CALIFORNIA CLEAN VEHICLE REBATE PROJECT

CVRP Greenhouse Gas Emission Reductions and Cost-Effectiveness

2020 Purchases/Leases

California Climate Investments
Cap and Trade Dollars at Work

California Air Resources Board

Center for Sustainable Energy™

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Executive Summary

Estimates of greenhouse gas (GHG) emission reductions associated with the Clean Vehicle Rebate Project (CVRP) were originally developed as a part of multi-program planning, were based upon average light-duty vehicle characterizations, and were described as intentionally conservative as a starting point for future refinement (CARB 2017b). Subsequent program-specific work by the authors that builds on (CARB 2017b) on behalf of CVRP specifically has included a life-of-program accounting through mid-2018 (Pallonetti and Williams 2021); an assessment of 2019 purchases/leases (Pallonetti and Williams 2022b; Williams and Pallonetti 2022b); and initial assessments of 2020, the most recent year of available program data (Williams and Pallonetti 2022b; Pallonetti and Williams 2022a). Here we finalize reporting on the GHG impacts and cost-effectiveness of rebating 2020 purchases/leases using updated data and inputs and an evolving methodology that is increasingly case-specific. For example, further tailoring of the characterization of the baseline gasoline vehicles "raised the bar" for rebated EVs by reducing the emission levels to which EVs are compared.

Emissions are estimated using disaggregated data from 37,201 CVRP approved rebate applications for plug-in hybrid electric vehicles (PHEVs), range-extended battery electric (BEVx) vehicles, all-battery electric vehicles (BEVs), and fuel-cell electric vehicles (FCEVs); as well as from 4,445 survey reponses weighted to represent program participants. The analysis incorporates state-specific or other best-available inputs that characterize fuel use and fuel carbon intensity for both rebated EVs and baseline vehicles, as well as data-based characterizations of rebate influence, tailored to each case.

Compared to new gasoline vehicles, GHG emission reductions associated with rebated EVs over the first year of ownership average 1.6–3.3 metric tons of carbon-dioxide-equivalent emissions per vehicle, depending on the EV technology type, with BEVs reducing the most on average. When scaled up to represent 100,000-miles of driving and totaled for all 2020 purchases/leases, an estimated 900,000 metric tons of carbon-dioxide-equivalent emissions are saved. Comparing rebate costs to all rebated-vehicle emissions benefits over a 100,000-mile quantification period produces carbon-dioxide-equivalent abatement costs averaging $91 and ranging from $79 to $374 per metric ton for PHEVs and FCEVs, respectively.

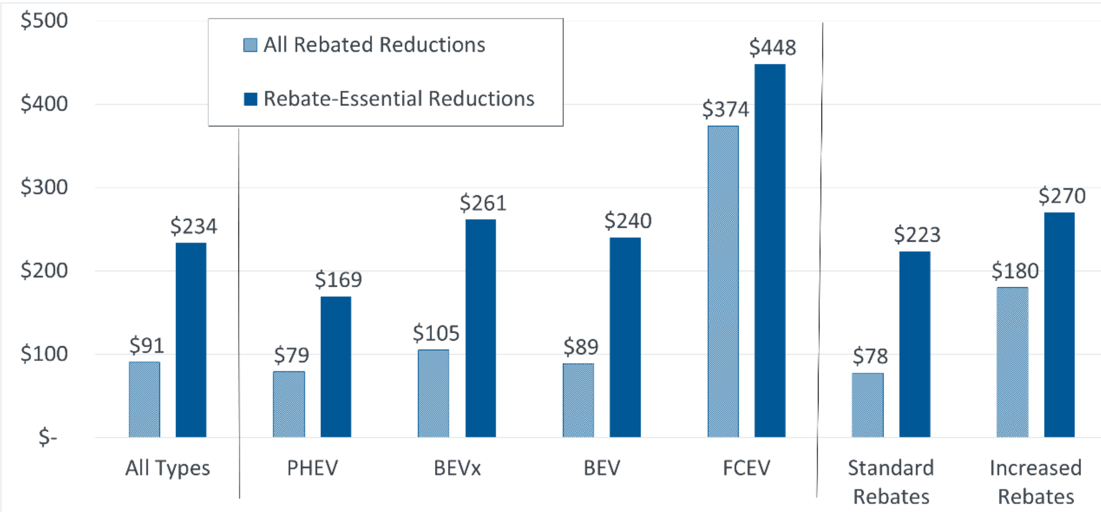
To isolate the emission reductions that are directly attributable to the program, case-specific indicators of *Rebate Essentiality* (Johnson and Williams 2017; Williams and Anderson 2018; Williams and Pallonetti 2022a) can be used. In total, approximately 39% of the rebated reductions in 2020 are associated with "*Rebate-Essential*" participants (those who were the most highly influenced by the rebate to purchase/lease). *Rebate Essentiality* was more frequent for recipients of CVRP's Increased Rebate for consumers with lower household incomes (67%) and FCEV rebates (83%). Cost-effectiveness of *Rebate-Essential* reductions range from $169–448 per ton for PHEVs and FCEVs, respectively, and from $223–

270 per ton for Standard and Increased Rebates, respectively. Figure ES-1 compares cost-effectiveness measures based on all rebated emission reductions to those based only on *Rebate Essential* reductions.

FIGURE ES1

Cost-Effectiveness and Rebate Influence

Rebate dollars per ton of GHG emissions reduced



Summary of results: Cost-effectiveness of GHG emission reductions varies widely by vehicle and rebate types. Costs increase when incorporating rebate influence, however, increases are less drastic for FCEVs and Increased Rebates that are associated with higher *Rebate Essentiality*.

The emission-reduction and cost-effectiveness results should be interpreted relative to the program context during 2020. Due to the onset of COVID-19, the 2020 program population was much smaller in size than in previous/following years and caused an anomalous year for the program in several other respects. For example, there was a decline in *Rebate Essentiality* in 2020, largely driven by Tesla consumers, which composed a large portion of the program in 2020 (Williams and Pallonetti 2022a). Further, program changes implemented in December 2019 that likely affected 2020 results include a $500 decrease in Standard Rebate amounts and $60,000 base MSRP cap for PHEVs and BEVs.

The results are found to be particularly sensitive to baseline vehicle fuel efficiency inputs and the quantification period (i.e., total number of operational miles or miles/year). Although those factors have been the focus of ongoing refinement, remaining uncertainty in EV use, counterfactual behavior, and other inputs presents opportunities for next steps that include planned further refinement using additional time-variant, participant-specific, or otherwise detailed inputs.

1. Introduction

A primary motivation for federal, state, and regional investment in widespread electric vehicle adoption is the need to reduce greenhouse gas (GHG) and other emissions. The California Air Resources Board's (CARB's) Clean Vehicle Rebate Project (CVRP) provides cash rebates for the purchase or lease of eligible light-duty electric vehicles (EVs) in California. Rebate investments exceeded $82 million for vehicles purchased/leased in 2020 alone. Here we aim to create a detailed picture of the size and cost-effectiveness of GHG reductions from those rebated vehicles.

As described in previous related work (Pallonetti and Williams 2022a), many studies have evaluated the emissions impacts of electric vehicles. Literature reviews of such studies (Marmiroli et al. 2018; Lattanzio and Clark 2020) have found a widely varying results. Lattanzio and Clark (2020) highlight that studies have generated a wide range of results due to differing goals, scopes, models, scales, timespans, and datasets used. Further, they explain that differing results can all be accurate based on each study's defined parameters. This underscores the need for context-specific analyses to understand EV impacts for a given vehicle population.

Prior estimates of GHG emission reductions associated with CVRP specifically have included annual projections in CARB's Funding Plans for Clean Transportation Incentives [e.g., (CARB 2019)]. These are based upon average light-duty vehicle characterizations and described as intentionally conservative as a starting point for future refinement. A recent audit of CARB by the California State Auditor (2021) emphasized the need for further refinement and the importance of basing funding and program design decisions on program benefits and costs. This underscores the importance of cost-effectiveness metrics that incorporate the effect of rebate influence.

Here we build on (CARB 2019) and previous work by the authors for CVRP that includes a full life-of-program accounting through August 2018 (Pallonetti and Williams 2021) and prior assessments of the rebate-influenced cost-effectiveness of 2019 and 2020 purchases and leases (Pallonetti and Williams 2022a; 2022b; Williams and Pallonetti 2022b). Compared to previous initial reporting about 2020 purchases/leases (the most recent year of available data), this analysis uses updated inputs and an evolving methodology that is increasingly case-specific. As one example with notable effect, we further tailor characterizations of baseline gasoline vehicles by including conventional gasoline hybrids and removing the influence of pickup trucks, a class of vehicles that had not yet received rebates. This acts to "raise the bar" for rebated EVs by reducing the baseline emission levels to which EVs are compared.

The remainder of the report is organized as follows. Section 2 characterizes the data used. Section 3 describes the approach taken to estimate GHG emission reductions. Section 4 describes and discusses the resulting estimates and provides caveats. Section 5 presents summarizing thoughts. Appendices provide further detail on inputs (both derived from the literature and calculated for this analysis), describe a sensitivity analysis, and detail how inputs and results have changed from 2019 to 2020.

2. Data Summary

The three main data sources are described below: rebate-application, participant-survey, and vehicle-registration data.

Rebate Application Data

The studied dataset was sourced from CVRP rebate applications and is comprised of vehicles that were purchased/leased in 2020. Public and private fleet vehicles totaled 2% of all records and were excluded from this study. Zero-emission motorcycles totaled <1% of rebates and were also excluded from this study. The final dataset includes 37,201 rebates totaling $82,019,025. Most rebates (72%) went to model year (MY) 2020 vehicles, 23% were MY 2021, 6% were MY 2019, and 0.1% were MY 2018. Note that not all EVs purchased in California receive rebates, nor are all EVs or EV consumers eligible (CVRP 2022a). Compared to 2020 light-duty EV registration totals in the state (Auto Innovators 2022), approximately 31% received rebates.

As detailed in Table 1, the data include plug-in hybrid electric vehicles (PHEVs), range-extended battery electric (BEVx) vehicles[1], all-battery electric vehicles (BEVs), and fuel-cell electric vehicles (FCEVs).[2]

TABLE 1

2020 Rebates by Vehicle Technology Type

Technology Type	Rebate Amount[3]	Rebate Counts	Total Rebate Dollars
PHEV	Standard/Increased: $1,000/$3,500	6,348 (17%)	$9,639,000 (12%)
BEVx	Standard/Increased: $2,000/$4,500	141 (0.4%)	$344,500 (0.4%)
BEV	Standard/Increased: $2,000/$4,500	29,966 (81%)	$68,394,625 (83%)
FCEV	Standard/Increased: $4,500/$7,000	746 (2%)	$3,640,900 (4%)
All	**Standard/Increased: $1,000/$7,000**	**37,201 (100%)**	**$82,019,025 (100%)**

[1] BEVx is a regulatory category of vehicles that are powered predominantly by an electric battery and equipped with a gasoline auxiliary power unit that does not operate until the energy storage device is depleted. The category consists only of the BMW i3 REx, which has recently been discontinued.

[2] See the CVRP Implementation Manual (CVRP 2022b) for vehicle category definitions.

[3] ~1% of applications had irregular rebate amounts due to extenuating circumstances.

As detailed in Tables 1 and 2, individual (nonfleet) consumers received one of two rebate types: Standard Rebates and Increased Rebates for Low-/Moderate-Income Consumers (CSE 2021).

TABLE 2

2020 Rebates by Vehicle Rebate Type

Rebate Type	Rebate Amount	Rebate Counts	Total Rebate Dollars
Standard	$1,000–$4,500	32,416 (87%)	$61,515,025 (75%)
Increased	$3,500–$7,000	4,785 (13%)	$20,504,000 (25%)
All	**$1,000–$7,000**	**37,201 (100%)**	**$82,019,025 (100%)**

Participant Survey Data

CVRP invites individual participants approved for a rebate to fill out a voluntary Consumer Survey. Survey responses are weighted using the raking method (iterative proportional fitting) to make them even more precisely representative of the program's population along the dimensions of technology type, vehicle model, purchase vs. lease, year of purchase/lease, and county of residence. The survey data included 4,445 responses from participants with purchase/lease dates from January through November 2020[4] and were separately weighted to represent nearly 27,100 program participants during that period. BEVx vehicles, though analyzed separately, were treated as BEVs for all assumptions where needed, as BEVx consumers are expected to be more akin to BEV consumers than PHEV consumers. (Similarly, the rebate provided by CVRP to BEVx vehicles is the same amount given to BEVs.)

Vehicle Registration Data

The authors calculated sales-weighted fuel consumption rates for baseline vehicles (i.e., the vehicle used for emissions comparison to the rebated EV) using monthly California new-vehicle registration data.[5] The dataset spans registration dates from February 2019 through October 2021 and is used to characterize vehicles of MYs 2020 and 2021.

[4] The 2017–2020 Edition of the CVRP Consumer Survey was switched over to a new edition toward the end of 2020; December 2020 responses will become available as a part of the currently running edition.

[5] Contains content licensed from IHS Markit © 2022.

3. Methods and Inputs

GHG reductions associated with the project are calculated by comparing estimates of fuel-cycle emissions for each rebated electric vehicle to a baseline gasoline vehicle. Fuel-cycle estimates account for "well-to-wheels" GHGs, including upstream (e.g., fuel production and distribution) and combustion emissions. Reductions are assessed at two levels: (1) savings associated with all rebated project participants, or "rebated reductions," and (2) savings associated with consumers most highly influenced by the rebate to purchase/lease an EV, or "*Rebate-Essential* reductions."

The methodology for estimating emissions is described next. Inputs and sources are detailed further in Appendix A, and sensitivity testing of those inputs is described in Appendix B. Only light-duty vehicles are included in the input data and assumptions throughout.

Methodology for Calculating GHG Emission Reductions

Rebated reductions (in metric tons of carbon-dioxide-equivalent emissions, or "tons") are calculated by summing for each rebate the difference between estimates of the emissions avoided (from a baseline vehicle) and the emissions produced (by a rebated vehicle) over a year of operation:

$$\text{Rebated reductions} = \sum_i (E_{i,\text{baseline}} - E_{i,\text{rebated}})$$

where:
i = each individual baseline and rebated vehicle pair, and
E = annual GHG emissions.

State-specific or other best-available inputs tailored to the program (and detailed further in Appendix A) are used to quantify emissions from each baseline and rebated vehicle. These inputs characterize the carbon intensity of fuels, the vehicle consumption rate of fuel, and the vehicle miles traveled.

Following the approach in (CARB 2019), emissions are calculated using statewide average carbon intensity (CI) values for each fuel and the baseline vehicle used for emissions comparison is a new gasoline vehicle.

In this analysis, a MY 2021 gasoline baseline is used for MY 2021 rebated EVs, and a MY 2020 baseline is used for MY 2018–2020 EVs. Further, the authors produce fuel consumption rates for each baseline vehicle by calculating California sales-weighted averages based on the EPA ratings for the 30 top-selling new light-duty gasoline vehicle models each MY. Vehicle miles traveled are determined by the paired EV. The emissions from each individual baseline vehicle are calculated as:

$$E_{i,\text{baseline}} = CI_{\text{gasoline}}(CY) * FC_{\text{gasoline}}(MY) * VMT_{\text{gasoline}}(d, r)$$

where:

CI_{gasoline} = carbon intensity of gasoline [in units of life-cycle carbon-dioxide-equivalent (CO_2e) emissions per gallon], which is calendar year (CY) specific;

$\text{FC}_{\text{gasoline}}$ = fuel consumption rate [in units of gallons per mile], which varies by model year (MY) of the paired rebated vehicle;

$\text{VMT}_{\text{gasoline}}$ = vehicle miles traveled annually, which varies by the paired rebated vehicle's drivetrain category (d), and for BEVs, range subcategory (r).

Rebated-vehicle fuel consumption rates are converted from the model- and model-year-specific combined city/highway fuel economy label ratings from the EPA (DOE and EPA 2021). Annual vehicle miles traveled (VMT) estimates are derived from surveys of EV drivers in California (detailed along with other inputs in Appendix A). These estimates vary by the rebated vehicle technology type and, for BEVs, a range subcategory (short or long range) of the model. For PHEVs and BEVx vehicles, which use both electric and gasoline fuels, a curve is fit through key data points in the literature to produce model-specific electric-VMT percentages (or utility factors) to assign proportions of total travel to electricity. The emissions produced by each individual rebated vehicle are calculated as:

$$E_{i,\text{rebated}} = \sum_f (CI_f(CY) * FC_f(m, MY) * [VMT_f(d, r) * P_f(m, MY)])$$

where:

f = fuel used by rebated vehicle {gasoline, electricity, hydrogen};

CI_f = carbon intensity of fuel f [in units of life-cycle CO_2e emissions per unit of fuel], which is calendar year (CY) specific for gasoline and electricity;

FC_f = fuel consumption rate [in units of gal, kWh, or kg of fuel f per mile], which varies by model (m) and model year (MY);

VMT_f = vehicle miles traveled annually on fuel f, which varies by drivetrain category (d), and for BEVs, range subcategory (r);

P_f = percent of miles traveled on fuel f, which varies by m for BEVx vehicles, and by m and MY for PHEVs.

Quantification Period

Following the approach in the CARB Funding Plans [e.g., (CARB 2019)], GHG emissions are annualized for simplicity. In this analysis, first-year GHG reduction estimates are reported using the annual vehicle miles traveled (VMT) values in Table A3, Appendix A. Additionally, first-year reductions are averaged per mile and scaled up and reported for 100,000 miles (100k mi) of operation. The 100k mi quantification period provides a useful unit for comparing potential emission reductions that does not depend on varying use per year across technologies or over time. Further, it is more intuitive to think of cost-effectiveness "per mile" than "per year." And although most EVs are expected to be in operation longer than 100k mi, and PHEVs specifically were required to have 150k-mi battery warranties in California during this time period,[6] 100k mi is both the most common battery warranty in the U.S. (United States Office of Energy Efficiency and Renewable Energy 2020) and the expected warranty requirement for both PHEVs and BEVs in the latest regulations proposed by CARB staff (CARB 2021).

Both first-year and 100k-mi perspectives are useful for different reasons. First-year GHG savings better illustrate the variations across vehicle and consumer types that result from differences in annual mileage estimates. First-year estimates also provide a rough mechanism (albeit one that ignores changes in annual VMT as vehicles age) for scaling up emissions savings to a variety of timescales of interest. On the other hand, 100k-mi reductions can be viewed as a conservative proxy for potential vehicle benefits over a substantial portion of its lifetime.

Rebate Influence

The CVRP Consumer Survey includes several questions that provide case-specific indicators of rebate influence. First, the survey includes the question, "How important [was the rebate] in <u>making it possible</u> for you to acquire your clean vehicle?" Those who answered moderately, very, or extremely important[7] are categorized as "*Rebate-Important*" consumers.[8] Further, a more direct, counterfactual, and conservative indicator is produced from the question, "Would you have purchased/leased your [rebated EV] if the state vehicle rebate (CVRP) did not exist?" Those who answer "No" are categorized as "*Rebate-Essential*" (Johnson and Williams 2017; Williams and Anderson 2018; Williams 2022).[9] *Rebate-Essential* reductions are calculated separately to estimate emission reductions attributable to the program. *Rebate Importance* is described simply to provide additional context for *Rebate Essentiality* and the complex influence of the rebate more generally.

Consistent with precursor work by the authors [e.g., (Pallonetti and Williams 2021)], *Rebate-Essential* reductions were calculated as follows (and *Rebate-Important* reductions were calculated similarly). If a participant was known to be *Rebate-Essential*, their emission reductions are included. If a participant was known to not be *Rebate-Essential*, their emission reductions are not included. If it was unknown whether a participant was *Rebate-Essential* (i.e., participants that didn't respond to the survey or this survey question), a proportion of their emission reductions are included equal to the weighted percentage of *Rebate Essentiality* among their cohort. The 2020 purchase/lease cohorts are defined as each distinct combination of technology type and rebate type (Table 3). Positive spillover and market effects are not analyzed; including these would increase the benefits attributable to the program.

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[6] PHEV and BEVx batteries are covered for 150,000 miles as required by California's ZEV Standards (California Code of Regulations 2012).

[7] Other response options included "Not at all important" and "Slightly important."

[8] *Rebate Importance*: Question *n* = 4,382 out of 4,445 total survey respondents.

[9] *Rebate Essentiality*: Question *n* = 4,418 out of 4,445 total survey respondents.

TABLE 3

Rebate Influence by Vehicle and Rebate Types

Technology Type	Standard Rebate *Rebate Essentiality*	Increased Rebate *Rebate Essentiality*	Standard Rebate *Rebate Importance*	Increased Rebate *Rebate Importance*
PHEV	41% (*n* = 672)	67% (*n* = 187)	85% (*n* = 670)	94% (*n* = 185)
BEV/BEVx	33% (*n* = 3,128)	66% (*n* = 317)	80% (*n* = 3,100)	95% (*n* = 314)
FCEV	83% (*n* = 107)	87%* (*n* = 76)	96% (*n* = 106)	99%* (*n* = 74)

*** Note**: FCEV Increased Rebate values calculated using the full 2017–2020 Survey Edition dataset (including purchases/leases from June 2017 through November 2020) to obtain a sufficient sample size.[10]

4. Results and Discussion

GHG Emission Reductions and Cost-Effectiveness: All Rebated Vehicles

CVRP rebated 37,201 PHEVs, BEVx vehicles, BEVs, and FCEVs that were purchased or leased in 2020. Total GHG emission reductions achieved by those EVs over the first year of ownership are estimated to be approximately 118,000 metric tons of CO_2-equivalent emissions. According to the EPA, this is roughly equivalent to the GHGs avoided by 32 wind turbines running for a year (United States Environmental Protection Agency 2022). Further, this estimate indicates that the emissions produced from these EVs are only 28% of what the baseline vehicles would have produced, or 72% fewer. The total GHG reductions estimate increases to approximately 900,000 tons when scaled to a 100,000-mile (100k mi) quantification period. Compared with the $82,019,025 in CVRP rebates (roughly $2,200 per vehicle), this total indicates each ton of GHG reductions is associated with approximately $91 in CVRP rebates. (Association versus attribution is discussed in subsequent sections on rebate influence.)

In total, estimated first-year reductions average 3.2 tons per vehicle and scale to 24 tons per vehicle over 100k mi (Table 4). By technology type, first-year reductions range from 1.6 tons per FCEV to 3.3 tons per BEV[11] and 100k mi reductions range from 13 tons per FCEV to 26 tons per BEV. Rebate dollars per ton of 100k mi reductions range from $79 for PHEVs to $374 for FCEVs.

[10] *Rebate Essentiality* and *Rebate Importance* among FCEV Increased Rebate recipients in 2020 were 100% (*n* = 7).
[11] EV emissions range from an average of 82 grams/mile for BEVs to 210 grams/mile for FCEVs.

TABLE 4

GHG Reduction and Cost-Effectiveness Estimates by Technology Type

All Rebated Emissions

Technology Type	Total Vehicles	Average First-Year Reductions Per Vehicle (tons)	Average 100k-mi Reductions Per Vehicle (tons)	Rebate Dollars Per Ton of GHG Reductions (100k mi)
PHEV	*N* = 6,348	2.6	19	$79
BEVx	*N* = 141	2.4	23	$105
BEV	*N* = 29,966	3.3	26	$89
FCEV	*N* = 746	1.6	13	$374
All	***N* = 37,201**	**3.2**	**24**	**$91**

When considering all rebated reductions, 100k-mi reductions from PHEVs were found to be the most cost-effective vehicle type at 79 rebate dollars per ton. This is largely due to their lower Standard Rebate amounts, which were $1,000 throughout 2020, whereas rebate amounts for BEVs (including BEVx) were $2,000 and FCEVs were $4,500.[12] If rebate levels were equivalent across vehicle categories, BEVs would be most cost-effective based on their advantage in per-vehicle savings. Reductions from FCEVs were found to be the least cost-effective due to a combination of their higher rebate amounts and lower per-vehicle savings compared to other vehicle types.

Note that these results are subject to the limitations described in the Limitations and Next Steps section below, and important program features and market dynamics described in the Progam & Market Context section should be considered. Also, as detailed in Appendix B, the results are sensitive to uncertainty in several of the inputs and assumptions. In that analysis, the cost-effectiveness for all vehicles ranges from the primary result of $91/ton up to $130/ton and down to $68/ton when testing alternative values for the most sensitive vehicle and fuel inputs (see Figure B1). FCEVs contain the most uncertainty, with cost effectiveness for FCEVs varying as much as 54% when using alternative inputs and costs decreasing to $177/ton when using more recent carbon intensity data.

Table 5 details GHG reductions and cost-effectiveness by rebate type. Per-vehicle savings for Increased Rebates were slightly lower than Standard Rebates due to a lower proportion of BEVs in the rebated vehicle mix. Because Increased Rebate amounts are higher than Standard Rebate amounts (+$2,500), they were also found to be less cost-effective. This result should be interpreted in the context of the

[12] All Standard Rebate amounts were decreased by $500 in December 2019.

primary purpose of the Increased Rebate, to enable an entire swath of lower income consumers to access an EV who would not otherwise participate in the program. Further, the gap in cost-effectiveness is narrowed when considering rebate influence, dicussed next.

TABLE 5

GHG Reduction and Cost-Effectiveness Estimates by Rebate Type

All Rebated Emissions

Rebate Type	Total Vehicles	Average First-Year Reductions Per Vehicle (tons)	Average 100k-mi Reductions Per Vehicle (tons)	Rebate Dollars Per Ton of GHG Reductions (100k mi)
Standard Rebate	*N* = 32,416	3.2	24	$78
Low-/Moderate-Income Increased Rebate	*N* = 4,785	3.1	24	$180
All	***N* = 37,201**	**3.2**	**24**	**$91**

GHG Emission Reductions and Cost-Effectiveness: *Rebate Essential* Vehicles

Using the case-specific metrics of rebate influence defined in the methodology section, approximately 39% of the total GHG reductions are associated with "*Rebate-Essential*" participants. This varies by vehicle technology type and rebate type. Across technologies, 47% of PHEV, 37% of BEV, 40% of BEVx, and 83% of FCEV reductions were *Rebate-Essential*. Approximately 35% of Standard Rebate reductions and 67% of Increased Rebate reductions were *Rebate-Essential*.[13] Noteworthy changes in *Rebate Essentiality* from 2019 to 2020 (during the onset of COVID-19) are discussed in the Program & Market Context section below.

When assessing cost-effectiveness based on *Rebate-Essential* emission reductions, the average increases from $91 in rebates per ton saved (Tables 4 & 5) to $234. The values range from $169 for PHEVs to $448 for FCEVs and from $223 for Standard Rebates to $270 for Increased Rebates. Consistent with results of all rebated reductions, PHEVs remained the most cost-effective vehicle type for *Rebate-Essential* emission reductions due to their lower rebate amounts. Similarly, BEVs would again be the most cost-effective if rebate levels were equivalent across vehicle categories, despite of their association with the lowest levels of *Rebate-Essentiality* for any vehicle type. FCEVs were again found to be the least cost-effective due to a combination of their higher rebate amounts and lower per-vehicle savings compared

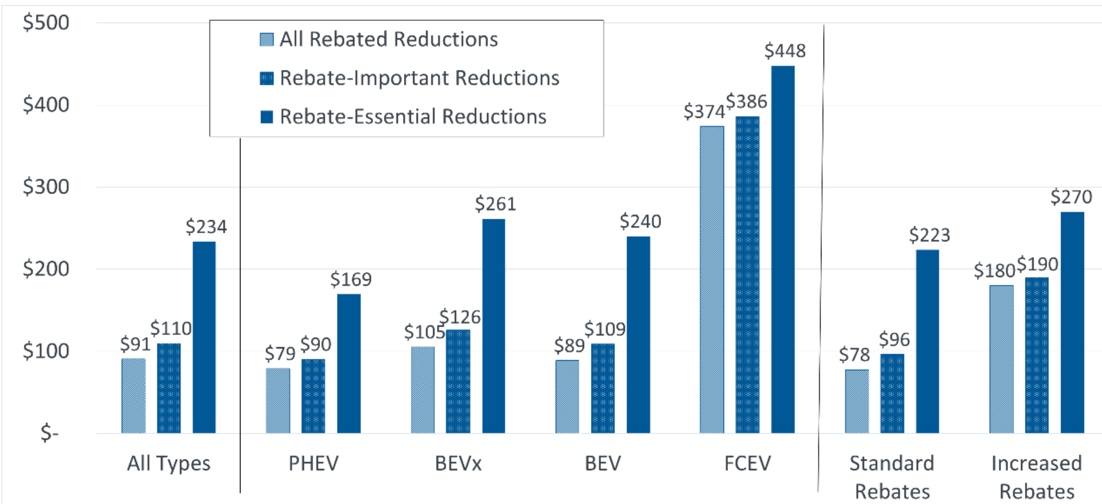
[13] Notably, the 67% of reductions from Increased Rebates determined to be *Rebate Essential* in this analysis and the 72% from the analysis of 2019 data (Pallonetti and Williams 2022) are substantially more than the 59% determined in precursor work that did not include rebate type as part of the definition of a cohort (Pallonetti and Williams 2021).

to other vehicle types. However, since the groups with higher rebate amounts like FCEVs and Increased Rebates were associated with higher *Rebate Essentiality*, the cost-effectiveness gap between these groups and the lower-rebate groups (i.e., non-FCEVs and Standard Rebates) narrows when assessing *Rebate-Essential* reductions. These findings are displayed in Figure 1, along with the cost-effectiveness of *Rebate-Important* reductions for additional context.

FIGURE 1

Cost-Effectiveness by Rebate Influence

Rebate dollars per ton of GHG emissions reduced



Summary of results: Cost-effectiveness of GHG emission reductions varies widely by vehicle and rebate types. Costs increase when incorporating rebate influence, however, increases are less drastic for FCEVs and Increased Rebates that are associated with higher *Rebate Essentiality*. *Rebate-Importance* provides additional context and indicates that many consumers who were not *Rebate-Essential* were nonetheless influenced by the rebate in some substantial but less straightforward way.

Interpreting Rebate Influence

Rebate-Essential reductions can be interpreted as the best available estimate of reductions that are directly attributable to the programs, based on case- and context-specific responses to a straightforward and counterfactual survey question asking consumers whether they would have purchased/leased their EV without the rebate. *Rebate Essentiality* data have displayed reasonable patterns and proven useful in a variety of other uses (Johnson and Williams 2017; Williams and Pallonetti 2022a; Williams 2022). This metric provides a clearer and potentially more conservative measurement of program impact than other candidate measures, barring any response or selection bias. Indeed, in support of its key recommendation that CARB refine the GHG emission reductions estimates in its funding plans, the California State Auditor Report (2021) presents a key finding that CARB may be overstating the GHG emissions reductions of its programs due to unaccounted factors. Those factors include determining whether the incentives are influencing consumers to acquire a cleaner vehicle than they otherwise would have, as well as accounting for potential overlap with other regulatory and incentive programs with the same goals. Measuring *Rebate-Essential* reductions can help account for these factors, as they provide an estimate of GHG reductions only from EV sales that reportedly would not have happened without the rebate, regardless of other factors.

While *Rebate-Essential* program participants (39% of 2020 purchases/leases) are not free riders, it is not necessarily the case that *all other* participants *are* free riders. Evidence for this can be found in the other metric of rebate influence, "*Rebate Importance.*" In all, 83% of survey respondents were *Rebate-Important* consumers (37% extremely, 27% very, and 19% moderately important) and influenced by the rebate in some less straightforward way. Even 73% of **non**-*Rebate-Essential* respondents reportedly found the rebate at least moderately important in making it possible for them to acquire their EV (20% extremely, 27% very, and 27% moderately important). Unlike *Rebate-Essential* emissions reductions, it is not accurate for programs to claim direct credit for all *Rebate-Important* emissions reductions (e.g., other incentives like the federal tax credit for EVs and/or regulatory factors could have played a part). However, the rebate reportedly played an important role for these consumers, likely disqualifying them from being true free riders (as 5% of "not at all important" consumers reported being, and the remaining 12% ["slightly important"] of *Rebate Un-Important* consumers might be).

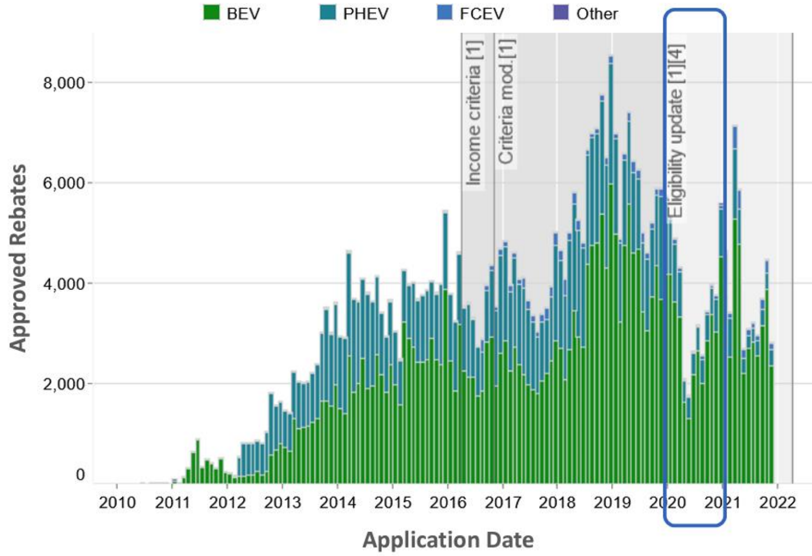
Program & Market Context

Caution should be taken when interpreting the 2020 results, as the onset of COVID-19 caused an anomalous year in several respects. As displayed in Figure 2, CVRP applications saw a dramatic decline and then significant recovery during the 2020 purchase/lease period. As such, the scale of the program was also much smaller during 2020 than in previous and following years. Further, the consumers that did participate in the program in 2020 were less frequently *Rebate-Essential* compared to previous years. As illustrated in Figure 3 below and detailed further in (Williams and Pallonetti 2022a), the decline in rebate influence in 2020 was largely driven by Tesla consumers, which composed a large portion of the program in 2020.[14] It should also be noted that a $60k base MSRP cap for PHEVs and BEVs, as well as a $500 decrease in Standard Rebate amounts were implemented in December 2019 (CSE 2021).

[14] In March 2022, Tesla raised the price of its vehicles over the CVRP MSRP cap, making them ineligible for the program.

FIGURE 2

Approved Rebate Applications Over Time



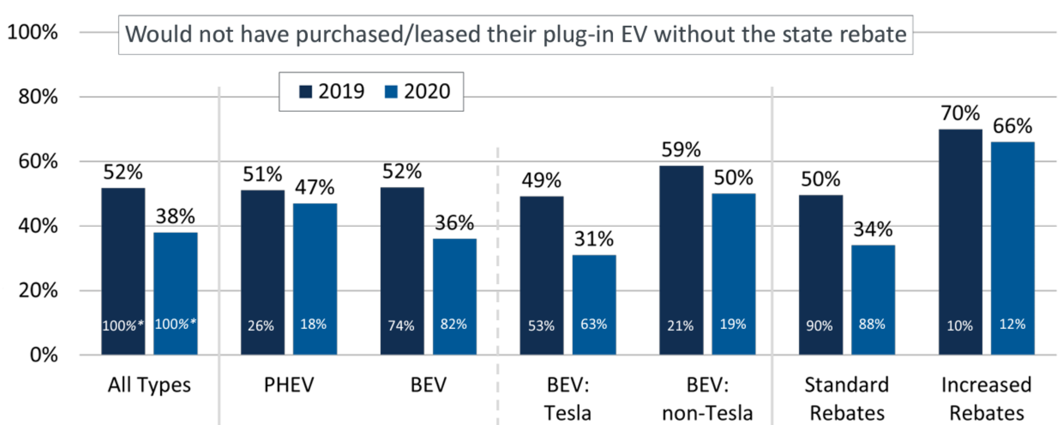
Summary of results: During the onset of COVID-19, CVRP applications saw a dramatic decline and then significant recovery. As such, the 2020 purchase/lease period results should be interpreted with caution.
Source: https://cleanvehiclerebate.org/en/rebate-statistics (12/29/2021).
Notes: With COVID exemptions, rebate applications for calendar year 2020 purchases/leases for individuals spanned 1/1/2020 to 4/15/2021; 12% applied in 2021.

FIGURE 3

Rebate Essentiality by Vehicle and Rebate Type

2019 & 2020 purchases/leases

Weighted Percent of Rebates



Summary of results: Compared to previous years, program participants in 2020 were less frequently *Rebate-Essential*—particularly non-*Rebate-Essential* Tesla consumers.
Source: (Williams and Pallonetti 2022a).
Notes: Includes plug-in EVs only (excludes FCEVs).
* Percentages in white inside columns represent the percent of total rebates given to individual consumers (excludes FCEVs).

Comparisons to Previous Research & Reporting

As described in the introduction, the results of this study should be expected to differ from other EV impacts assessments, including previous studies of CVRP specifically. Each study's goals and scope differ, as do the nature, quality, and vintage of the data available at the time. Indeed, the contributions of this work include focusing on the most recent data and using an increasingly case-specific methodology. Further, care should be taken when comparing results over time as the performance and types of vehicles on the market is evolving and program eligibility changes (see Program & Market Context above) alter the mix of vehicles and consumers. For reference, Appendix C includes tables that compare select inputs and results across three analyses.

Limitations and Next Steps

Next steps for this and related investigations include ongoing opportunities for further refinement using additional participant-specific, time-variant, or otherwise more detailed, inputs. For example, future work could vary fuel carbon intensity and annual VMT for each year of a vehicle's operational life rather than scale up first-year emissions benefits. It could also incorporate increasingly case-specific VMT and carbon-intensity estimates and consider marginal/induced grid emissions. Missing values of *Rebate Essentiality* could be addressed with model-specific cohorts or predictive modeling. Prioritization of these further refinements could be based on a Monte Carlo analysis of inputs and their impacts (Williams and DeShazo 2014).

Additional opportunities for next steps are highlighted by the sensitivity analysis. The current analysis shows that emission reduction estimates are sensitive to deviations from assumed fuel consumption rates of the baseline vehicles. Therefore, accuracy of the reduction estimate relies on the accuracy of these assumptions. As larger electric vehicle classes like pickup trucks become more prominent, class-specific baselines for comparison will be included as a next step. Further, a more appropriate baseline for evaluating the impact of the project could be calculated using more nuanced counterfactual fleet and travel behavior likely to exist in the project's absence. This counterfactual information could be derived from answers to the CVRP Consumer Survey about what type of travel rebated EVs replace and what would have occurred if rebates for EVs were not available.

The scope of this work could also be expanded, for example to include: quantification of other vehicle pollutants; quantification of vehicle life-cycle emissions impacts (including those related to vehicle or battery production, maintenance and disposal); assessment of travel-behavior effects and/or household-level impacts such as vehicle substitution for lengthy trips; exploration of market spillover benefits and network effects; and review of the literature to further enrich understanding of program influence, attribution, and cost-effectiveness.

5. Summary

Prior estimates of greenhouse gas (GHG) emission reductions associated with CVRP have included those based upon average light-duty vehicle characterizations, were described as intentionally conservative as a starting point for future refinement, and/or focused on full life-of-program accounting. Here we create a more detailed, context-specific, and current picture of program impacts and cost-effectiveness, focusing on vehicles purchased or leased in 2020 and including measures of rebate influence.

Depending on the technology of the vehicle, reductions estimates associated with rebated EVs over the first year of ownership average 1.6–3.3 metric tons of CO_2-equivalent emissions per vehicle. Comparing rebate costs to rebated-vehicle emissions benefits over a 100,000-mile quantification period produces CO_2-equivalent abatement costs ranging from $79 to $374 per metric ton for PHEVs and FCEVs, respectively. Approximately 39% of the rebated reductions in 2020 are associated with "*Rebate-Essential*" participants who were most highly influenced by the rebate to purchase/lease. This metric can help to isolate the impacts that are directly attributable to the program. *Rebate Essentiality* was more frequent for recipients of CVRP's Increased Rebate for consumers with lower household incomes (67%) and FCEV rebates (83%). Cost-effectiveness of *Rebate-Essential* reductions range from $169–448 per ton for PHEVs and FCEVs, respectively, and from $223–270 per ton for Standard and Increased Rebates, respectively.

The emission reduction and cost-effectiveness results should be interpreted relative to the program context during 2020. Due to the onset of COVID-19, the 2020 program population was much smaller in size than in previous/following years and caused an anomalous year for the program in several other respects. For example, there was a decline in *Rebate Essentiality* in 2020, largely driven by Tesla consumers which composed a large portion of the program in 2020. Further, program changes implemented December 2019 that likely affected 2020 results include a $500 decrease in Standard Rebate amounts and $60k base MSRP cap for PHEVs and BEVs.

Various opportunities for next steps and scope additions have been identified. The sensitivity analysis can be used to inform the most impactful next steps. The results are found to be particularly sensitive to baseline vehicle fuel efficiency and quantification period (i.e., total number of operational miles or VMT/year). Uncertainty in those and other inputs presents opportunities for next steps that include further refinement using additional time-variant, participant-specific, or otherwise detailed inputs.

Acknowledgements

This study was conducted by the Center for Sustainable Energy on behalf of CVRP and we thank CARB staff for the opportunity to contribute to the conversation. However, it does not necessarily represent the views of CARB. Nor does it represent a final determination. The authors thank all who provided feedback on the report (and we invite additional feedback). Particular thanks are due to Eric Fullenkamp and Keir Havel for analytical support.

Appendix A: First-Year Input Values

State-specific or other best-available inputs tailored to the program are used to quantify emissions from each baseline and rebated vehicle. Each are described further below.

Carbon Intensity of Fuels

Consistent with (CARB 2019), emissions are calculated using statewide average gasoline, hydrogen, and electric-fuel carbon intensity (CI) values from California's Low Carbon Fuel Standard (LCFS) regulation (CARB 2020b; 2022a). These values account for carbon-dioxide-equivalent (CO_2e) emissions over the entire well-to-wheels fuel cycle, including upstream (e.g., fuel production and distribution) and combustion emissions.

The values used in this work, detailed in Table A1, were selected to best-represent the California transportation fuel pool in 2020. Appendix C compares these values to those used in previous related work.

TABLE A1

Fuel Life-Cycle Carbon Intensity Values and Sources

Fuel	Carbon intensity	Detail and sources
Gasoline	10,654 gCO_2e/gal	LCFS benchmark for 2020, converted from (CARB 2020b)
Electricity	276 gCO_2e/kWh	LCFS annual update for 2020 data year, converted from (CARB 2020b; 2022a)
Hydrogen	13,393 gCO_2e/kg	SB 1505-compliant 33% renewable mix, converted from (CARB 2020b)

Fuel Consumption Rate

Rebated-vehicle fuel consumption rates are converted for each rebated vehicle from the model- and model-year-specific combined city/highway fuel economy ratings from the EPA (DOE and EPA 2021).

Following the approach in (CARB 2019), the baseline vehicle that EV emissions are compared to is a new gasoline vehicle. In this analysis, the baseline-vehicle fuel consumption rates are model-year-specific (MY 2020 for MY 2020 and earlier-MY-rebated vehicles, or MY 2021 for MY 2021 rebated vehicles) and produced by calculating California sales-weighted averages based on the EPA ratings for the 30 top-selling new light-duty gasoline vehicle models each MY.[15] Vehicles within each MY were assessed at the model-level and vehicle classes that were not represented in the rebate data (i.e., pickup trucks) were excluded. For models with multiple trims or series with varying fuel efficiency within a given MY, the

[15] Sales are based on new vehicle registration data from IHS Markit. The 30 top-selling models were found to compose 50% or more of the light-duty vehicle sales for each model year.

most efficient (and therefore most conservative) fuel economy value was used in the sales-weighting calculations. Averages of the model-specific EV fuel consumption rates and the model-year-specific baseline vehicle rates are reported in Table A2.

TABLE A2

Fuel Efficiency Averages and Sources

Technology Type	Rebate Counts	Average Fuel Efficiency*	Detail and Sources
PHEV (on electricity, on gasoline)	6,348	3.4 mi/kWh, 47 mi/gal	Calculated based on 2020 CVRP application data and ratings from (DOE and EPA 2021) for each rebate.
BEVx (on electricity, on gasoline)	141	3.1 mi/kWh, 31 mi/gal	Calculated based on 2020 CVRP application data and ratings from (DOE and EPA 2021) for each rebate.
BEV	29,966	3.4 mi/kWh	Calculated based on 2020 CVRP application data and ratings from (DOE and EPA 2021) for each rebate.
FCEV	746	64 mi/kg	Calculated based on 2020 CVRP application data and ratings from (DOE and EPA 2021) for each rebate.
Baseline Vehicle	n.a.	31.4 mi/gal	Calculated using MY 2020–2021 registration data from IHS Markit and ratings from (DOE and EPA 2021)

*** Note**: Fuel efficiency values converted from fuel consumption rates (e.g., gallons/mile) used in GHG calculations.

Vehicle Miles Traveled

Annual vehicle miles traveled (VMT) estimates come from surveys of EV drivers in California. These estimates vary by the rebated vehicle technology type and, for BEVs, a range subcategory (short or long range) of the model (see Table A3).

TABLE A3

Annual VMT Values and Sources

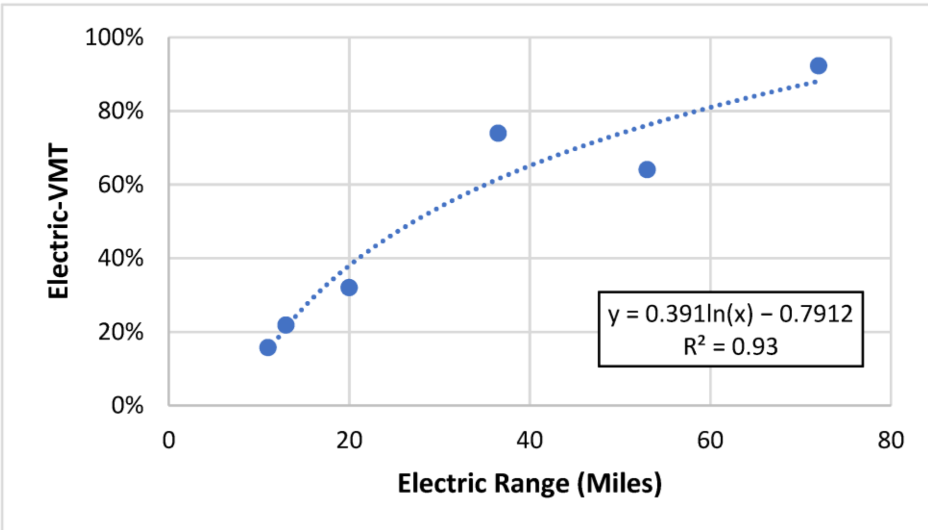
Technology type	Annual VMT	Source
PHEV	13,475	(Chakraborty, Hardman, and Tal 2021)
BEVx / short range BEV	10,484	(Chakraborty, Hardman, and Tal 2021)
Long range BEV (200+ mi.)	13,018	(Chakraborty, Hardman, and Tal 2021)
FCEV	12,445	(Hardman 2019)
Baseline vehicle	10,484 to 13,475	Same as paired rebated vehicle, consistent with (CARB 2019)

For PHEVs and BEVx vehicles, which use both electric and gasoline fuels, a model-specific electric-VMT (e-VMT) percentage (or utility factor) is used to assign proportions of total travel to electricity. Consistent with the general approach in (CARB 2020a), in cases where on-road studies of driving behavior have been conducted for specific rebated models, the e-VMT findings from those studies are used (or averages of findings, for models with more than one study). For models that have not been studied, e-VMT percentages are determined as a function of electric range, derived from plotting e-VMT findings from studied models by their corresponding electric ranges from (DOE and EPA 2021). The e-

VMT studies (Duhon et al. 2015; Francfort et al. 2015; Idaho National Laboratory 2015; Boston and Werthman 2016; CARB 2017a; Tal et al. 2020) are the same as those used in precursor work by the authors [e.g., (Pallonetti and Williams 2021)]. The plot, function, and relationship between the variables are presented in Figure A1.

FIGURE A1

PHEV and BEVx Model-Specific Electric-VMT by Electric Range



Summary of results: A strong correlation is found between electric range of PHEV and BEVx models and electric-VMT percentages found in on-road studies of those models, with 93% of the variation in the electric-VMT accounted for by the variation in electric range.
Source: (Pallonetti and Williams 2021)

Appendix B: Sensitivity Analyses

Sensitivity analyses were conducted to assess the impact of the uncertainty in several of the input values on the cost-effectiveness results. The following sections detail sensitivity analyses on vehicle and fuel inputs, quantification period, and rebate influence.

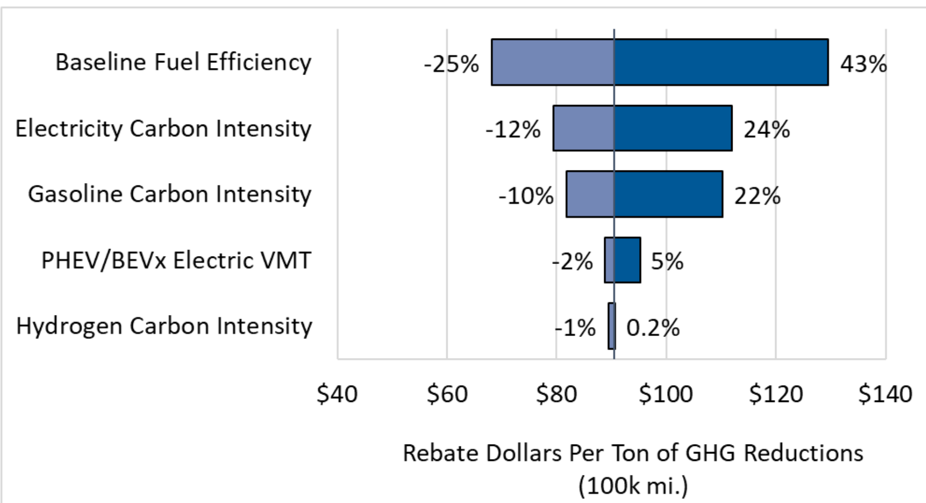
Sensitivity to Vehicle and Fuel Inputs

The literature about related topics helped inform value ranges for sensitivity tests of vehicle and fuel inputs, each of which are described further below. Highlights are displayed in Figure B1.

FIGURE B1

Impact of Uncertainty on Cost-Effectiveness

Vehicle and Fuel Inputs



Summary of results: Alternate vehicle and fuel inputs from the literature are used to assess the impact of uncertainty in these values on results. Cost-effectiveness is found to be particularly sensitive to baseline vehicle fuel efficiency, with results varying as much as -25% and +43%. Carbon intensity inputs are also found to be relatively impactful, varying results from -12% to 24%.
Notes: The baseline fuel efficiency test illustrated in the figure is 40 MPG (various fuel efficiencies are tested below).

Baseline-Vehicle Fuel Efficiency: The low fuel-efficiency bound is based on the U.S. production-weighted car-and-truck fuel economy averages for each baseline model year, equal to 25.4 MPG for 2020 and 25.3 MPG for 2021[16] (United States Environmental Protection Agency 2021). The high fuel-efficiency bound in Figure B1 uses a 40 MPG input. In Table B1 below, the impact of using 30 and 50 MPG are also included, as well as an illustrative test using.the fuel economy of the most efficient

[16] Model year 2021 value is preliminary.

gasoline vehicle in (DOE and EPA 2021) for each baseline model year, equal to 58 MPG for 2020 and 59 MPG for 2021 and based on the Hyundai Ioniq Blue Hybrid in both cases.

TABLE B1

Sensitivity of Cost-Effectiveness to Baseline-Vehicle Fuel Efficiency

Baseline-vehicle fuel efficiency scenario	Rebate dollars per ton of GHG reductions
Primary (CA sales-weighted average by MY)	$91
U.S. production-weighted car-and-truck average by MY	$68 (-25%)
30 MPG	$85 (-6%)
40 MPG	$130 (+43%)
50 MPG	$189 (+108%)
Most efficient gasoline model by MY	$254 (+181%)

Carbon Intensity: Sensitivity to the carbon intensity of each fuel was tested separately. Gasoline CI was varied from the LCFS 2020 benchmark (10,654 gCO_2e/gal) down to the 2030 benchmark of 9,214 gCO_2e/gal in the Gasoline Low CI scenario and up to the LCFS 2010 baseline of 11,518 gCO_2e/gal in the Gasoline High CI scenario (CARB 2020b).

Electricity CI was varied from the 2020 LCFS value (276 gCO_2e/kWh) down 45.7% to 150 gCO_2e/kWh in the Electricity Low CI scenario, based on a projected decrease from 2020 to 2030 in (Grubert et al. 2020), and up to 449 gCO_2e/kWh in the Electricity High CI scenario, based on the U.S. average in the GREET 2020 Model (Argonne National Laboratory 2020).

Hydrogen CI was varied from the LCFS default assumption of a SB 1505-compliant 33% renewable mix (13,393 gCO_2e/kg) down to the most recent CI value from LCFS quarterly reporting of 4,810 gCO_2e/kg, reflective of fuel used during Q1 2022 (CARB 2022b), and up to the highest quarterly CI value since 2020 of 14,900 gCO_2e/kg, reflective of fuel used in Q1 2020.

The results from each test on each vehicle type are presented in Table B2.

TABLE B2

Sensitivity of Cost-Effectiveness to Carbon Intensity of Fuels

Rebate dollars per ton of GHG reductions

Fuel carbon intensity (CI) scenario	All	PHEV	BEVx	BEV	FCEV
Primary (LCFS 2020 CI)	$91	$79	$105	$89	$374
Gasoline Low CI	$110 (+22%)	$95 (+20%)	$129 (+22%)	$108 (+22%)	$577 (+54%)
Gasoline High CI	$82 (-10%)	$72 (-9%)	$95 (-10%)	$80 (-10%)	$309 (-17%)
Electricity Low CI	$79 (-12%)	$71 (-10%)	$91 (-14%)	$77 (-13%)	n.a.
Electricity High CI	$112 (+24%)	$93 (+18%)	$135 (+28%)	$111 (+25%)	n.a.
Hydrogen Low CI	$89 (-1%)	n.a.	n.a.	n.a.	$177 (-53%)
Hydrogen High CI	$91 (+0.2%)	n.a.	n.a.	n.a.	$457 (+22%)

While the carbon intensity tests produced cost-effectiveness results across all vehicle types that ranged from -12% to +24%, the variation for FCEVs was the most drastic (-53% to +54%). With respect to changing gasoline CI, this was due to the fact that FCEVs had the lowest GHG savings average, so a ~5 ton variation in GHG reductions per vehicle represents a larger percent-change from the FCEV primary result of 13 tons of reductions than the BEVs' 26 tons. For hydrogen CI, this was due to a higher degree of uncertainty in the CI value, which is embodied in the range of values used in the tests. Based on quarterly LCFS data reports, hydrogen fuel CI has been rapidly decreasing since 2020 due to an increasing supply of carbon-negative hydrogen. As such, the input value used for the low CI test had much larger variation from the primary input (-68%) than those used to test other fuels. (However, the resulting 53% improvement in cost-effectiveness of FCEV rebates in the Low Hydrogen CI scenario only improves program-wide cost-effectiveness by 1% since FCEVs make up a small piece of the program.)

Electric-VMT Percentage: Sensitivity to the electric-vehicle-miles-traveled (e-VMT) percentage used for PHEVs and BEVx vehicles was tested in the same manner as in the precursor work by the authors [e.g., (Pallonetti and Williams 2021)]: using the highest value (74.5%) and lowest value (12%) for any PHEV model found in e-VMT studies compiled in (CARB 2017a) and varying the BEVx percentage from 92% up to 100% and down by the same magnitude, to 84%. The PHEV tests resulted in the dollars per ton of GHG reductions from PHEVs to decrease from $79/ton to $69/ton (-12%) in the high e-VMT scenario and increase to $123/ton (+56%) in the low scenario. The BEVx tests resulted in the dollars per ton of GHG reductions from BEVx vehicles to change from $105/ton to $97/ton (-8%) and $116/ton (+10%) in the low and high scenarios. Together, these tests changed combined cost-effectiveness for all vehicles from $91/ton to $89/ton (-2%) and $95/ton (+5%).

Sensitivity to Quantification Period

The operational period over which emission reductions are quantified can play an even more crucial role than vehicle and fuel inputs. As described in (Pallonetti and Williams 2021), 100k-mi estimates are arguably still a conservative proxy for useful vehicle life, depending on a balance of conflicting factors. Due to the uncertainty around EV lifetimes and the sensitivity of the GHG estimates to the quantification period used, various operational timeframe scenarios are compared in Table B3.

TABLE B3

Sensitivity of GHG Reductions and Cost-Effectiveness to Quantification Period

Operation scenario	Average GHG reductions per vehicle (tons)	Rebate dollars per ton of GHG reductions
Primary (100,000 miles)	24	$91
2.5-year rebate “project life” (CARB 2019)	8 (-68%)	$279 (+208%)
6-year ownership (Demuro 2019)	19 (-23%)	$117 (+29%)
100,000-/150,000-mile battery warranty life*	26 (+7%)	$85 (-6%)
11.2-year average CA vehicle age (Auto Innovators 2021)	35 (+45%)	$62 (-31%)
150,000 miles	37 (+50%)	$60 (-33%)
15-year project-comparison life (CARB 2019)	47 (+95%)	$46 (-49%)
200,000 miles	49 (+100%)	$45 (-50%)

* In this scenario, a quantification period of 150,000 miles is used for PHEVs and BEVx vehicles, based on the 150,000-mile battery warranty required by the current California ZEV Standards (California Code of Regulations 2012).

Sensitivity to Rebate Influence

Sensitivity of the *Rebate-Essential* reductions estimates to the *Rebate Essentiality* percentages was tested by adding and subtracting 11 percentage points from each. Eleven percentage points is equal to the highest margin of error among any of the cohorts—that of Standard Rebate FCEVs.[17] Though the bulk of the program (72%) is comprised of the Standard Rebate BEV cohort, which was found to have a margin of error of only 2%, the much larger error value for Standard Rebates FCEVs (which only compose 2% of the program) is used in order to account for the potential of any unknown response bias (resulting from respondents answering questions inaccurately) or selection bias (resulting from the survey being voluntary). Note that the 11% margin of error is also more than the proportion of survey respondents that reported seemingly inconsistent results (e.g., being *Rebate-Essential* but not *Rebate-Important*). Adding or subtracting 11 percentage points from the *Rebate Essentiality* percentage of each cohort changed the cost-effectiveness estimates of all *Rebate-Essential* GHG reductions from $234/ton down to $187/ton (-20%) and up to $312/ton (+33%).

[17] Margins of error for the *Rebate Essentility* percentages, based on the sample proportion and sample size of each cohort, are evaluated at the 99% confidence level. Excludes Increased Rebate FCEVs which comprise 0.3% of the studied data and were analyzed differently from other cohorts (see Table 3).

Appendix C: Comparisons to Previous Research & Reporting

Table C1 compares inputs used in analysis of 2019 purchases/leases (Pallonetti and Williams 2022b) with inputs used in the Funding Plan (CARB 2019) and compares inputs used in this analysis of 2020 purchases/leases those used in the analysis of 2019. Table C2 details the impact of those inputs on emission estimates. Recommendations for future Funding Plans based on previous comparisons to (CARB 2019) can be found in (Pallonetti and Williams 2022a).

TABLE C1

Cross-study Data and Input Comparison

Input	**Funding Plan** [MY 2019, ex-ante] (CARB 2019)	**Previous Study** [CY 2019, ex-post] (Pallonetti and Williams 2022b)	**Current Study** [CY 2020, ex-post]
Carbon intensity			
Gasoline (gCO_2e/gal)	11,518 (2010 estimate)	10,799 (2019 estimate)	10,654 (2020 estimate)
Electricity (gCO_2e/kWh)	338 (2016 estimate)	273 (2019 estimate)	276 (2020 estimate)
Hydrogen (gCO_2e/kg)	13,392	13,393	13,393
Baseline vehicle fuel efficiency (average of MY-specific values for Previous and Current Studies)			
Gasoline (MPG)	34.4	28.4	31.4
Rebated vehicle fuel efficiency (average of model- and MY-specific values for Previous and Current Studies)			
PHEV (mi/kWh, e-VMT, MPG)	3.6, 40%, 43	3.3, 54%, 45	3.4, 56%, 47
BEVx (mi/kWh, e-VMT, MPG)	n.a.	3.1, 92%, 31	3.1, 92%, 31
BEV (mi/kWh)	3.6	3.4	3.4
FCEV (mi/kg)	89	65	64

TABLE C2

Comparison of CVRP EV GHG Emissions Estimates

Average grams per mile

Technology Type	**Funding Plan** [MY 2019] (CARB 2019)	**Previous Study** [CY 2019]* (Pallonetti and Williams 2022b) [Percent change from Funding Plan]	**Current Study** [CY 2020] [Percent change from Previous Study]
PHEV	198	161 [-19%]	147 [-8%]
BEV	93	81 [-13%]	82 [+2%]
FCEV	150	207 [+38%]	210 [+2%]

*Note: only minor differences (<2%) present in results when modifying the 2019 study to examine MY 2019 rather than CY 2019; calendar year is presented for comparability to the primary (2020) tables and results.

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