efficiency	0.30 kWh/mi	0.28 kWh/mi	30.7 gal/mi	37.4 gal/mi
Average annual vehicle miles traveled	14,586 miles			
Maintenance cost	\$0.026/mi	\$0.026/mi	\$0.061/mi	\$0.061/mi

Vehicle efficiency is assumed to start at 0.3 kWh/mile for BEVs and at 0.03 gallons/mile for ICE vehicles in 2020.³³ Both efficiencies are projected to increase over time while charger efficiency, separate from vehicle efficiency estimates and not included in Table 2, is estimated to remain at 88% based on U.S. EPA findings and reported charger efficiency from different models.³⁴ For each vehicle, we assume annual VMT of approximately 14,586 miles annually over the five year period. While the electronic components of EV drivetrains are currently more expensive, they contain fewer parts than conventional power trains, notably in the gearbox, engine, and transmission, and experienced less brake wear-and-tear due to regenerative braking. Based off a UBS analysis, we utilize maintenance cost assumptions of \$0.061 per mile and \$0.026 per mile for conventional vehicles and BEVs, respectively.³⁵

To evaluate the cost of fueling as part of the TCO, we use California retail motor gasoline and electricity rate price forecasts from EIA, as summarized in Table 3 below. For home charging and public level 2 charging, we assume EIA’s residential and commercial electricity prices. For DC fast charging, per-kWh charging costs on the market include commercial energy costs, infrastructure costs, associated grid fees and operating costs; we exclude the infrastructure costs to avoid double-counting, as we include this cost separately in the TCO. We estimate that the per-kWh cost for a fast charger with 20% utilization includes the per-kWh commercial electricity cost estimated by EIA, in addition to demand charge fees and non-energy operating expenses that begin at \$0.20 per kWh in 2020 and decline to \$0.10 per kWh by 2030. Together, this adds up to a higher DC fast charging cost of \$0.37 per kWh in 2020 for California. A review of

32 Bloomberg New Energy Finance, “Battery Pack Prices Fall as Market Ramps Up with Market Average At \$156/kWh in 2019,” (December 2019) <https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/>.

33 Nikita Pavlenko, Peter Slowik, and Nic Lutsey, *When does electrifying shared mobility make economic sense?* (ICCT: Washington, DC, 2019), https://theicct.org/sites/default/files/publications/Electric_shared_mobility_20190114.pdf.

34 U.S. Department of Energy, “Where the Energy Goes: Electric Cars,” accessed December 3, 2020, <https://www.fueleconomy.gov/feg/atv-ev.shtml>.

35 UBS, “UBS Evidence Lab Electric Car Teardown –Disruption Ahead?” (Q-Series, May 2017), <https://neo.ubs.com/shared/d1wkuDIebYPJF/>.

current literature suggests that home charging accounts for 80% of charging,³⁶ with the remaining non-residential charging split between 15% Level 2 public or workplace charging stations and the remaining 5% from DC fast charging.³⁷

Table 3: Assumptions for energy costs for TCO analysis

	2020	2030
California residential electricity	\$0.20/kWh	\$0.23/kWh
California commercial electricity	\$0.17/kWh	\$0.19/kWh
DC fast charging electricity	\$0.37/kWh	\$0.29/kWh
Gasoline	\$2.99/gal	\$3.76/gal
Charging Infrastructure	\$1,445/BEV	\$1,174/BEV

In addition to the cost of electricity supplied to EVs, we include the cost of charger hardware, planning, and installation for both home and non-home charging, based on a ICCT projection of charging infrastructure needs in U.S. metro areas.³⁸ In that study, home charger costs vary by housing type, and include the costs of upgrading an outlet to service a Level 1 and Level 2 charger. For public chargers, estimates of hardware and installation costs for Level 1, Level 2, and DC fast chargers, are informed by their power rating, measured in kW, of each station and the number of chargers per site. A 3% annual hardware cost reduction was applied across all charger types. The total infrastructure costs in that study are then divided by EV sale forecasts for the average cost of home, public, and DC chargers on a per-BEV and per-PHEV basis annually. We use that study's 2020 estimate of \$1,445 per BEV for charging infrastructure costs, which declines to \$1,174 by 2025. There is some evidence that per-BEV infrastructure costs may increase beyond 2025, due to the most economical public charging locations having already been established by 2025; on the other hand, there may also be countervailing trends of continued hardware and installation cost decreases. Therefore, we keep infrastructure costs fixed after 2025.

Charging infrastructure levelized costs and credit generation potential

We evaluate the infrastructure credit generation and cost-effectiveness of operating a public charging station as an LCFS compliance pathway for both Level 2 public chargers and DC fast chargers, based on varying assumptions regarding charging speed and charger utilization. We estimate the credit generation per charger based on the California carbon intensity standard for gasoline (CI_{standard}), the carbon intensity of electricity ($CI_{\text{electricity}}$), and the EER for light-duty electric vehicles. The quantity of credits is then estimated based on the carbon reductions achieved relative to the LCFS carbon intensity targets and the electricity supplied per charger (E_c), as shown for electric vehicles in Equation 1 above.

Table 4 summarizes our assumptions for charging infrastructure crediting in this analysis. We assume that public chargers will consist of Level 2 chargers with a power of approximately 6.6 kW and DC fast chargers with a power of 50 kW or 150 kW. There are

36 Idaho National Laboratory, "What Were the Driving and Charging Behaviors of High Mileage Accumulators?" (2015)

37 Electric Power Research Institute, "Consumer Guide to Electric Vehicle Charging," (October 2019), <https://www.firstenergycorp.com/content/dam/customer/get-help/files/PEV/guide-to-ev-charging.pdf>

38 Michael Nicholas, *Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas*, (ICCT: Washington, DC, 2019), https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf

approximately 6,000 public Level 2 chargers and over 1,000 DC fast charging stations in California.³⁹ While the majority of DC fast chargers have approximately 50 kW of power, higher transfer speeds may be more common by mid-decade.⁴⁰ We assume charger costs based off California prices, and including labor, materials, permitting, and taxes, developed from a previous ICCT analysis.⁴¹ While we utilize costs for single chargers in this analysis, we note that installation costs per charger can decrease significantly for sites with multiple chargers due to economies of scale. For example, the per-charger installation cost decreases by approximately 30% and 60% for Level 2 and DC fast chargers when there are 6 or more chargers per site.⁴² We also estimate the cost of operating sites with two chargers per site to assess the efficacy of multi-charger sites.

Table 4: Charging infrastructure power and capacity assumptions

	Level 2 charger	DC fast charger	DC fast charger
Nameplate power	6.6 kW AC	50 kW DC	150 kW DC
Utilization	1, 2, 4 or 6 hours per day		
Total daily charging capacity, for infrastructure capacity credits	N/A	250 kWh/day	410 kWh/day
Accessibility	24 hours per day		
Charger efficiency	88%		
Non-energy operating costs	\$1000 per year	\$2,500 per year	\$2,500 per year
Demand charges	N/A	\$7,200 per year	\$21,600 per year
Installation cost for single charger and two chargers per site	\$4,148 (\$3,039)	\$45,506 (\$36,235)	\$47,781 (\$38,047)
Revenue	\$0.20 per kWh	\$0.37 per kWh	\$0.37 per kWh

Note: N/A = Not Applicable

To assess the cost of operating charging infrastructure as a LCFS compliance pathway, we incorporate several assumptions on charging infrastructure operating costs and revenue. For both DC fast chargers, we assume a \$12 per kW demand charge scaled to the nameplate capacity of the charger and applied monthly, whereas we assume the peak power from the Level 2 charger is insufficient to warrant additional demand charges. We note that demand charges may change substantially in future years as utilities seek to accommodate greater numbers of charging infrastructure on the grid, and our \$12 per kW assumption may be conservative. Already, Pacific Gas & Electric (PG&E) has introduced commercial EV rates for fleet operators (e.g., trucks and buses) that are approximately 30% cheaper than previous rates; as this practice becomes more widespread and accessible to passenger vehicles, we anticipate that fast charging costs will decline further.⁴³

39 Electric Vehicle Charging Station Locations (accessed August 3rd, 2020), https://afdc.energy.gov/fuels/electricity_locations.html#/analyze?fuel=ELEC&country=US®ion=US-CA

40 Dale Hall and Nic Lutsey, *Electric vehicle charging guide for cities*, (ICCT: Washington, DC, 2020), https://theicct.org/sites/default/files/publications/EV_charging_guide_02262020.pdf

41 Michael Nicholas, *Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas*.

42 Ibid.

43 Miles Muller, "Reforming Rates for Electric Trucks, Buses & Fast Chargers (blog post)," Natural Resources Defense Council, May 4, 2020, <https://www.nrdc.org/experts/miles-muller/reforming-rates-electric-trucks-buses-fast-chargers>

The non-energy operating costs for charging infrastructure can be significant, as high as 50% of total operating costs for some charging locations.⁴⁴ We assume annual maintenance costs of \$200 and \$500 per charger for Level 2 and DC fast chargers, respectively. Maintenance costs are assumed to be 20% of non-energy operating costs, and the remaining operating costs are then scaled up based on the assumed maintenance costs. Per-kWh retail income for each location is based on a review of fees and charges of publicly-accessible Level 2 and DC fast chargers in California available via Chargepoint.⁴⁵

The cost-effectiveness of charging infrastructure is highly contingent on charger utilization; therefore, we present results for average daily utilization of 1, 2, 4, and 6 hours. However, utilization of public chargers is highly uncertain. An analysis of EvGo DC fast charger activity data by Fitzgerald and Nelder in 2017 notes variation in charging activity based on site, with durations for individual charging sessions ranging from 18 to 22 minutes.⁴⁶ While present-day utilization of both Level 2 and DC fast chargers is low, it is projected to increase concurrently with an expansion in BEV fleet size.⁴⁷

Total capacity for the DC fast chargers ($Capacity_{FCI}$), estimated in kWh per day, is assumed to be proportional to the nameplate power of the chargers (P_{FCI}), consistent with the fast charger infrastructure LCFS reporting template. This calculation understates the total potential capacity of the chargers and is designed for crediting purposes, based on the principle that installation costs are not linearly proportional to nameplate power (kW).

$$Capacity_{FCI} = 43 \times (P_{FCI})^{0.45}$$

Equation 2: Calculation of DC fast charger capacity as a function of charger nameplate power

To calculate the annual infrastructure credits available from a DC fast charging station, we utilize the guidance from California Air Resources Board for credit generation from capacity expansion, which differs from that for fuel pathways. We estimate infrastructure credits using Equation 3 for charger capacity based on the daily capacity estimated via Equation 2 ($Capacity_{FCI}$) in conjunction with the carbon intensity target for the year ($CI_{standard}$), the carbon intensity of the supplied electricity ($CI_{electricity}$), and the EER. This value is adjusted based on the annual utilization of the charger (UT) and the actual quantity of electricity dispensed ($Elec_{disp}$); while this pathway is intended to be calculated quarterly, we estimate annual potential credit generation. The quantity of credits awarded during a period is proportional to the utilization of the charging infrastructure—as utilization increases, the quantity of infrastructure credits declines.

44 “The Costs of EV Fast Charging Infrastructure and Economic Benefits to Rapid Scale-Up” (EVGo blog, May 18, 2020), <https://www.evgo.com/about/news/the-costs-of-ev-fast-charging-infrastructure-and-economic-benefits-to-rapid-scale-up/>.

45 Charging Map, accessed August 30, 2020, https://na.chargepoint.com/charge_point

46 Garrett Fitzgerald and Chris Nelder, “EvGo Fleet and Tariff Analysis,” (Rocky Mountain Institute: Boulder, Colorado, 2017), https://rmi.org/wp-content/uploads/2017/04/eLab_EVgo_Fleet_and_Tariff_Analysis_2017.pdf

47 Michael Nicholas, *Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas*

Credits (tonnes)

$$= (CI_{standard} \times EER - CI_{electricity}) \times 3.6 \frac{MJ}{kWh} \times (Capacity_{FCI} \times UT_{annual} - Elec_{Dispensed}) \times \left(1 \times 10^{-6} \frac{\text{tonnes } CO_2e}{\text{grams } CO_2e} \right)$$

Equation 3: Calculation for capacity credit generation for DC fast charging infrastructure

Biofuel blending costs

To compare the levelized cost of deploying EV chargers to other compliance pathways within the LCFS, we assess the cost of carbon abatement from two types of biofuels currently used to generate credits within California. We assess corn ethanol, which displaces gasoline, and used cooking oil (UCO) renewable diesel, which displace diesel. While electricity primarily displaces gasoline, we include UCO renewable diesel as a comparison point because of its recent rapid expansion in California due to LCFS incentives and lack of blending constraints, thus being the fuel used as the marginal unit of compliance for the program. We estimate these fuels' prices by taking a five-year average of rack prices of corn ethanol collected by USDA Economic Research Service.⁴⁸ For renewable diesel, which is a more recent technology without widely-available commodity price data, we use a modeled production cost estimate for used UCO renewable diesel production.⁴⁹

To provide a consistent basis for comparison between technologies with different energy densities, we estimate the cost of carbon reductions on an energy basis relative to the 2020 CI standard for gasoline and diesel. We assess the range of CI for each feedstock, as estimated by California Air Resources Board from certified fuels within the LCFS.⁵⁰ We then compare the per-unit energy costs of these biofuels with a five-year average of wholesale gasoline and diesel prices in California, deriving the cost of supplying carbon reductions, and by extension generating LCFS credits, from each fuel.⁵¹ Table 5 summarizes the range of levelized cost of abatement for blending each biofuel. It is important to note that corn ethanol faces blending constraints of approximately 10%. Therefore, at higher CI target levels there is a much stronger incentive to blend fuels like UCO-derived renewable diesel, which offer high carbon reductions and pose no blending constraints—thus, in recent years the LCFS credit price has increased to match the cost of the marginal fuel for LCFS compliance.⁵² We assume that UCO renewable diesel is the marginal fuel for LCFS compliance and thus use its cost for the upper end of the range of possible LCFS biofuel blending compliance costs, for a range of \$66 to \$262 per tonne of CO₂e. These costs do not reflect other policies such as the RFS or blending tax credits on the private cost of supplying biofuels.

48 US Bioenergy Statistics, (Prices, July 21, 2020), <https://www.ers.usda.gov/data-products/us-bioenergy-statistics/us-bioenergy-statistics/#Prices>

49 Nikita Pavlenko, Stephanie Searle, and Adam Christensen, *The Cost of Supporting Alternative Jet Fuels in the European Union*, (ICCT: Washington, DC, 2019), https://theicct.org/sites/default/files/publications/Alternative_jet_fuels_cost_EU_2020_06_v3.pdf

50 California Air Resources Board, "Low Carbon Fuel Standard Data Dashboard," July 31, 2020, <https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm>

51 Refiner Petroleum Product Prices by Sales Type (Energy Information Administration, September 1, 2020), https://www.eia.gov/dnav/pet/PET_PRI_REFOTH_DCUI_NUS_M.htm

52 Steve Hanson and Neil Agarwal, "Renewable diesel is increasingly used to meet California's Low Carbon Fuel Standard," (U.S. Energy Information Administration, November 13, 2018), <https://www.eia.gov/todayinenergy/detail.php?id=37472>

Table 5: Biofuel blending levelized cost of compliance ranges reflecting 2015-2019 price data.

Biofuel Type	Price (\$/gallon)	Carbon intensity	Emissions reduction cost
UCO renewable diesel	\$3.89/gal	8.6-28.4 gCO ₂ e/MJ	\$204 to \$262/tonne
Corn ethanol	\$1.39/gal	53.5-85.6 gCO ₂ e/MJ	\$66 to \$398/tonne

Results

Estimating the value of a LCFS for EV deployment

We use California's LCFS as a case study to estimate how its greater revenue generation could translate into incentives to accelerate the deployment of EVs. Figure 3 displays the average annual residential charging revenue and rebate value an average BEV owner in California could create from 2021 to 2025. Taking into account the lower CI of California's electricity grid compared the U.S. grid average, we estimate that a typical BEV would save approximately 2.9 tonnes of CO₂e emissions relative to the gasoline CI standard from annual home charging. Additional incremental credits could also be generated through Smart Charging or charging from Zero-CI electricity, but these would not go towards point-of-sale rebates. We estimate the average incremental carbon savings from a BEV charging at home with Zero-CI electricity to be approximately 1.1 tonnes; resulting in an additional \$200 worth of credits annually to be spent on promoting vehicle electrification.

To estimate the aggregate revenue for Clean Fuel Rewards point of sale rebates, we assume that total revenues for rebates are based on a weighted average of vehicle usage within utility territories based on CVRP survey data and the reinvestment requirements for utilities shown in Table 1. Based on sales projections and estimated carbon savings from 2021 to 2025, we estimate that residential EV charging on average could generate sufficient credit revenue to support rebates of around \$1,400 for new BEVs. These rebates would apply to new vehicle purchases and do not include additional incentives that could be supported through LCFS funding, such as utility rebate programs for customers. The average rebate for PHEVs is based on vehicle model and would range from \$500 to \$1,400 depending on battery capacity. Figure 3 illustrates the synergy between incentivizing future BEV owners based on current EV usage, showing the per-BEV revenue generation for base credits used for rebates, and the holdback and incremental credits used for more general transport electrification. Given that there are more EVs on the road than annual sales, the per-BEV rebate is higher than the annual credit generation from individual cars. The growth of the EV fleet will lead to higher base credit generation and thus higher average EV point-of-sale rebates for new cars. Furthermore, California allows for combining rebates across programs, allowing prospective BEV purchasers to combine California's existing Clean Vehicle Rebate Projects' \$2,000 rebate, or an increased rebate of \$4,500 for qualifying low or moderate-income consumers, with the Clean Fuel Rewards rebate, resulting in nearly doubling the total rebate with \$3,400 off the purchase cost.⁵³

⁵³ Center for Sustainable Energy, "How often do the CVRP requirements change?" (April 14, 2020), <https://cleanvehiclerebate.org/eng/faqs/how-often-do-cvrp-program-requirements-change-0>

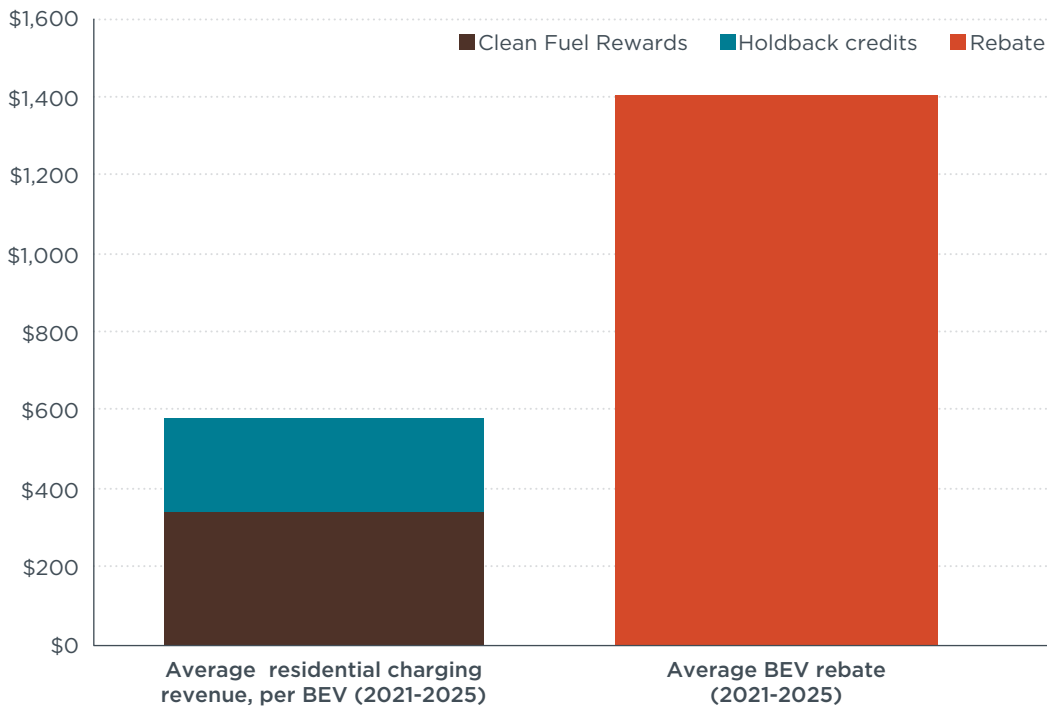


Figure 3: Average residential charging revenue and rebate value for BEVs in California from 2021-2025.

We next estimate the potential per-BEV credit generation for a hypothetical national LCFS for residential charging, assuming the same carbon intensity target but higher grid electricity emissions. Under these conditions, we estimate that the average BEV would generate approximately 2.5 tonnes of carbon reductions annually from residential charging, with the decrease in reductions due to the higher electricity grid carbon intensity. From 2021 to 2025, we estimate that residential charging would generate approximately \$550 million in 2021, increasing to \$1.1 billion by 2025. If utilities had similar reinvestment requirements as in California (i.e., approximately 60% of total residential credits), that would generate sufficient revenue to award an average per-BEV point-of-sale rebate of nearly \$1,200 over that time span. In this estimate, the per-BEV credit generation is lower than in the California case due to higher national average grid electricity emissions; therefore, the per-sale rebate values would be lower than those in California. A national-level program could opt for utilities to spend residential charging credit revenue differently, however. Alternative options include programs to build out charging infrastructure or investment in other electrification projects. As the grid continues to decarbonize and the EV fleet grows, a sustained, virtuous cycle emerges which increases aggregate revenue generation to sustain growing rebate demand.

In practice, the credit generation from residential charging may be even higher. Incremental credits from renewable electricity-derived charging or smart charging could provide additional credits for EV charging. We estimate that for 100% renewable-powered residential charging, an additional 1.1 tonnes of carbon reductions, equivalent to approximately \$200, could be generated annually from a BEV. Load-serving entities providing low-CI electricity for EV charging would be obligated to support further electrification of the sector from which they were generated. In this case, an electricity utility or community choice aggregator supplying renewable

electricity could use the revenue to incentivize additional metered charging or by lowering prices for its charging customers.⁵⁴

Electric vehicle levelized cost of compliance

Based on the TCO analysis and estimates of five-year carbon savings and credit generation per BEV-250, we estimate the levelized cost of compliance for BEV deployment within California’s LCFS and a national LCFS. Figure 4 illustrates the cost per tonne of LCFS credits from a BEV-250 each year from 2020 through 2030 for both California and the U.S. For each year, the line illustrates the five-year cost divided by the credited carbon reductions for five years of driving. California, which has a lower grid carbon intensity, has a steeper decline than the U.S. at first, but the costs converge as the grid intensity of the U.S. grid declines and the cost of electricity in California increases. We estimate that by the end of the decade, BEVs will become one of the cheapest sources of carbon reductions within both a national LCFS and California’s program, approaching \$0 per tonne of carbon reductions as they achieve cost-parity with conventional ICE vehicles. This compares favorably with the current credit price in California’s LCFS, which has approached its cost containment cap of \$200 per tonne and will likely remain there in the near future as the stringency of the CI target increases.

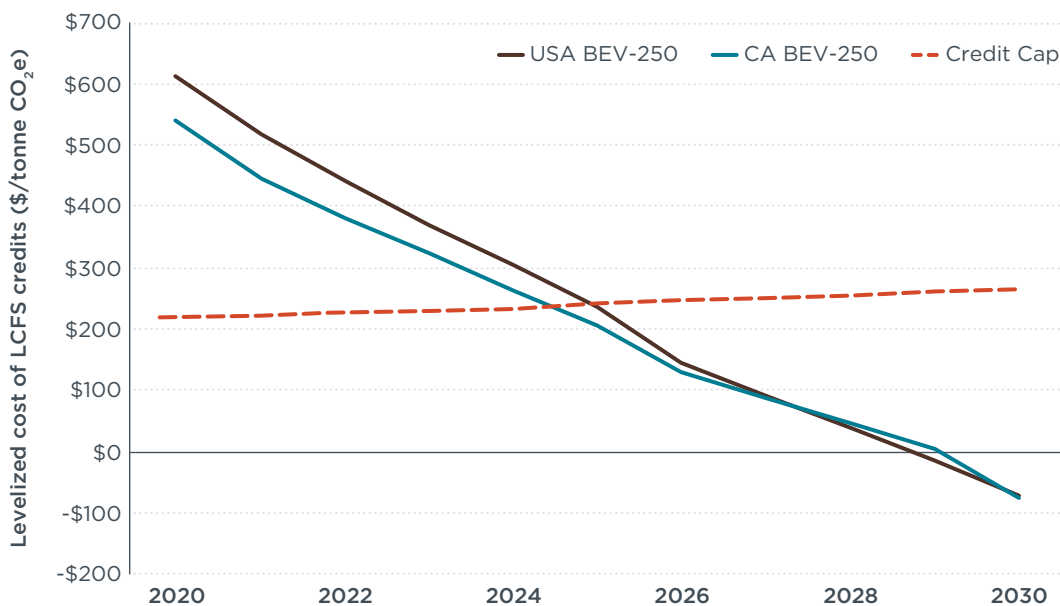


Figure 4: Levelized cost of carbon reductions for a BEV-250 deployed in California and the United States.

The results of this assessment suggest that by the end of the decade, electrification will become the most cost-effective transport fuel for decarbonization. While we do not assess the second-order effects of electrification on LCFS credit markets, this suggests that the growing share of EV charging within a LCFS can crowd out more expensive sources of carbon reductions. The primary drivers of the levelized-cost decrease for BEV deployment are the decline in battery costs projected through 2030, followed by the projected increase in fueling savings for BEV drivers as the cost difference between electricity and gasoline increases over time. We note that while

⁵⁴ California Air Resources Board, “Electricity Credit Proceeds Spending Requirements,” (March 2020), https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/guidance/lcfsguidance_20-03_ADA.pdf

the levelized cost of compliance from a BEV-250 become much cheaper by 2028, these costs are not borne by oil refiners or obligated parties to the LCFS, but rather, primarily by consumers and charging infrastructure providers. Therefore, while EVs are the most cost-effective mode of generating LCFS credits, their effectiveness may not be accurately valued by obligated parties who purchase compliance credits from utilities at market rates.

Cost-effectiveness of LCFS compliance via charging infrastructure

Here we assess the cost effectiveness of constructing new charging infrastructure as a mode of LCFS compliance, estimating the total costs relative to the five-year LCFS credit generation from three different levels of chargers. Figure 5 illustrates the levelized cost of carbon reductions from a Level 2, 50 kW DC fast charger, and 150 kW fast charger installed in 2020, with four different utilization rates. We compare the costs to the range of biofuel blending costs in the shaded green area, which range from \$54 per tonne to \$238 per tonne. Generally, as the utilization of a given charger increases, its cost-effectiveness increases rapidly—for example, at only 4 hours of utilization daily, all three types of chargers are well below the current California LCFS credit price of \$190 to \$200 per tonne and cost-competitive with first-generation biofuels.

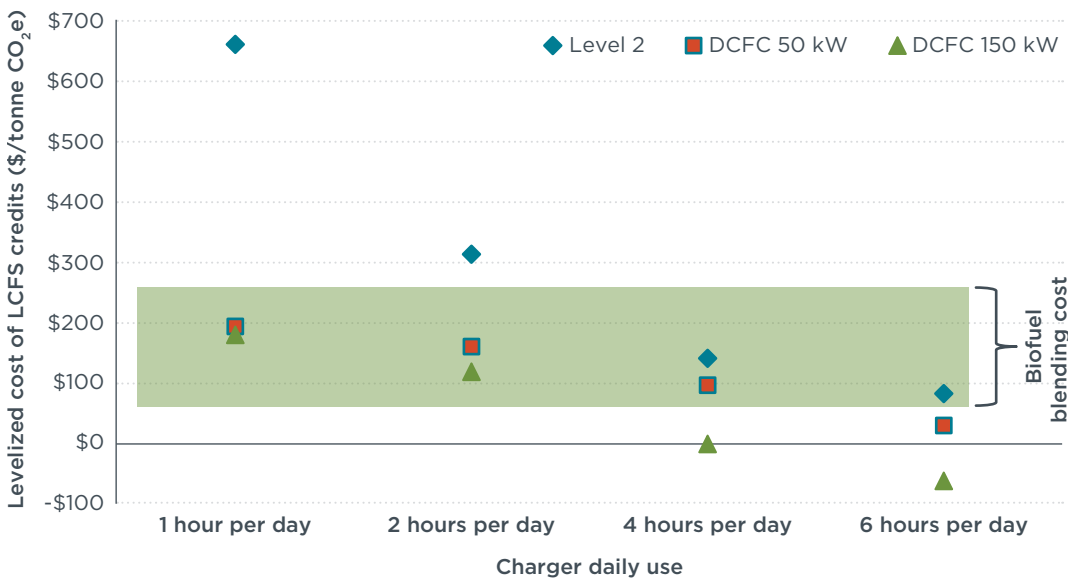


Figure 5: Cost of LCFS credits from charging infrastructure installed in 2020 across multiple utilization rates relative to the cost of blending biofuel.

We find that at beyond 2 hours of daily use, Level 2 chargers become cost-competitive relative to present-day LCFS credit prices and become substantially cheaper as they approach 8 hours of charging per day. While there is substantial variability in the actual kWh of charging necessary to fill up a parked car, this suggests workplace chargers with more than 4 hours of daily charging could provide substantial credit generation at a low upfront capital cost. However, with under 2 hours of daily use, Level 2 chargers were the most expensive charger per tonne of carbon reductions, due to the low quantity of electricity dispensed relative to their capital costs.

The cost analysis of fast charger installations also indicated several interesting trends. Due to the contribution of fast charging infrastructure credits, which are granted at low levels of utilization, the cost of generating credits from these chargers was within

the range of present-day LCFS credit prices. At just 2 hours of utilization per day, both the 50 kW and 150 kW chargers become cost-effective compared with biofuels. At 2 hours of charging per day, infrastructure credits would provide between 35% and 65% of total credit generation per charger for the 50 kW and 150 kW chargers, respectively. At 4 hours and beyond, however, the bulk of credit generation from fast charging is generated by the electricity dispensed, as the fast-charging infrastructure credits begin to phase out at higher utilization rates. As utilization increases beyond 2 hours per day, the infrastructure credit contribution steadily decreases to zero; we estimate that at 6 hours per day of charging, all LCFS credit generation would come from supplying electricity. At higher utilization levels, we find that the revenue from fast charging (at \$0.37 per kWh) pays for the bulk of the infrastructure and operating costs, greatly reducing the cost of credit generation from fast charging. This suggests that in the near-future, fast charger infrastructure construction could become a very cost-effective means of generating LCFS credits in regions with some certainty of at least 2 hours of daily usage. As the volume of EVs on the road increases and charger utilization increases in turn, fast chargers will become attractive sources of LCFS credits even as the infrastructure capacity credit application phases out after 2025.

Economies of scale also greatly increase the cost-effectiveness of charging infrastructure. At sites with multiple charging points, the fixed cost of installation per charger decreases substantially but the credit generation opportunities remain proportional to the total capacity and electricity supplied. Figure 6 illustrates the cost of carbon reductions from charging infrastructure with two chargers per site across multiple utilization rates. In this scenario, we illustrate that increasing the charging points per site to two and by reducing the capital costs by 20%, the cost of carbon reductions from each charger type declines in turn. Installing multiple chargers per site can reduce the cost of generating carbon reductions for charging infrastructure substantially. At lower utilization rates, the per-tonne cost declines by approximately 15% and decreases further as utilization increases. For sites with a sufficient userbase to justify more than five chargers, we estimate that fast charging will be cheaper than blending biofuels with only two hours of utilization per day due to economies of scale.

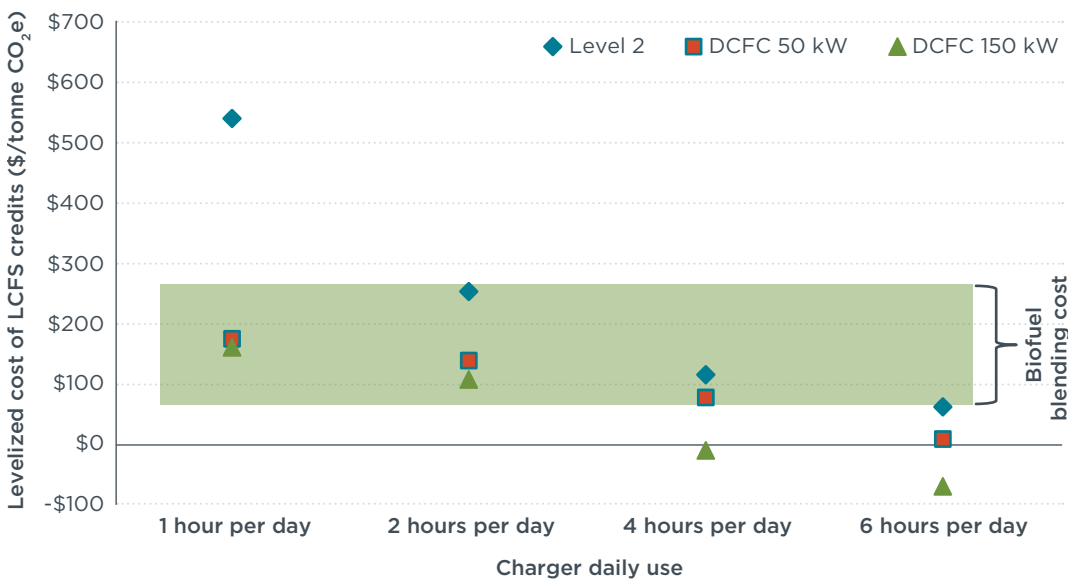


Figure 6: Cost of LCFS credits from charging infrastructure across multiple utilization rates relative to the cost of blending biofuel, for sites with 2 chargers.

Conclusion

Electrification plays a pivotal role in reducing carbon emissions from the transportation sector. Based on best practices established in California's LCFS program, a future national LCFS could establish the framework and market mechanisms necessary to support the most cost-effective decarbonization strategy: widespread electric vehicle and charging infrastructure deployment. This analysis highlights the potential for LCFS programs to accelerate the transition to electric drive, and by extension, reductions in carbon emissions through self-sustaining incentive programs and market-mechanisms. We draw the following conclusions based on this analysis:

- » **Low-carbon fuel standards provide a durable financial instrument for supporting vehicle electrification.** We estimate that a national LCFS could generate approximately \$500 per BEV annually from home charging. Revenue from a national LCFS could be used to fund a variety of incentives for electrification, including point-of-sale rebates and grants for charging infrastructure. Based on an analysis of the revenue potential, we estimate that California's LCFS can provide approximately \$1,300 in point-of-sale rebates per BEV sold from 2021 to 2025 based on business-as-usual sales trends. We estimate that a nationwide LCFS would be able to provide approximately \$1,200 per BEV based on national sales projections. Synchronizing the rebate revenue stream to the quantity of electricity charging and carbon reductions creates a virtuous cycle, in which higher EV uptake would facilitate greater aggregate revenue generation to accelerate EV deployment.
- » **Electric vehicles will become one of the most cost-effective ways of decarbonizing the transport fuels mix by mid-decade.** Even in the absence of outside incentives such as the Federal Tax Credit or California's Clean Vehicle Rebate Program, we estimate that the levelized cost of EV deployment will become cheaper than the present-day LCFS credit price by approximately 2025. In 2025, the cost of deploying EVs will be cheaper than advanced biofuels and cost-competitive with first-generation biofuels. By 2030, we estimate that the levelized cost of compliance from electric vehicles will approach zero relative to conventional ICE vehicles. This suggests that electrification is one of the most cost-effective methods of transport decarbonization. Additionally, as electric vehicle market share grows the increased availability of credits will apply further downward pressure on compliance costs, opening the door for more ambitious carbon reduction targets. This means that electrification from 2030 onward will enable far more tightening of the LCFS program's carbon intensity values.
- » **New charging infrastructure can supply LCFS credits cost-competitively.** Estimating the levelized cost of carbon reductions from building charging infrastructure in California, we find that the cost of carbon reductions from Level 2 chargers falls below the current LCFS credit price at four or more hours of daily use. We estimate that at lower levels of utilization, DC fast chargers benefit from infrastructure capacity credits and can generate LCFS credits at less than \$200 per tonne even at 1 hour of daily use. Beyond two hours of daily use, even with the phase out of the infrastructure capacity credit, we estimate that DC fast chargers can generate LCFS credits at a cheaper price than even blending first-generation biofuels. Future changes to utility rate structures for electric vehicle infrastructure would also further reduce the operating costs for charging network operators, as demand charges comprise a significant portion of expenses at lower utilization levels. For a national LCFS, a capacity crediting option like in California would help to expand fast charging availability in other states in the near-term and mitigate the downsides of lower-

traffic charging locations. We estimate that with economies of scale for installing multi-charger sites, locations with high expected EV utilization may be a low-cost source of LCFS credit generation. Therefore, near-term charging infrastructure expansion can be a viable source of LCFS compliance for obligated parties.

Although it is evident that electrification will become one of the cheapest methods of decarbonizing the transport fuels mix over the next decade, more work is necessary to understand the relationship between LCFS programs and their interplay with EV deployment. The size of EV incentives from a LCFS is volatile, as the value of LCFS credits is set by market demand, and we do not know the second-order effects of electrification on credit markets or how a national market may differ from California's existing carbon market. Further analysis must be done to assess how LCFS-driven smart-charging and additional deployment of renewable electricity could change the credit generation potential for EVs and synergize with efforts to modernize the electricity grid. Furthermore, the cost-effectiveness of any given charging site depends on a variety of factors, including local installation and permitting costs, utility rate structures, and anticipated consumer utilization, thus making the market prospects for any given charging site dependent on unique, site-specific factors. While there remain many uncertainties on the exact form that a national LCFS could take, examples from California's implementation suggests that LCFS programs provide a powerful incentive to drive EV deployment on the federal level.