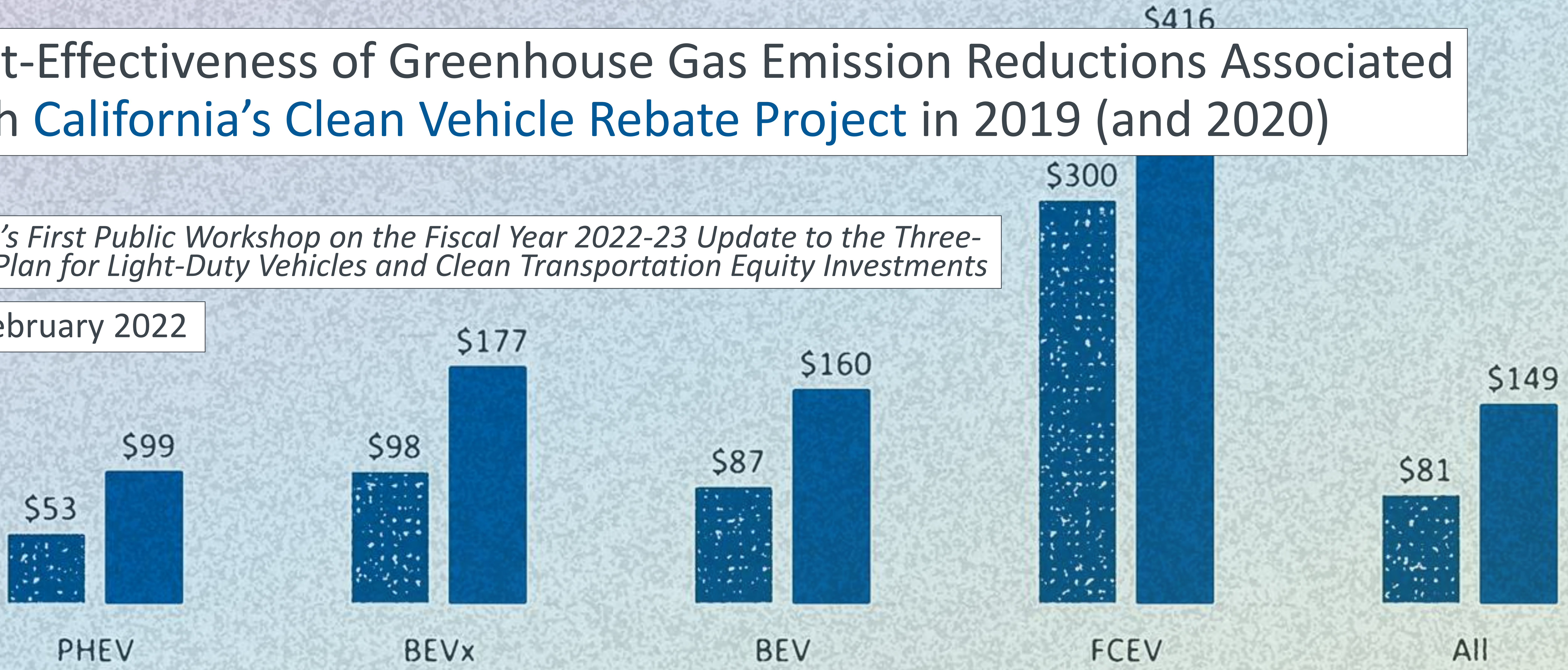
Cost-Effectiveness of Greenhouse Gas Emission Reductions Associated with California's Clean Vehicle Rebate Project in 2019 (and 2020)

CARB's First Public Workshop on the Fiscal Year 2022-23 Update to the Three-Year Plan for Light-Duty Vehicles and Clean Transportation Equity Investments

10 February 2022



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CALIFORNIA CLEAN VEHICLE REBATE PROJECT℠

with thanks to M. Eluganti and others at the Center for Sustainable Energy (CSE)
and to client state agencies including CARB & MA DOER

State EV Rebate Programs Administered by CSE (as of 7/6/2021)

	California Clean Vehicle Rebate Project	MOR-EV Massachusetts Offers Rebates for Electric Vehicles	CHEAPR Connecticut Hydrogen and Electric Automobile Purchase Rebate	New York State	Oregon Clean Vehicle Rebate Program	chargeup New Jersey
Fuel-Cell EVs	$4,500 (+2,500*)	$2,500	$7,500 (+$2,000*)	≥ 200 e-miles†: $2,000 ≥ 40 e-miles: $1,000 < 40 e-miles: $500 Base MSRP > $42k: $500	≥ 10 kWh: $2,500 (+$2,500*) < 10 kWh: $1,500 (+$2,500*)	--
All-Battery EVs	$2,000 (+2,500*)	$2,500	$2,250 (+$2,000*)			$25/e-mile†: $2,000 max for MSRP < $55k; $5,000 max for MSRP < $45k
Plug-in Hybrid EVs	BEVx = $2,000 Others = $1,000 (+$2,500*)	BEVx = $2,500 Others = $1,500	$750 (+$1,500*)			
Zero-Emission Motorcycles	$750	--	--	--	$750 (and NEVs)	--
Program Design Elements	* Rebate adder: income-qualified	--	* Rebate adder: qualified by proxy	--	* Rebate adder: income-qualified	--
	--	--	Point-of-sale option	Point-of-sale	Point-of-sale option	Point-of-sale
	Base MSRP: - PEVs ≤ $60k	Purchase price ≤ $50k	Base MSRP: - FCEVs ≤ $60k - PEVs ≤ $42k	Base MSRP > $42k = $500	Base MSRP < $50k	Trim-specific MSRP < $55k
	≥ 30 e-miles†	≥ 25 e-miles†	--	--	--	--
	Income cap	--	• Used EV program ($7.5k/$3k/$1.125k) • $125/$75 dealer sales incentive	--	Used EVs also qualify	--

BEVx = range-extended battery electric vehicle (BMW i3 REx). NEV = Neighborhood EV. Electric miles (e-miles) are U.S.-EPA-rated all-electric miles.

Outline: Cost-Effectiveness of GHG Emission Reductions

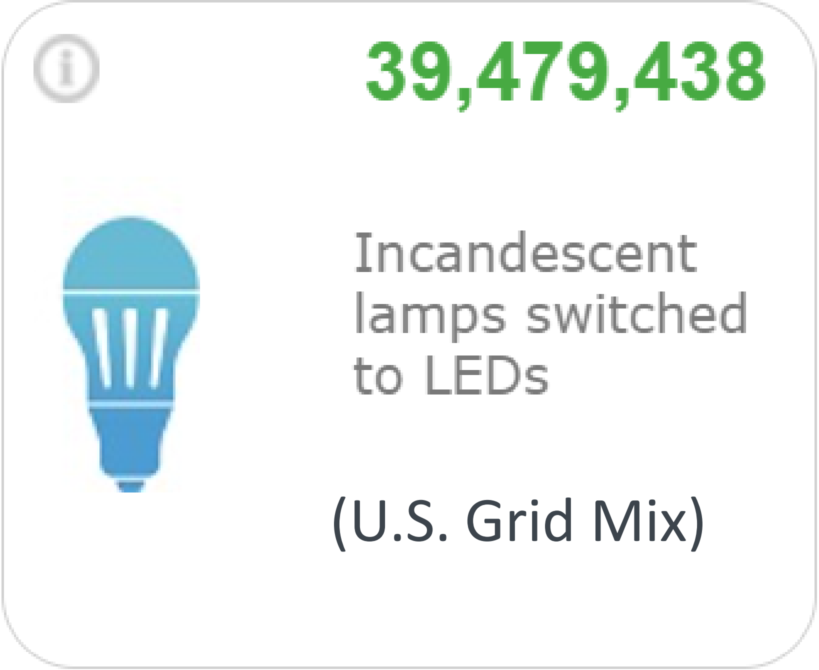
CALIFORNIA CLEAN VEHICLE REBATE PROJECT

Latest version of paper:
https://cleanvehiclerebate.org/eng/content/evaluating-cost-effectiveness-greenhouse-gas-emission-reductions-associated-statewide

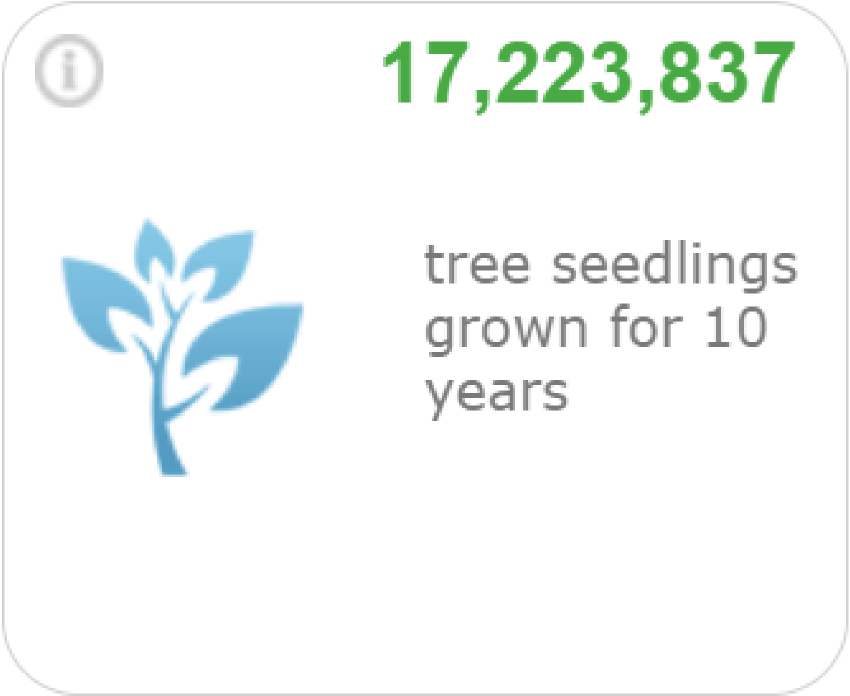
Prologue: Estimated Greenhouse-Gas Emissions Reductions from *Rebate-Essential* Calendar-Year 2019 Purchases/Leases

Technology type	Total vehicles	Average first-year GHG reductions per vehicle (tons*)	Average warranty-life GHG reductions per vehicle (tons*)	Total *Rebate-Essential* warranty-life reductions	Rebate dollars per *Rebate-Essential* warranty-life ton reduced
All	*N* = 63,096 55% Rebate Essential	3.5 tons	30 tons	1 million tons †	$149/ton

† 1 million tons avoided is the same as…



-or-



* ton GHGs = metric ton carbon-dioxide-equivalent (CO_2e) emissions.

† U.S. EPA GHG equivalency from: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Introduction

Research Contributions, Program Context

Disclaimer

Center for Sustainable Energy™

This study was conducted by the Center for Sustainable Energy to inform CVRP.

- It does not necessarily represent the views of CARB staff.
- Nor does it represent a final determination for project-reporting purposes.

We thank CARB staff for the opportunity to contribute to the conversation.

CVRP = Clean Vehicle Rebate Project
CARB = California Air Resources Board

Context & Contributions

This presentation is **based upon**:

– a juried paper for the International Energy Program Evaluation Conference

– a precursor research article in the journal *Energies*

It **builds upon:**

– CARB's Funding Plans for its broad portfolio of Clean Transportation Incentives

- Forward-looking, multi-program, use vehicle averages, characterized as intentionally conservative and to be updated as data become available

Contributions

– Informs methodological enhancements to CVRP program evaluation

– Demonstrates the impact of using program-derived and case-specific data

– *Energies* article examined life of program through mid-2018

– IEPEC paper: most recent complete year of data available

- Calendar-year (CY) 2019 purchases/leases

– This presentation also includes preliminary CY 2020 estimates

Links direct to CVRP or CARB websites; details provided on reference slides

Program Designs Affect Program Outcomes

	as of 1/1/2019	as of 12/3/2019
Fuel-Cell EVs	$5,000	$4,500
All-Battery EVs	$2,500	$2,000
Plug-in Hybrid EVs	BEVx*: $2,500 Others: $1,500	BEVx*: $2,000 Others: $1,000
Zero-Emission Motorcycles	$900	$750
Program Design Elements	• +$2,000 for qualified lower-income households‡ • Income cap • ≥ 20 electric miles† • 18-month application window (Waitlist 6/5 – 9/23 for standard rebates)	• +$2,500 for qualified lower-income households‡ • Income cap • ≥ 35 electric miles† • 1 rebate limit § • Base MSRP ≤ $60k (PEVs)

* BEVx = range-extended battery electric vehicle (BMW i3 REx). † Based on the Urban Dynamometer Driving Schedule (UDDS).
‡ < 300% Federal Poverty Level (FPL). § A second rebate can be approved for a FCEV if the first rebate was for a PEV.

Funding Availability Has Been Regularly Disrupted

(as of Oct 2019)

Table 3: CVRP Waitlists

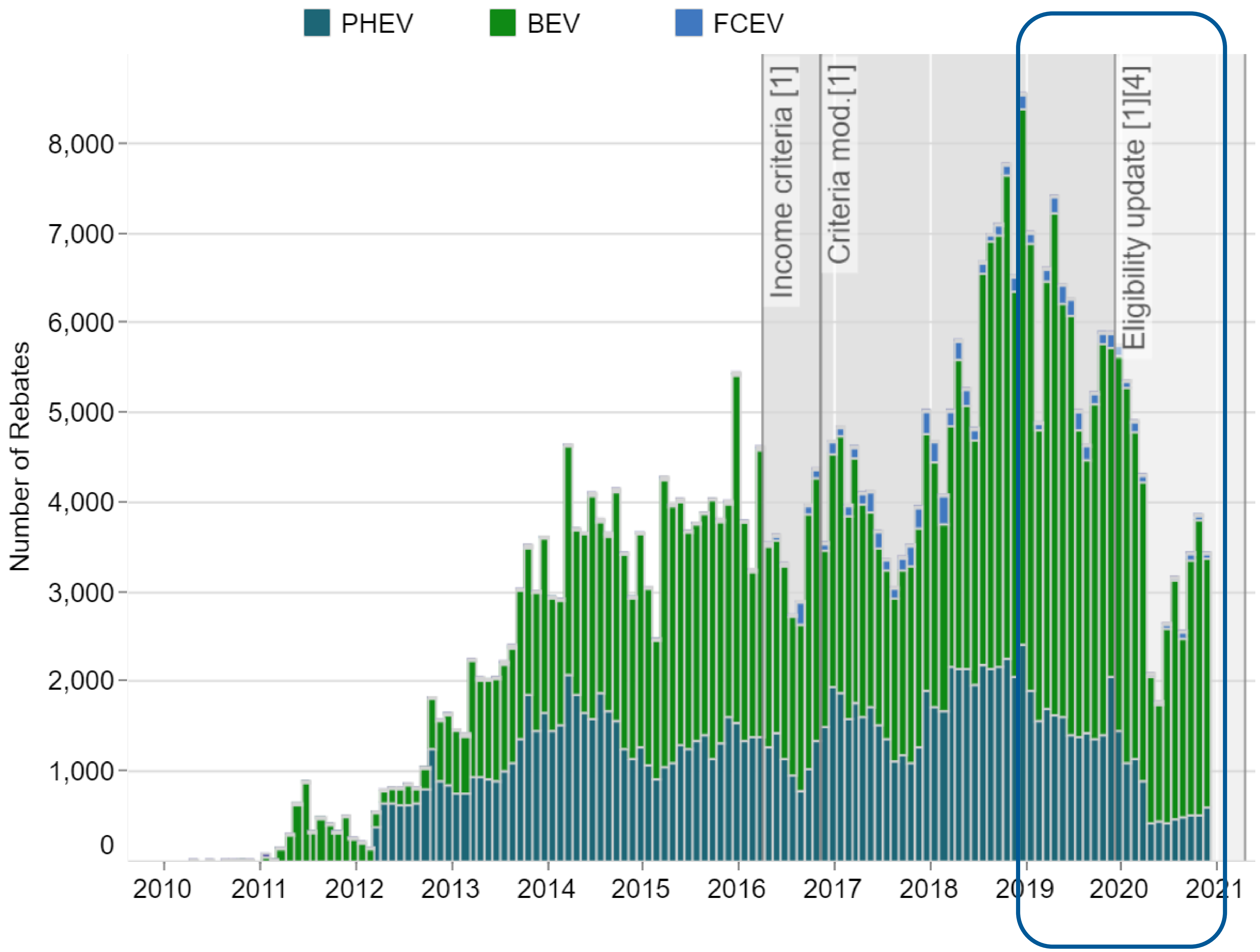
Waitlist Year	Start Date	End Date	Length in Days
2011*	6/20	9/30	102
2013*	5/1	6/30	60
2014	3/28	7/22	116
2016	6/11	9/28	109
2017**	6/30	11/20	143
2019**	6/5	9/23	110

** Dates approximate.*

*** For standard applications only; no waitlist for income-qualified increased rebates.*

Image from https://cleanvehiclerebate.org/sites/default/files/attachments/CVRP_Disruptions_Fact_Sheet.pdf

Approved Applications Over Time: CY 2019 Purchases/Leases



With COVID exemptions, rebate applications for calendar-year (CY) 2019 purchases/leases for individuals spanned 1/1/2019 – 1/6/2021

16% applied in 2020.

5/3/21 image from https://cleanvehiclerebate.org/eng/rebate-statistics

Data Summary

Rebate-Application, Participant-Survey & Vehicle-Registration Data

Data Summary

Program Application and Survey Data

	CY 2019	CY 2020	Total
Rebates	*N* = 63,096 $155,312,369	*N* = 37,201 $82,019,025	> 100k rebated EVs ~ $240M in rebates
Survey responses (weighted*)	*n* = 6,496	*n* = 4,331	~ 11k survey responses

Sales Data

Monthly CA new-vehicle registration data (licensed from IHS Markit)

* Survey data weighted to represent the program population along the dimensions of technology type, vehicle model, county and buy vs. lease using iterative proportional fitting (aka raking method). Details in appendix.

Rebate Application Data

Vehicles Purchased/Leased in CY 2019

Technology type	CVRP vehicles	CVRP rebates
PHEV	16,177 (26%)	$27,978,300 (18%)
BEVx	703 (1%)	$1,893,500 (1%)
BEV	44,440 (70%)	$116,141,069 (75%)
FCEV	1,776 (3%)	$9,299,500 (6%)
Total	**63,096**	**$155,312,369**

PHEV = plug-in hybrid electric vehicle
BEVx = range-extended battery electric vehicle (BMW i3 REx)
BEV = battery electric vehicle
FCEV = fuel-cell electric vehicle

Methodology

Rebated Reductions, Inputs, Sensitivity Analysis

Methodology

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

E = emissions
i = each individual **baseline** and **rebated** vehicle pair

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

carbon intensity
fuel consumption
vehicle miles traveled

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

percent of miles traveled on fuel *f*

Operational Timeframe

Estimates are simplified by **scaling**
E.g., Warranty-life: 150,000 miles for PHEVs (required by ZEV regulations) and 100,000 miles for others (typical)

Methodology Details

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

where:

E = annual emissions
i = each individual **baseline** and **rebated** vehicle pair

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

where:

CI_{gasoline} = **carbon intensity** of gasoline [life-cycle CO_2e per gallon]
FC_{gasoline} = **fuel consumption** rate [gallons per mile]; varies by model year (MY) of the paired rebated vehicle
VMT_{gasoline} = **vehicle miles traveled** annually; varies by the paired rebated vehicle's drivetrain (d), and, for BEVs, range subcategory (r)

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

where:

f = fuel used by rebated vehicle {gasoline, electricity, hydrogen}
CI_f = carbon intensity of fuel f [life-cycle CO_2e per unit of fuel]
FC_f = fuel consumption rate [gal, kWh, or kg of fuel f per mile]; varies by model (m) and model year (MY)
VMT_f = vehicle miles traveled annually on fuel f; varies by drivetrain category (d), and, for BEVs only, range subcategory (r)
P_f = **percent of miles** traveled on fuel f, which varies by m for BEVx vehicles, m and MY for PHEVs.

Operational Timeframe

Estimates are simplified by **scaling** first-year emission reductions to represent various operational-timeframes.

E.g., Warranty-life: 150,000 miles for PHEVs (required by ZEV regulations) and 100,000 miles for others (typical)

First-Year Inputs

Input Sources	
Inputs	Primary Source
Baseline-Vehicle Fuel Efficiency	CA sales-wgtd ave. **calculated** by MY
Annual VMT	UCD Survey data (by tech type)
Gasoline Carbon Intensity	Low Carbon Fuel Standard 2019 CI
Electricity Carbon Intensity	LCFS 2019 CI
PHEV Percent Electric	**Lit./curve fit**. (e-range vs. e-VMT)
Hydrogen Carbon Intensity	LCFS in CARB FP
BEVx Percent Electric	**Lit./curve fit.** (e-range vs. e-VMT)

VMT = vehicle miles traveled
ton GHGs = metric ton of CO_2-equivalent emissions

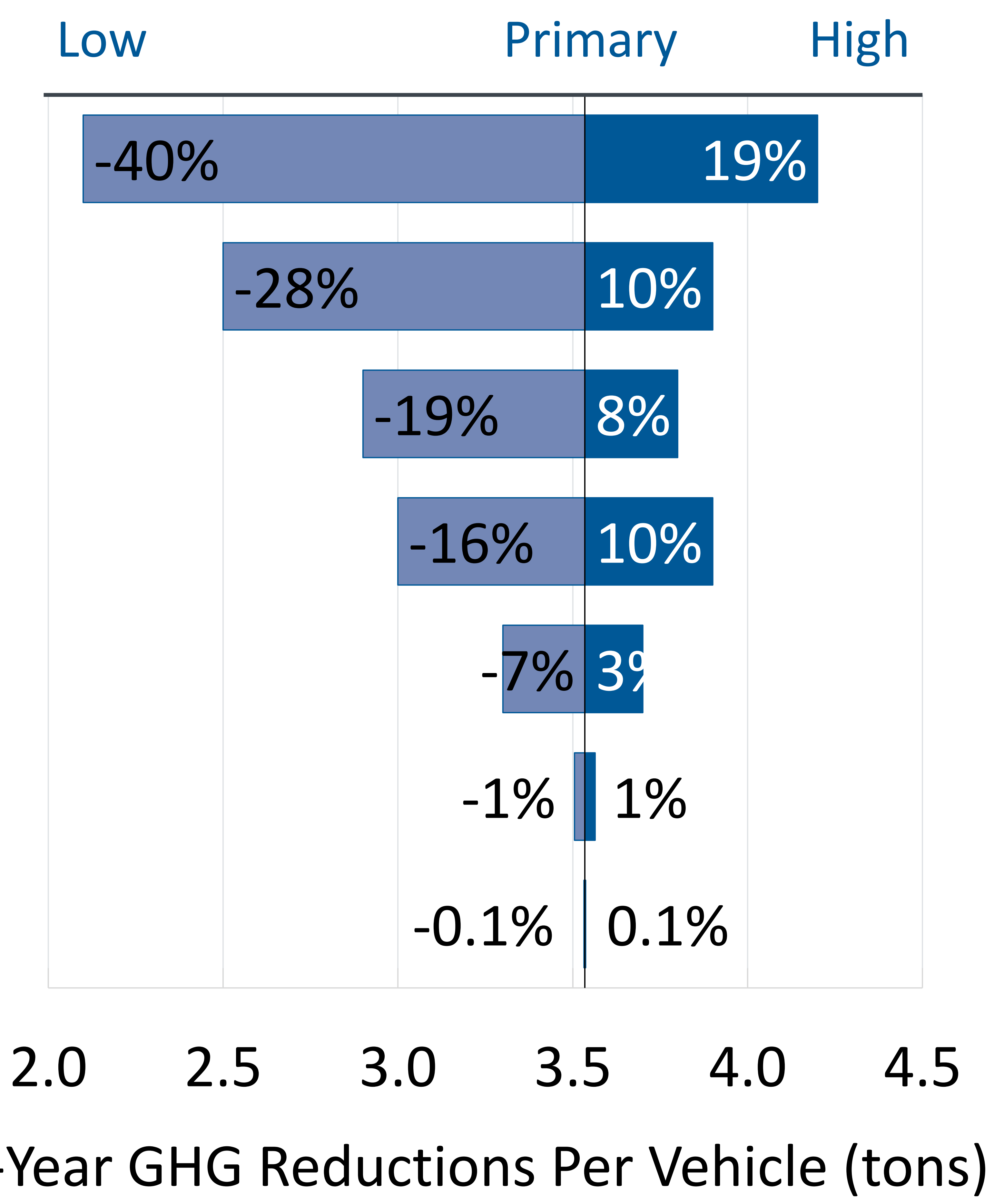
First-Year Inputs & Sensitivity Analysis

CALIFORNIA CLEAN VEHICLE REBATE PROJECT

Input Sources & Ranges Tested

Inputs	Low	Primary Source	High
Baseline-Vehicle Fuel Efficiency	40 MPG	CA sales-wgtd ave. **calculated** by MY	U.S. car-and-truck
Annual VMT	-23% to -40%	UCD Survey data (by tech type)	+0% to +15%
Gasoline Carbon Intensity	CY 2030	Low Carbon Fuel Standard 2019 CI	CY 2010
Electricity Carbon Intensity	U.S. avg.	LCFS 2019 CI	CY 2030
PHEV Percent Electric	12%	**Lit./curve fit.** (e-range vs. e-VMT)	74.5%
Hydrogen Carbon Intensity	+41%	LCFS in CARB FP	-41%
BEVx Percent Electric	84%	**Lit./curve fit.** (e-range vs. e-VMT)	100%

Sensitivity



VMT = vehicle miles traveled
ton GHGs = metric ton of CO_2-equivalent emissions

Results & Discussion

All Rebated Reductions, Rebate Influence, Changes Over Time

All Rebated Reductions

GHG Reduction & Cost-Effectiveness: All Rebated Vehicles

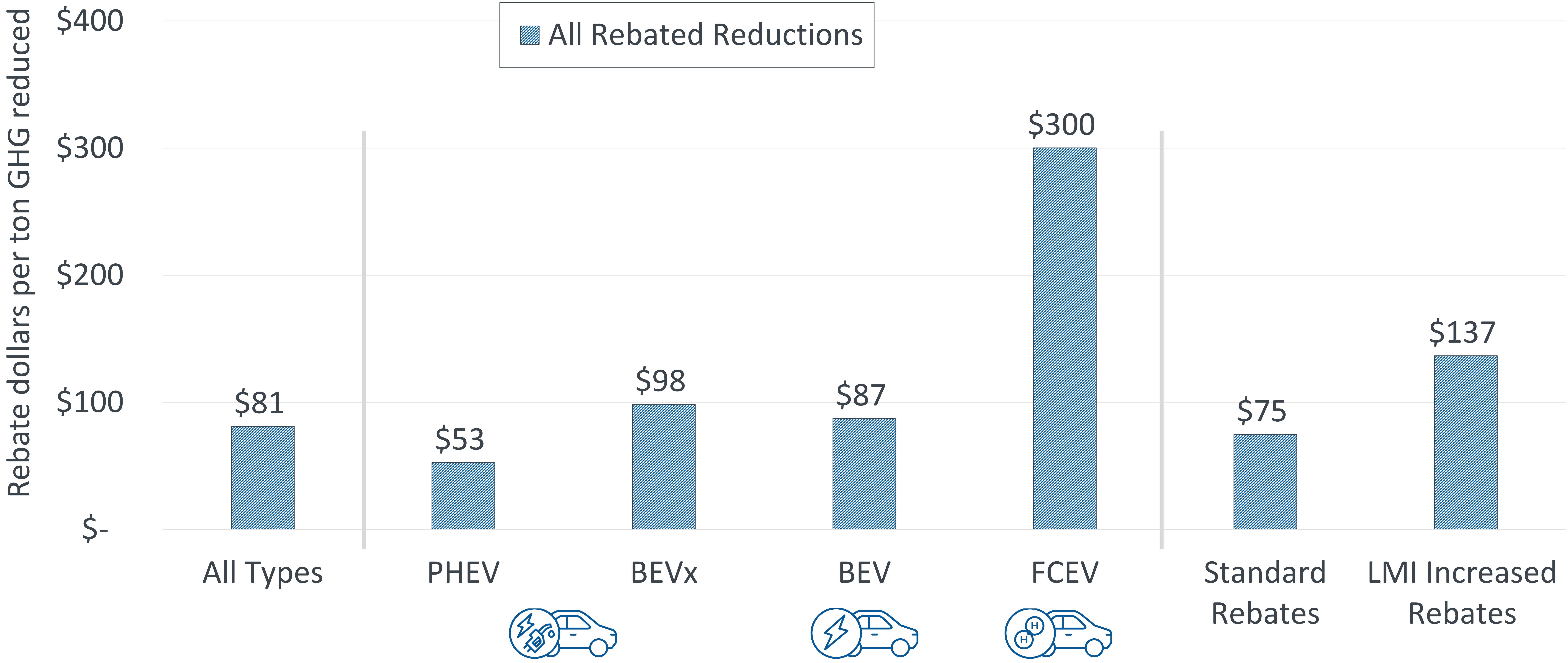
2019 Purchases/Leases, by Technology Type

Technology type	Total vehicles	Average first-year GHG reductions per vehicle (tons)	Average warranty-life GHG reductions per vehicle (tons)	Total warranty-life GHG reductions (tons)	Rebate dollars per warranty-life ton GHGs reduced
PHEV	*N* = 16,177 (26%)	3.0	33	533k (28%)	$53
BEVx	*N* = 703 (1%)	2.9	27	19k (1%)	$98
BEV	*N* = 44,440 (70%)	3.8	30	1,330k (70%)	$87
FCEV	*N* = 1,776 (3%)	2.2	17	31k (2%)	$300
All	***N* = 63,096**	**3.5**	**30**	**1,913k**	**$81**

ton GHGs = metric ton CO_2e.
U.S. EPA GHG equivalency from: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

CVRP Cost-Effectiveness: All Rebated Reductions

2019 Purchases/Leases, Warranty-Life



ton GHG = metric ton of CO_2-equivalent emissions

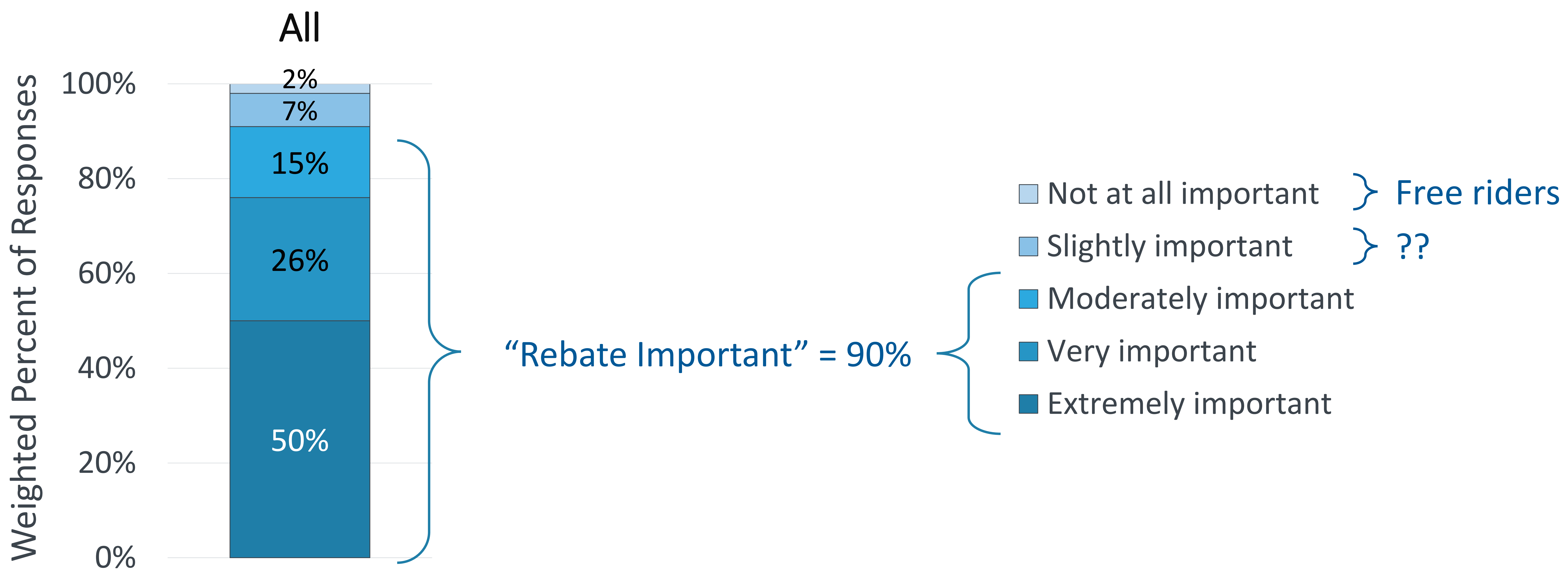
LMI = Low-/Moderate-Income

Rebate Influence

Rebate Importance

2019 Purchases/Leases

How important was the state rebate in making it possible for you to acquire your clean vehicle?

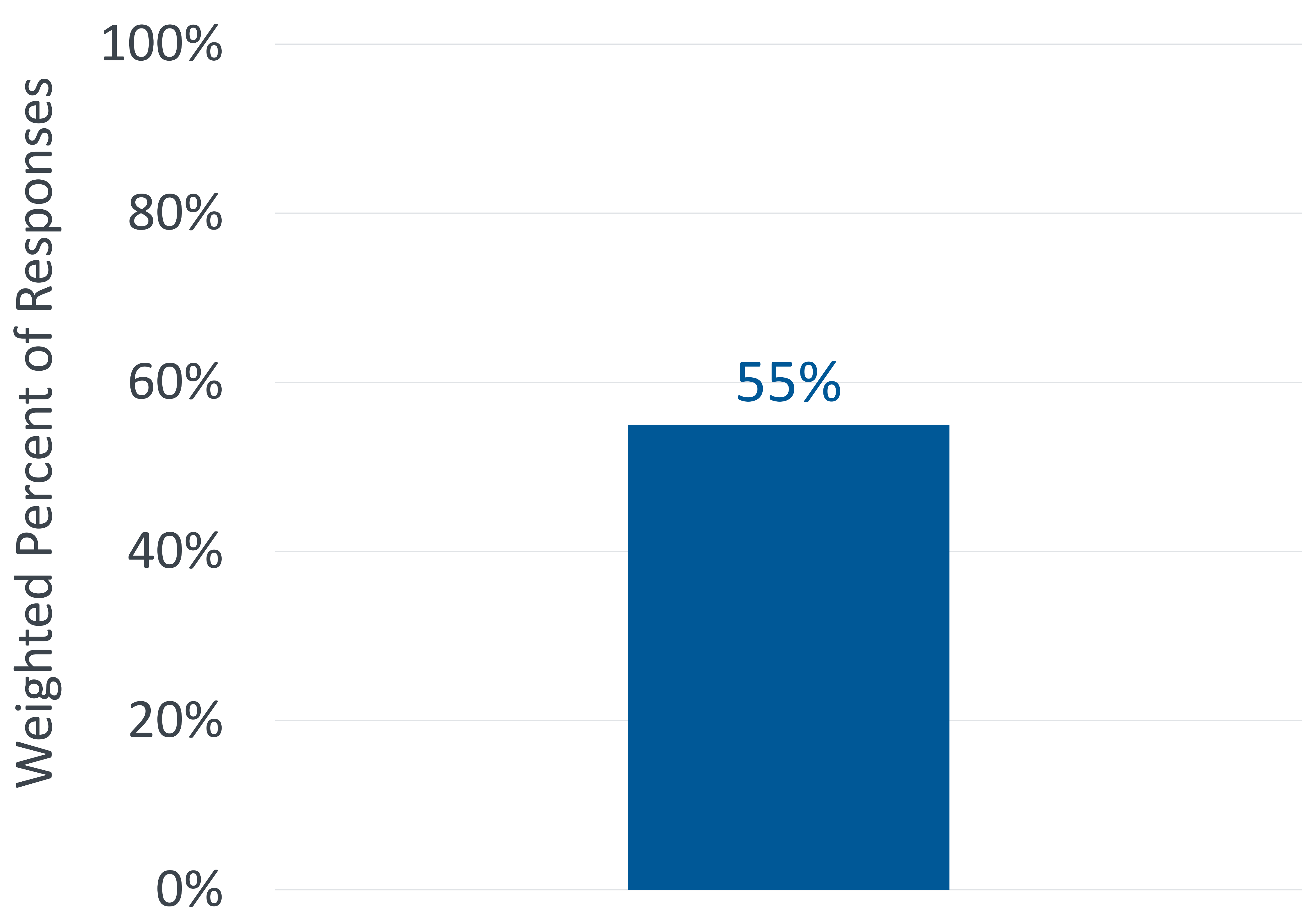


CVRP Consumer Survey: 2017–2019 edition. Filtered question n = 6,418.
Starting Dec. 2019, PEVs with base MSRP greater than $60k became ineligible.

Rebate-Essential Participants

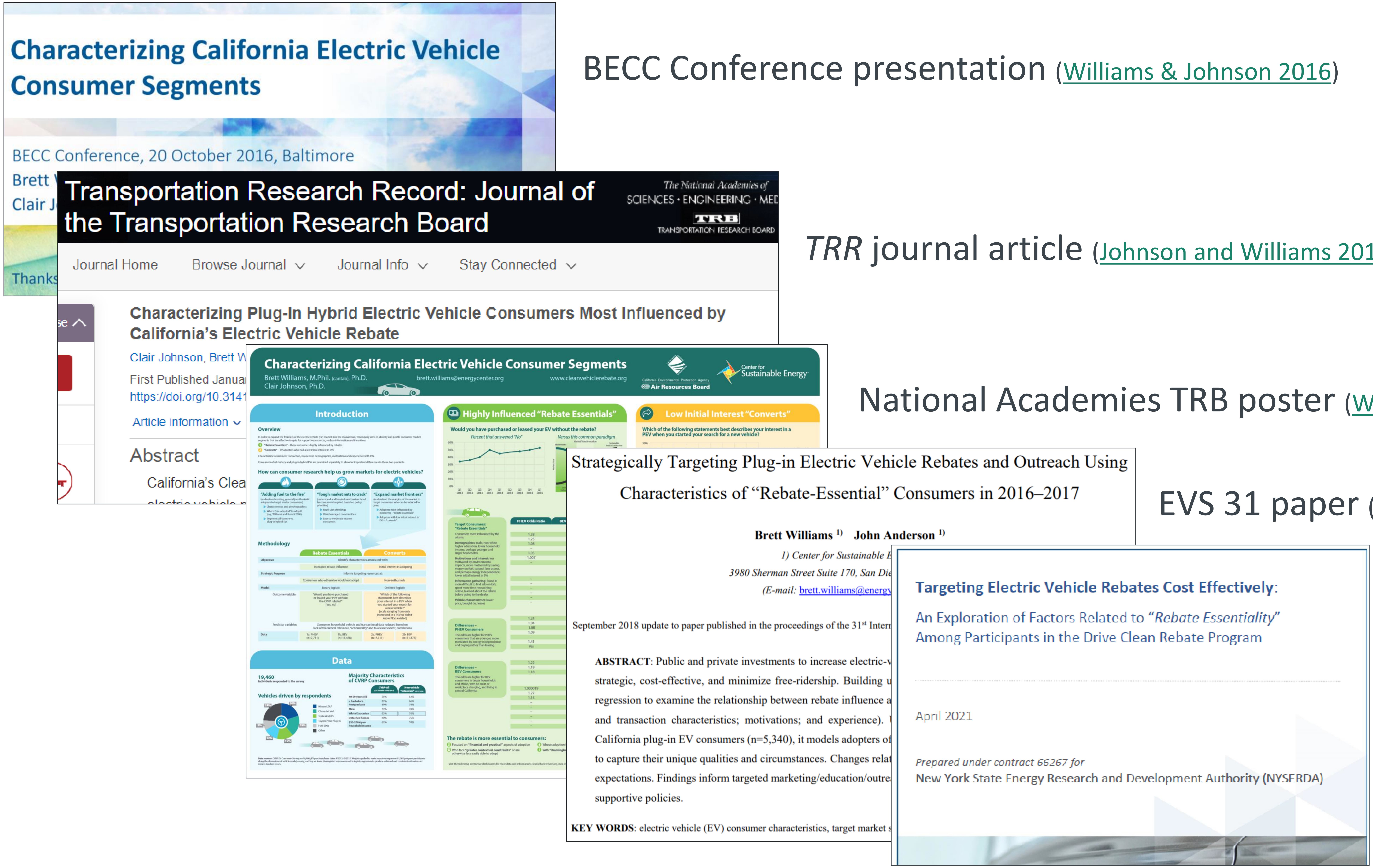
2019 Purchases/Leases

Would not have purchased/leased their EV without the state rebate



CVRP Consumer Survey: 2017–2019 edition. Filtered question n = 6,457. Starting 12/2019, PEVs with base MSRP > $60k became ineligible.

Previous Work on *Rebate Essentials*: Summary



BECC Conference presentation (Williams & Johnson 2016)

TRR journal article (Johnson and Williams 2017)

National Academies TRB poster (Williams and Johnson 2017)

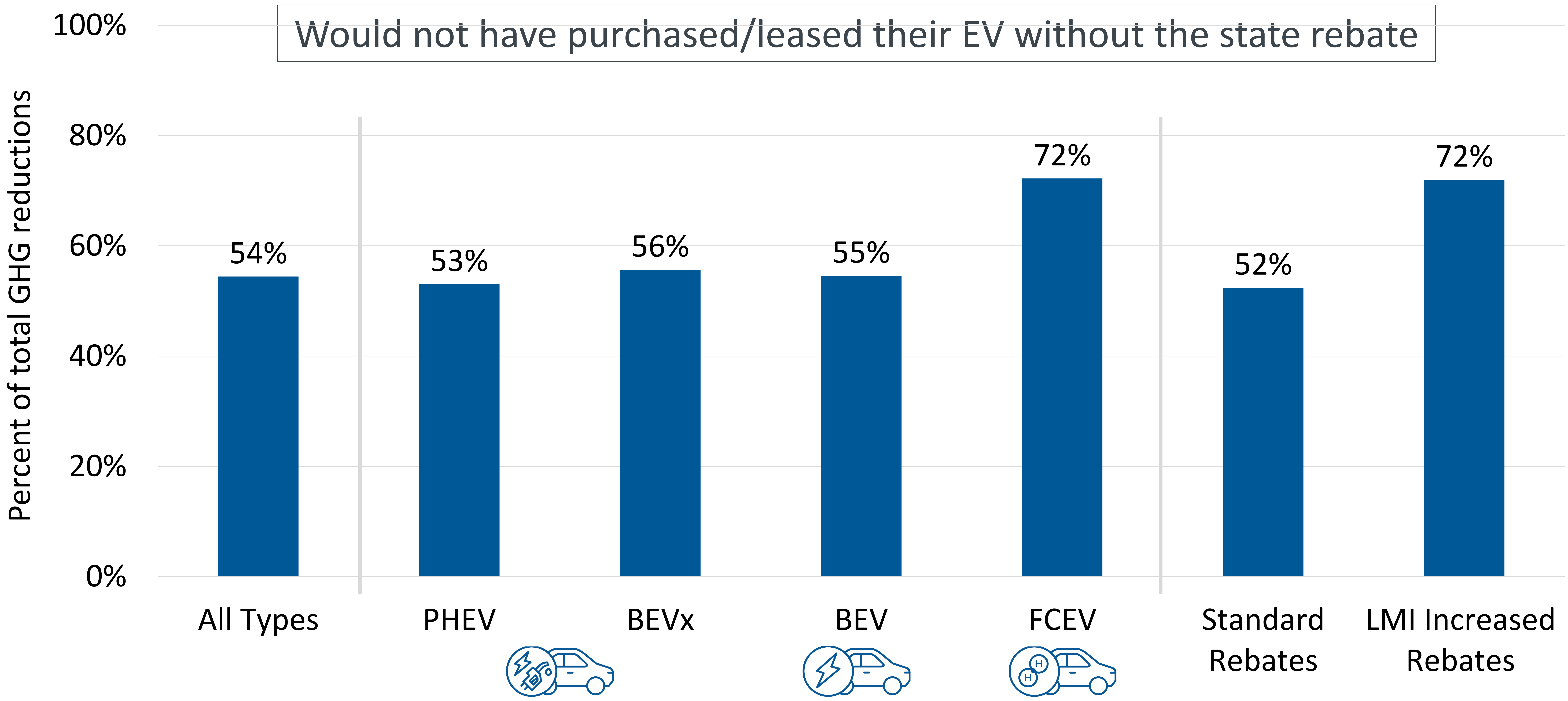
EVS 31 paper (Williams & Anderson 2018)

Report for NYSERDA

(Williams & Anderson 2021)

Rebate-Essential Reductions: Warranty Life

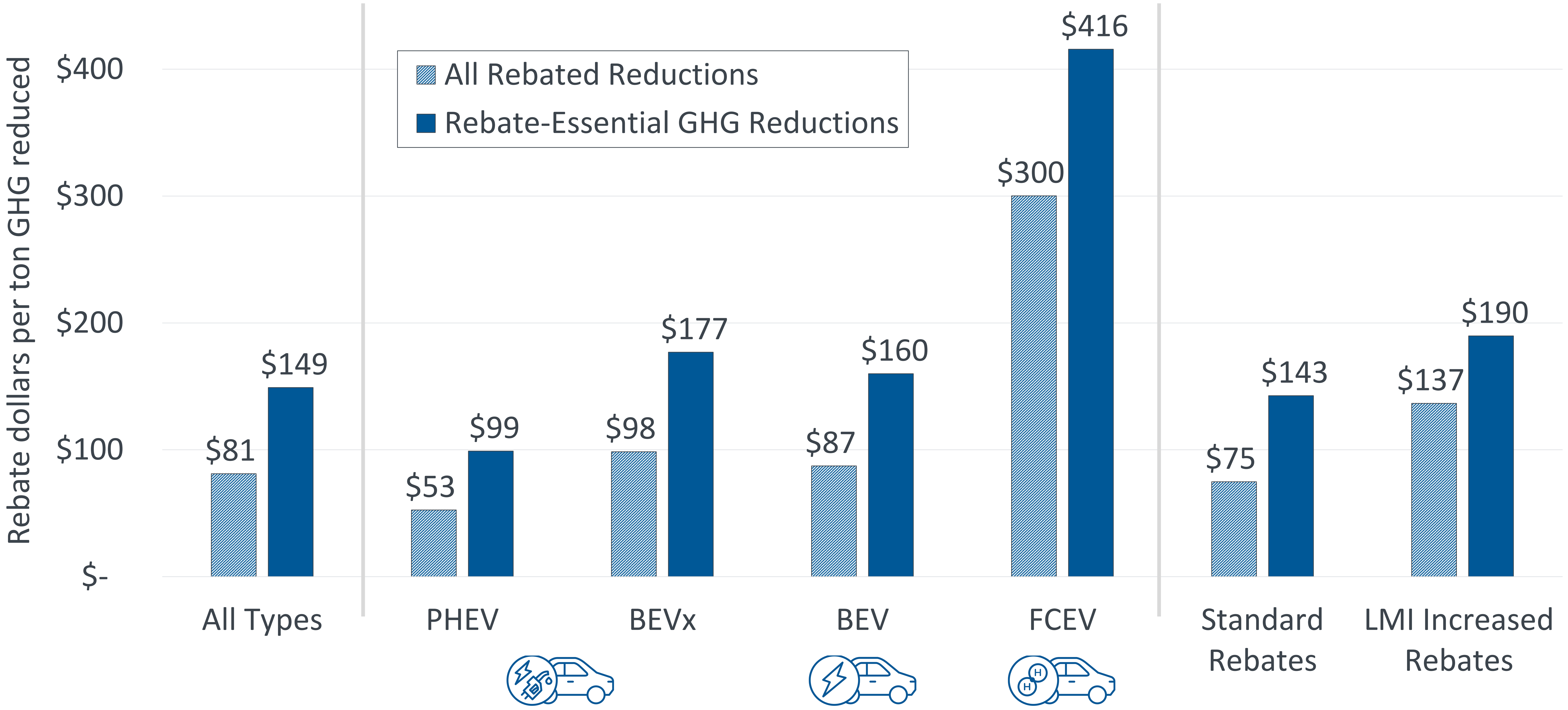
2019 Purchases/Leases



LMI = Low-/Moderate-Income

CVRP Cost-Effectiveness: *Rebate-Essential* Reductions

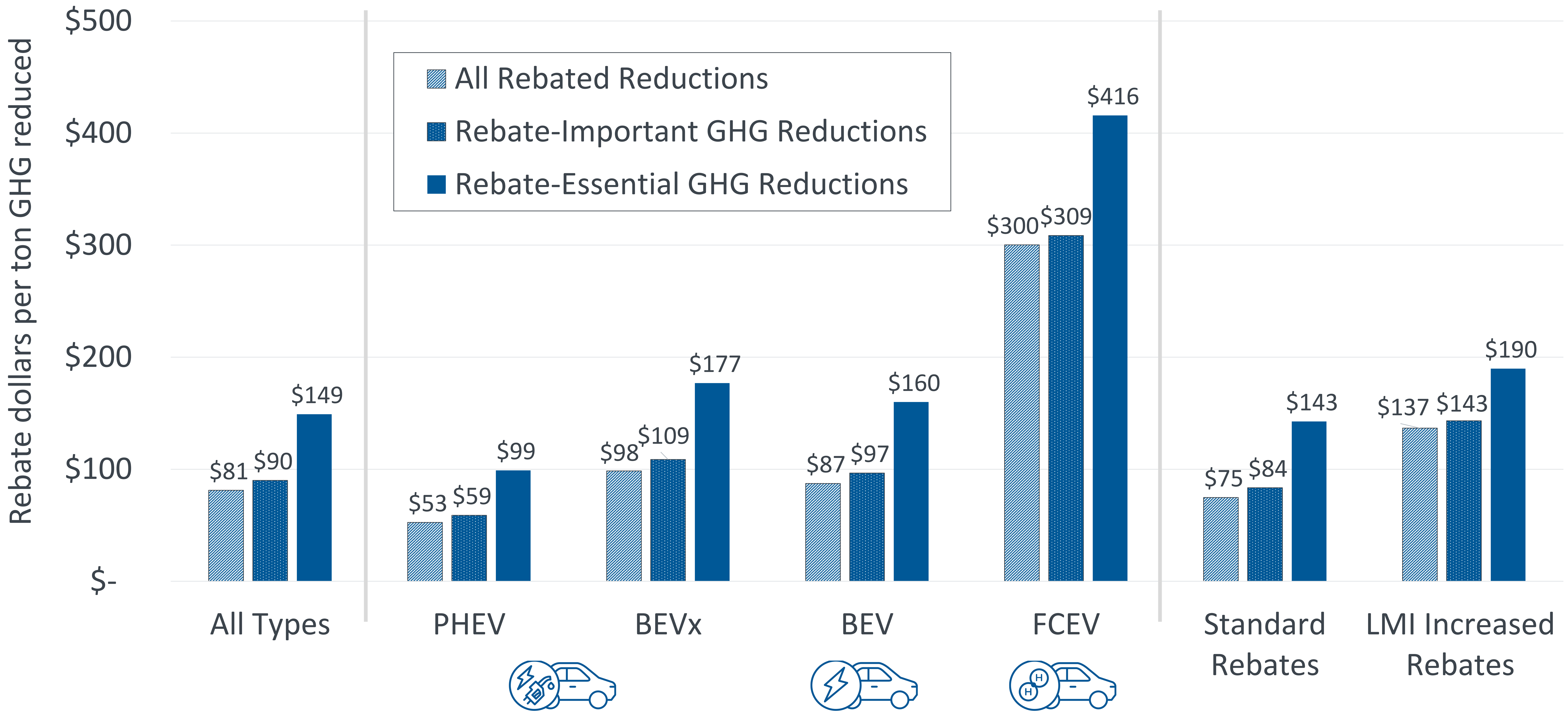
2019 Purchases/Leases, Warranty-Life



ton GHG = metric ton of CO_2-equivalent emissions; LMI = Low-/Moderate-Income

Cost-Effectiveness & Rebate Influence

2019 Purchases/Leases, Warranty-Life



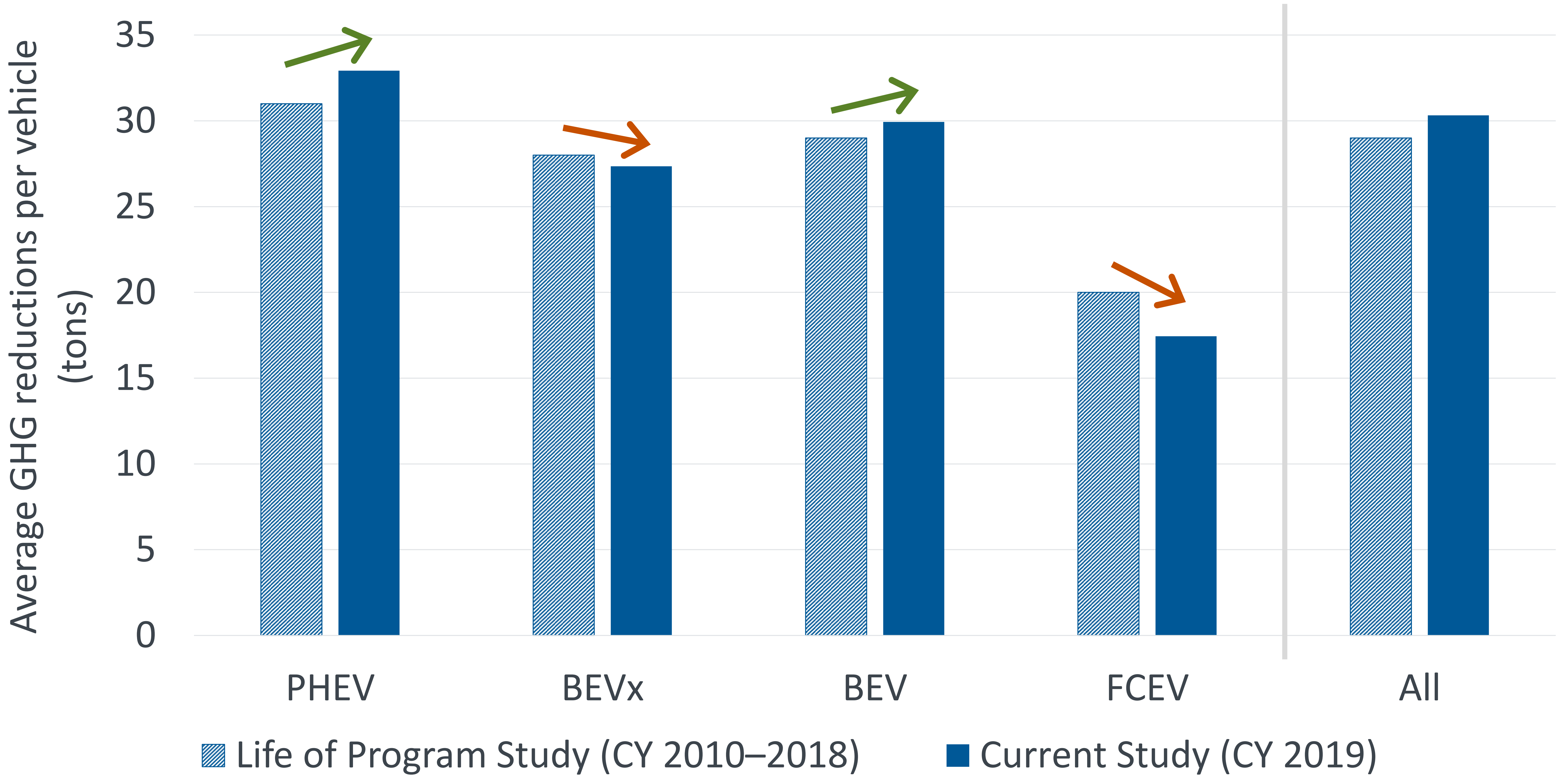
ton GHG = metric ton of CO_2-equivalent emissions; LMI = Low-/Moderate-Income

Changes Over Time

Life-of-Program Through mid-2018 (*Energies*) vs. 2019 (IEPEC)

Comparisons: Per-Vehicle Reductions, Warranty Life

Life-of-Program Thru 2018 (journal *Energies*[1]) vs. 2019 (IEPEC procs.[2])



- BEVx and FCEV decreases largely from an improving gasoline baseline
- BEV and PHEV increases largely from improving electricity CI
  - And, to a lesser extent, increasing fuel efficiency

[1] https://cleanvehiclerebate.org/eng/content/refining-estimates-fuel-cycle-greenhouse-gas-emission-reductions-associated-cvrp

[2] https://cleanvehiclerebate.org/en/content/evaluating-cost-effectiveness-greenhouse-gas-emission-reductions-associated-statewide

ton GHGs = metric ton of CO_2-equivalent emissions

Changes Over Time

Draft 2020 Results In “Additional Details” Appendix

Conclusion

Selected Summary, Recommendations, Limitations & Next Steps

Summary of Select Findings

	Warranty-life GHG savings (tons)	Rebate dollars per warranty-life ton reduced	*Rebate-Essential* GHG Reductions (percent of total)	Rebate dollars per *Rebate-Essential* ton reduced
CY 2019	From 17 tons (FCEVs) to 33 tons (PHEVs)	From $53 (PHEVs) to $300 (FCEVs) per rebated ton	54% (72% for Increased Rebate)	From $99 (PHEVs) to $416 (FCEVs) per *RE* ton
CY 2020 (partial update)	From 16t (FCEVs) to 34t (PHEVs)	From $45 (PHEVs) to $304 (FCEVs) per rebated ton	39% (67% for Increased Rebate)	From $96 (PHEVs) to $356 (FCEVs) per *RE* ton

- Results particularly sensitive to baseline vehicle fuel efficiency and VMT/lifetime
- Optimizing cost-effectiveness in isolation can have undesirable consequences (e.g., decreased share of increased rebates for lower-income consumers, who are highly influenced by rebates)
- The gasoline baseline is improving, raising the bar
- 2020 paints a different picture: electricity CI, EV efficiency, and *Rebate Essentiality* did not improve

ton GHGs = metric ton of CO_2-equivalent emissions. VMT = vehicle miles traveled. CI = carbon intensity

Funding Plan Recommendations

CALIFORNIA CLEAN VEHICLE REBATE PROJECT™

Consider:

- Referencing annual LCFS CI benchmarks for gasoline CI
  - Gasoline consumed in California has become cleaner since 2010 under the LCFS
- Modeling new gasoline vehicle fuel efficiency based on recent vehicle sales
- Referencing the latest program data for fuel efficiency of EVs & e-VMT %
- Referencing the latest available studies to derive annual VMT estimates
- For GHGs, using warranty life and an out-of-state vehicle leakage adjustment rather than 2.5-year project life

Limitations & Next Steps

Limitations & Next Steps: Further Refinement

Ongoing opportunity for further refinement using:

- Additional participant-specific inputs
  - Enhance baseline vehicles based on survey data on counterfactual purchase decisions, or other methods emerging in literature
  - Base fuel CI on electric utility territory and/or survey data on solar use
  - Incorporate predictive *Rebate Essentiality*
- Time-variant inputs for fuel CI and annual VMT
  - Rather than scaling up first-year emissions
- Other more detailed inputs

CI = carbon intensity
VMT = vehicle miles traveled

Limitations & Next Steps: Broadening Scope

- Additional research to further improve understanding of rebate influence, attribution, and cost-effectiveness
- Quantifying full vehicle life-cycle emissions impacts and other vehicle pollutants
- Evaluating potential climate effects on vehicle performance
- Assessing travel-behavior-change effects and/or household-level impacts
  - Such as vehicle substitution for lengthy trips
- Exploring market spillover (e.g., network) effects

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Additional Detail

GHG-Reduction Cost-Effectiveness

Program Application & Survey Data Summary

CALIFORNIA CLEAN VEHICLE REBATE PROJECT™

Application Data

	CY 2019	CY 2020
Rebated vehicles	***N*** **= 63,096 ($155,312,369)**	***N*** **= 37,201 ($82,019,025)**

> 100k rebated EVs
> $237M in rebates

Survey Data

	Consumer Survey, 2017–19 Edition	**Consumer Survey, 2017–20 Edition**
Participant survey responses	*n* = 26,464	*n* = 33,524
Weighted* to represent program participants	*N* = 153,890	*N* = 198,922
Vehicle purchases/leases	June 2017 – Dec. 2019	June 2017 – Nov. 2020
Responses filtered by CY purchases/leases	***n*** **= 6,496**	***n*** **= 4,331**

> 10k survey responses

* Survey data weighted to represent the program population along the dimensions of technology type, vehicle model, county and buy vs. lease using iterative proportional fitting (aka raking method)

Primary Inputs: Carbon Intensity (CI) of Fuel Lifecycles

CALIFORNIA CLEAN VEHICLE REBATE PROJECT

Fuel	CY 2019	CY 2020	Approach, Sources
Gasoline (gCO_2e/gal)	10,799	10,654	LCFS benchmarks, converted from (CARB 2020)
Electricity (gCO_2e/kWh)	273	273 (CY19 value used for "partially updated" results) 276 (LCFS draft CY20 value, used for "draft" results)	LCFS updates, converted from (CARB 2020; 2021; 2022)
Hydrogen (gCO_2e/kg)	13,393		LCFS weighted mix: 33% renewable, converted from (CARB 2020)

LCFS = Low Carbon Fuel Standard

References provided at end of presentation

Sensitivity of CY 2019 first-year GHG reductions per vehicle:

Carbon intensity

Carbon intensity (CI) scenario	All	PHEV	BEVx	BEV	FCEV
Primary (LCFS 2019 CI)	3.5	3.0	2.9	3.8	2.2
Gasoline Low CI	2.9 (-19%)	2.4 (-18%)	2.3 (-19%)	3.1 (-19%)	1.5 (-32%)
Gasoline High CI	3.8 (+8%)	3.2 (+8%)	3.1 (+9%)	4.1 (+8%)	2.5 (+15%)
Electricity Low CI	3.9 (+10%)	3.2 (+8%)	3.2 (+12%)	4.2 (+11%)	n.a
Electricity High CI	3.0 (-16%)	2.6 (-13%)	2.3 (-19%)	3.1 (-17%)	n.a
Hydrogen Low CI	3.6 (+1%)	n.a	n.a	n.a	3.2 (+48%)
Hydrogen High CI	3.5 (-1%)	n.a	n.a	n.a	1.1 (-48%)

Primary Inputs: Fuel Efficiencies

Vehicle	CY 2019 Ave. of model-/MY-specific values	CY 2020 Ave. of model-/MY-specific values	Approach, Sources
PHEV (on electricity, on gasoline)	3.3 mi/kWh, 45 mi/gal	3.4 mi/kWh, 47 mi/gal	EPA rating for specific model/MY, derived from (DOE and EPA 2021)
BEVx (on electricity, on gasoline)	3.1 mi/kWh, 31 mi/gal	3.1 mi/kWh, 31 mi/gal	
BEV	3.4 mi/kWh	3.4 mi/kWh	
FCEV	65 mi/kg	64 mi/kg	
Baseline Vehicle	28.4 mi/gal	28.5 mi/gal	CA-sales-weighted average of EPA ratings for 30 top-selling light-duty gasoline models in each MY, **calculated** using data from (DOE and EPA 2021) and (IHS Markit 2021)

Ave. = average. MY = model year. mi = mile. kWh = kilowatt-hour. gal = gallon.
Fuel efficiency ratings: EPA-adjusted combined city/hwy

Sensitivity of CY 2019 first-year GHG reductions:
Baseline-vehicle fuel efficiency

Baseline-vehicle fuel efficiency scenario	Average first-year GHG reductions per vehicle (tCO_2e)
Primary (CA sales-weighted average by MY)	3.5
U.S. production-weighted car-and-truck average by MY	4.2 (+19%)
30 MPG	3.3 (-7%)
40 MPG	2.1 (-40%)
50 MPG	1.4 (-60%)
Most fuel-efficient gasoline model each MY	1.0 (-71%)

Primary Inputs: Operation Timeframe

Operation Timeframe	CY 2019 & CY 2020	Source
PHEVs	150,000 miles	ZEV regulation battery warranty mileage requirement (California Code of Regulations 2009; 2012)
Other EV types	100,000 miles	Typical battery warranty mileage (EERE, 2020)

Sensitivity of CY 2019 first-year GHG reductions: Operation timeframe

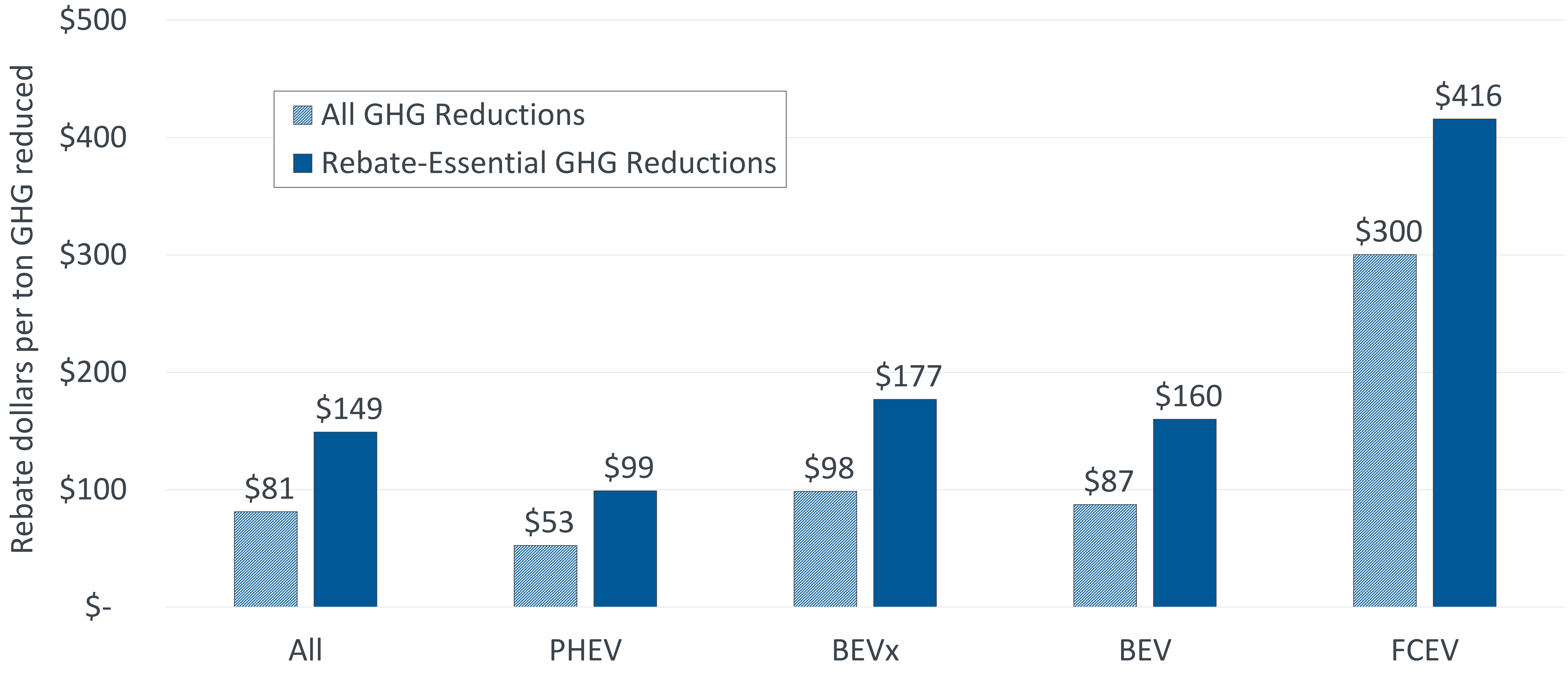
Operation timeframe scenario	Average operation-life GHG reductions per vehicle (tons)	Rebate dollars per ton GHGs reduced
Primary input (100,000-/150,000-mile battery warranty life)	30	$81
2.5-year rebate "project life" (CARB 2019)	9 (-71%)	$279 (+243%)
6-year ownership (Demuro 2019)	21 (-31%)	$117 (+44%)
100,000 miles	28 (-9%)	$89 (+10%)
11.2-year average CA vehicle age (Auto Innovators 2021b)	40 (+31%)	$62 (-23%)
150,000 miles	41 (+36%)	$60 (-27%)
15-year project-comparison life (CARB 2019)	53 (+75%)	$46 (-43%)
200,000 miles	55 (+81%)	$45 (-45%)

ton GHGs = metric ton of CO_2-equivalent emissions.

References provided at end of presentation, in the IEPEC paper, and/or in the precursor article in the journal *Energies*

CVRP *Rebate-Essential* Cost-Effectiveness (Warranty Life)

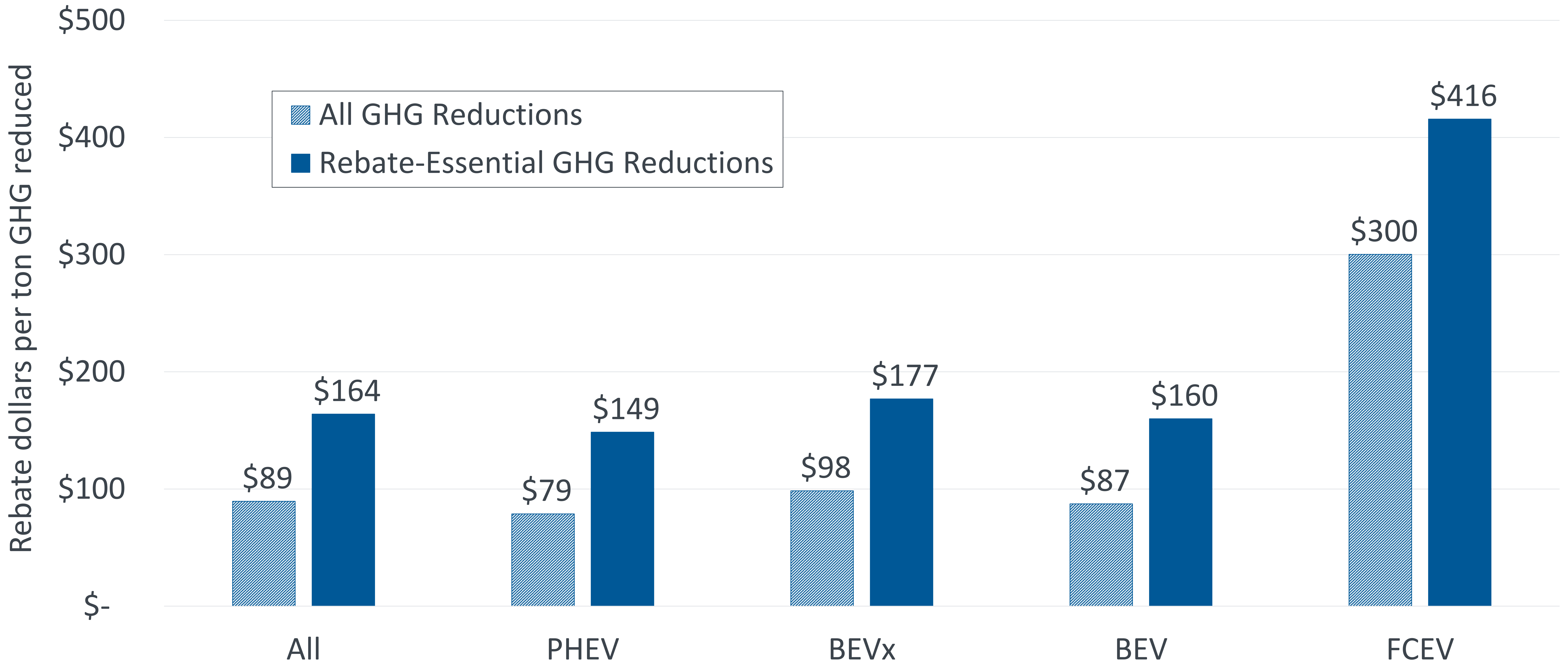
by Vehicle Category, 2019 Purchases/Leases



ton GHG = metric ton of CO_2-equivalent emissions

CVRP *Rebate-Essential* Cost-Effectiveness (100k-Mile Life)

by Vehicle Category, 2019 Purchases/Leases

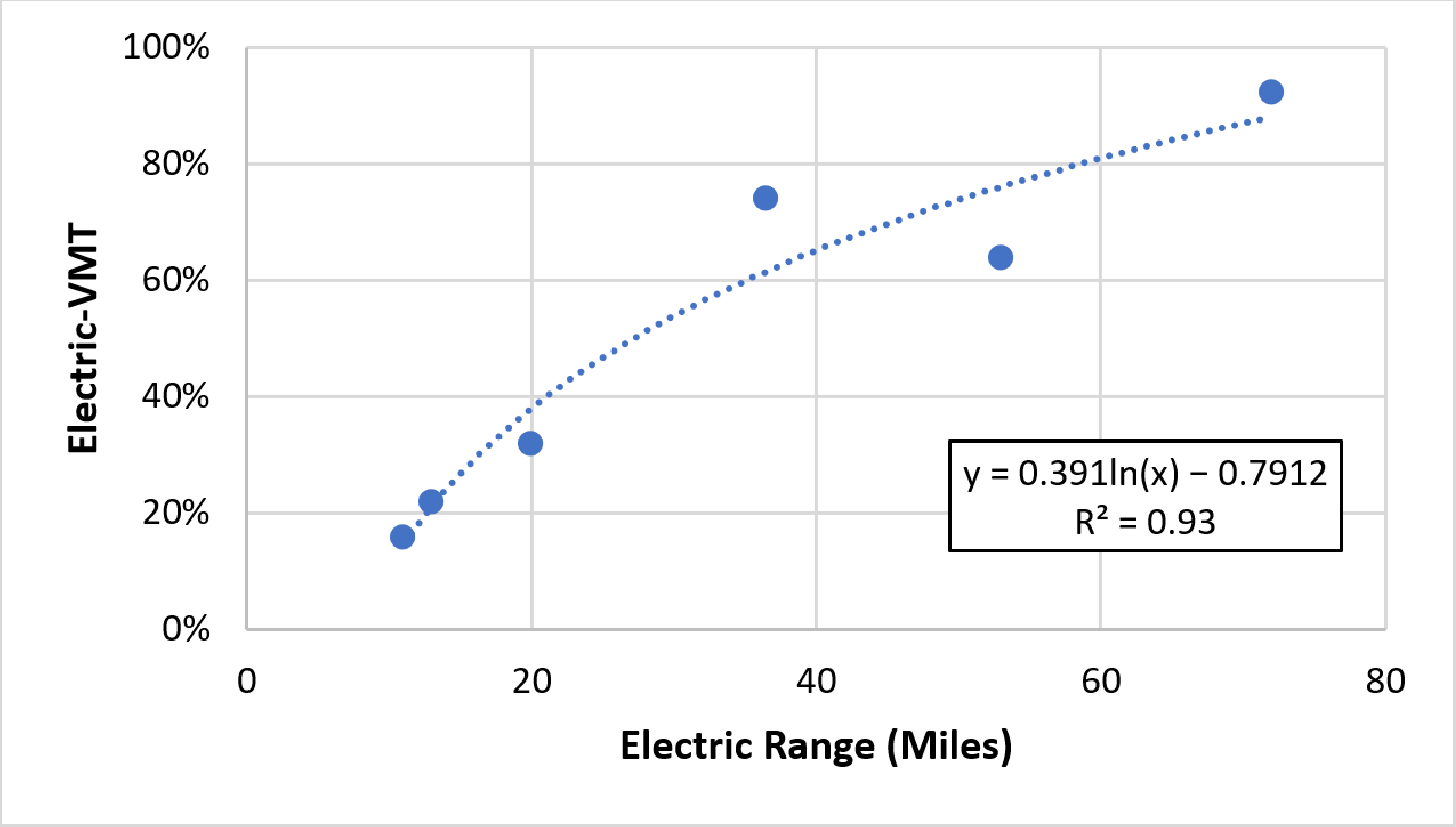


ton GHG = metric ton of CO_2-equivalent emissions

Primary Inputs: Percent Electric Vehicle Miles Traveled

CALIFORNIA CLEAN VEHICLE REBATE PROJECT

Vehicle	CY 2019	CY 2020	Approach, Sources
PHEV (Ave. of model-/MY-specific values)	54%	56%	Model-/MY-specific percentage from literature when available (Tal, et al. 2019), (CARB 2017) or calculated as a function of electric range using data from (DOE and EPA 2018), (Tal, et al. 2019), (CARB 2017), (INL 2015), (Carlson 2015), (Duhon, et al. 2015), (Boston and Werthman 2016)
BEVx	92%	92%	(CARB 2017)



Primary Inputs: Annual Vehicle Miles Travelled (VMT)

CALIFORNIA CLEAN VEHICLE REBATE PROJECT™

Vehicle	Annual VMT	Approach, Sources
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)

References provided at end of presentation

Sensitivity of CY 2019 first-year GHG reductions: Annual VMT

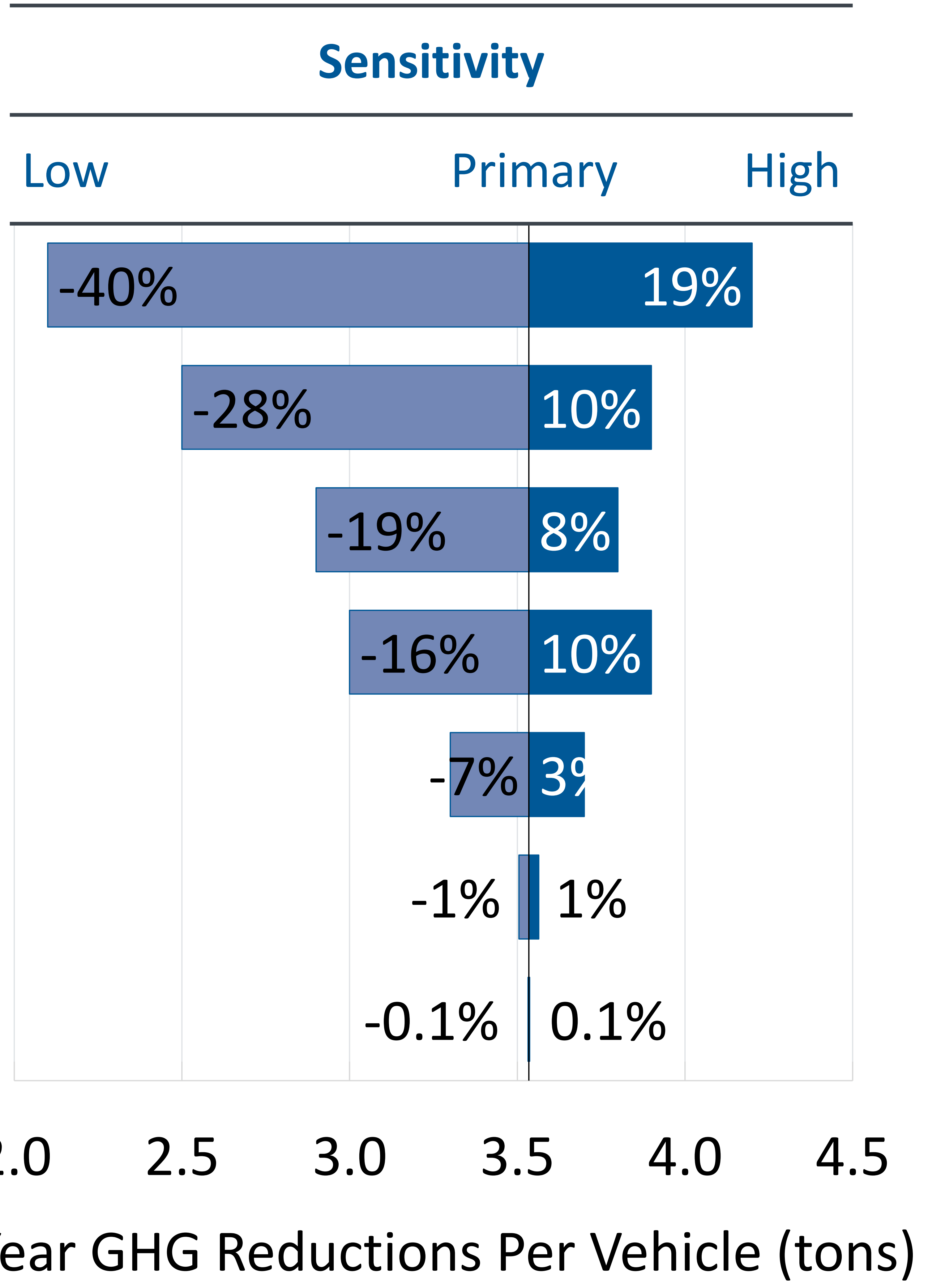
Annual VMT scenario	Average first-year GHG reductions per vehicle (tCO_2e)
Primary (UC Davis survey data)	3.5
NHTS 2017 CA add-on	2.5 (-28%)
CEC Consumer Vehicle Survey	2.9 (-19%)
UC Davis on-board recorder data	3.9 (+9%)
Highest for each technology type (CEC and UC Davis)	3.9 (+10%)

First-Year Input Values & Sensitivity Analysis

CALIFORNIA CLEAN VEHICLE REBATE PROJECT

Input Values & Ranges Tested

Inputs	Low	Primary	High
Baseline Fuel Efficiency (MPG)	40	28.3 or 28.7 (avg = 28.4)	24.9 or 25.7 (avg = 25.0)
Annual VMT	-23% to -40%	10,484 to 13,475 (avg = 12,884)	+0% to +15%
Gasoline Carbon Intensity (gCO_2e/gal)	9,214	10,799	11,518
Electricity Carbon Intensity (gCO_2e/kWh)	449	273	162
PHEV Electric Operation	12%	27% to 72% (avg = 54%)	74.5%
Hydrogen Carbon Intensity (gCO_2e/kg)	+41%	13,393	-41%
BEVx Electric Operation	84%	92%	100%



VMT = vehicle miles traveled
ton GHGs = metric ton of CO_2-equivalent emissions

GHG Reduction & Cost-Effectiveness: All Rebated Vehicles

2019 Purchases/Leases, by Rebate Type

Rebate type	Total vehicles	Average first-year reductions per vehicle (tons)	Average warranty-life reductions per vehicle (tons)	Total warranty-life GHG reductions (tons)	Rebate dollars per warranty-life ton GHGs reduced
Standard Rebate	*N* = 56,688 (90%)	3.5	30	1,715k (90%)	$75
Low-/Moderate-Income Increased Rebate	*N* = 6,408 (10%)	3.5	31	198k (10%)	$137
All	***N* = 63,096**	**3.5**	**30**	**1,913k**	**$81**

ton GHGs = metric ton CO_2e.
U.S. EPA GHG equivalency from: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Methodology: Rebate Influence

Rebate-Essential or *Rebate-Important* GHG Reductions

- Survey respondents:
  - If a participant was known to be *Rebate-Essential* or *Rebate-Important*, their emission reductions are included in *Rebate-Essential* or *Rebate-Important* metrics, respectively
  - if a participant was known *not* to be *Rebate-Essential* or *Rebate-Important*, their emission reductions are *not* included
- Survey non-respondents:
  - if it was unknown whether a participant was *Rebate-Essential* or *Rebate-Important*, a fraction of their emission reductions are included, equal to the percentage of *Rebate Essentiality* or *Rebate Importance* among their vehicle- and rebate-type cohort

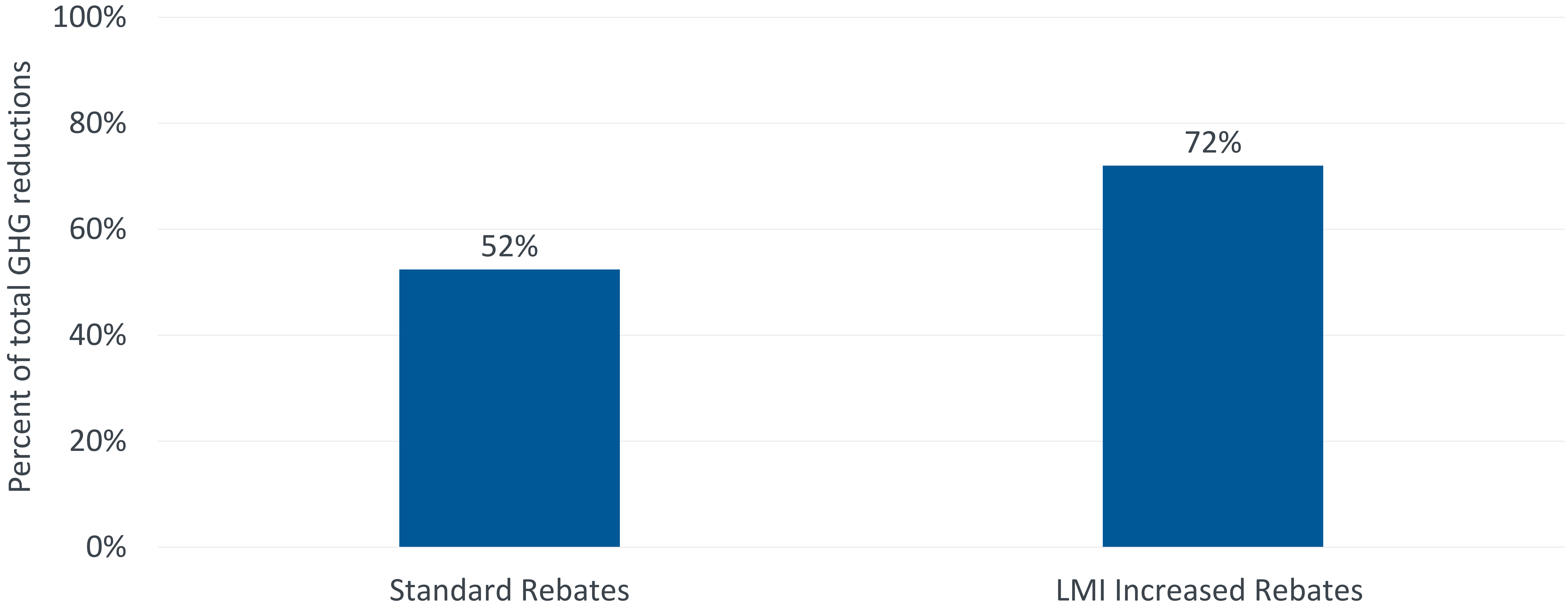
Sensitivity Analysis: Rebate Influence

First-Year

- Sensitivity of *Rebate-Essential* reductions to the *Rebate Essentiality* survey percentages was tested by adding or subtracting 15 percentage points from each
  - +/- 15pp is far more than the expected margin of error for these percentages (based on precursor work), to account for any unknown response or selection biases
- This changed the *Rebate-Essential* GHG reductions estimate by +/- 13%

CVRP *Rebate-Essential* Reductions (Warranty Life)

by Rebate Type, 2019 Purchases/Leases

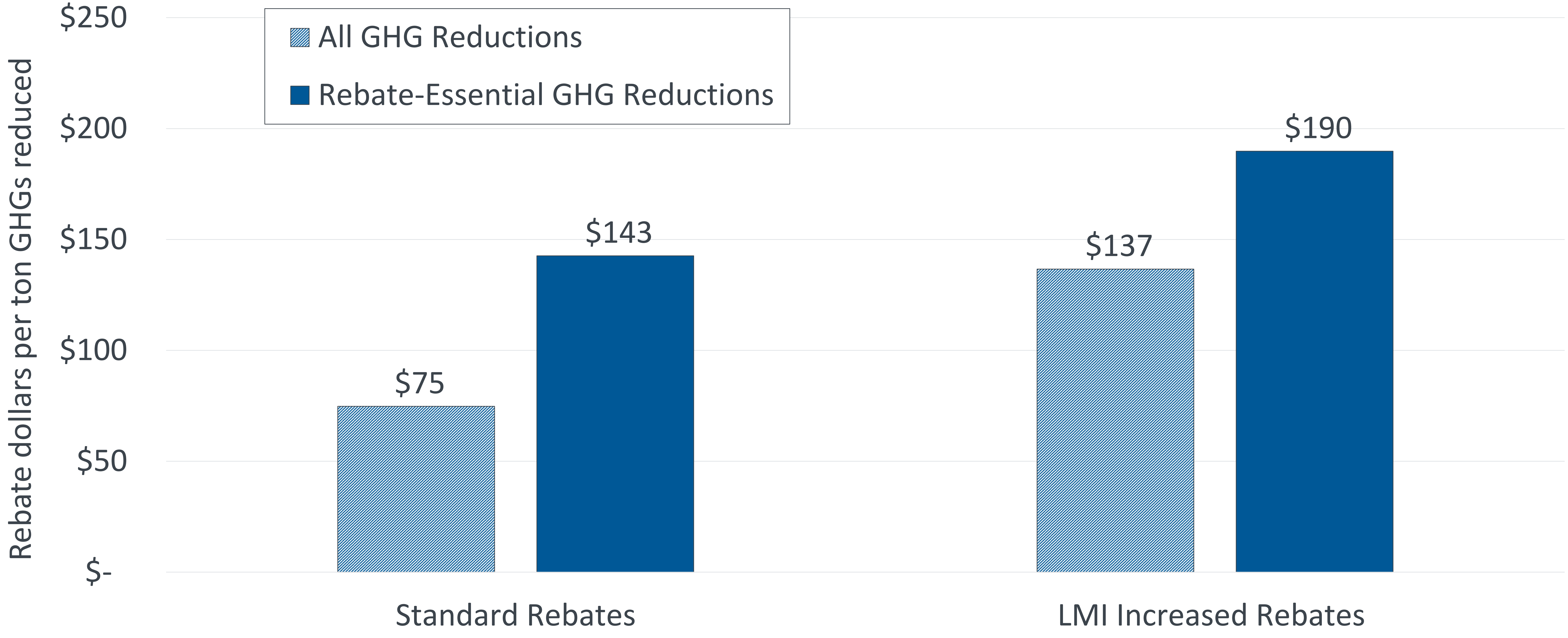


LMI = Low-/Moderate-Income

CVRP *Rebate-Essential* Cost-Effectiveness (Warranty Life)

by Rebate Type, 2019 Purchases/Leases

CALIFORNIA CLEAN VEHICLE REBATE PROJECT™



LMI = Low-/Moderate-Income

ton GHGs = metric ton of CO_2-equivalent emissions

Comparisons: Inputs

Carbon Intensity

Fuel	Life of Program Study [CY 2010–2018] (Pallonetti and Williams 2021)	Funding Plan [MY 2019] (CARB 2019)	Current Study [CY 2019]
Gasoline (gCO_2e/gal)	11,518 (2010 estimate)	11,518 (2010 estimate)	10,799 (2019 estimate)
Electricity (gCO_2e/kWh)	379 (2010 estimate)	338 (2016 estimate)	273 (2019 estimate)
Hydrogen (gCO_2e/kg)	13,393	13,392	13,393

Comparisons: Inputs
Fuel Efficiency

Vehicle	Life of Program Study* [CY 2010–2018] (Pallonetti and Williams 2021)	Funding Plan [MY 2019] (CARB 2019)	Current Study* [CY 2019]
PHEV (mi/kWh, e-VMT, MPG)	3.0, 49%, 42	3.6, 40%, 43	3.3, 54%, 45
BEVx (mi/kWh, e-VMT, MPG)	3.4, 92%, 38	n.a.	3.1, 92%, 31
BEV (mi/kWh)	3.1	3.6	3.4
FCEV (MPkg)	66	89	65
Baseline Gasoline (MPG)	28.2	34.4	28.4

* averages of model- and MY-specific values for EVs & average of MY-specific values for Baseline

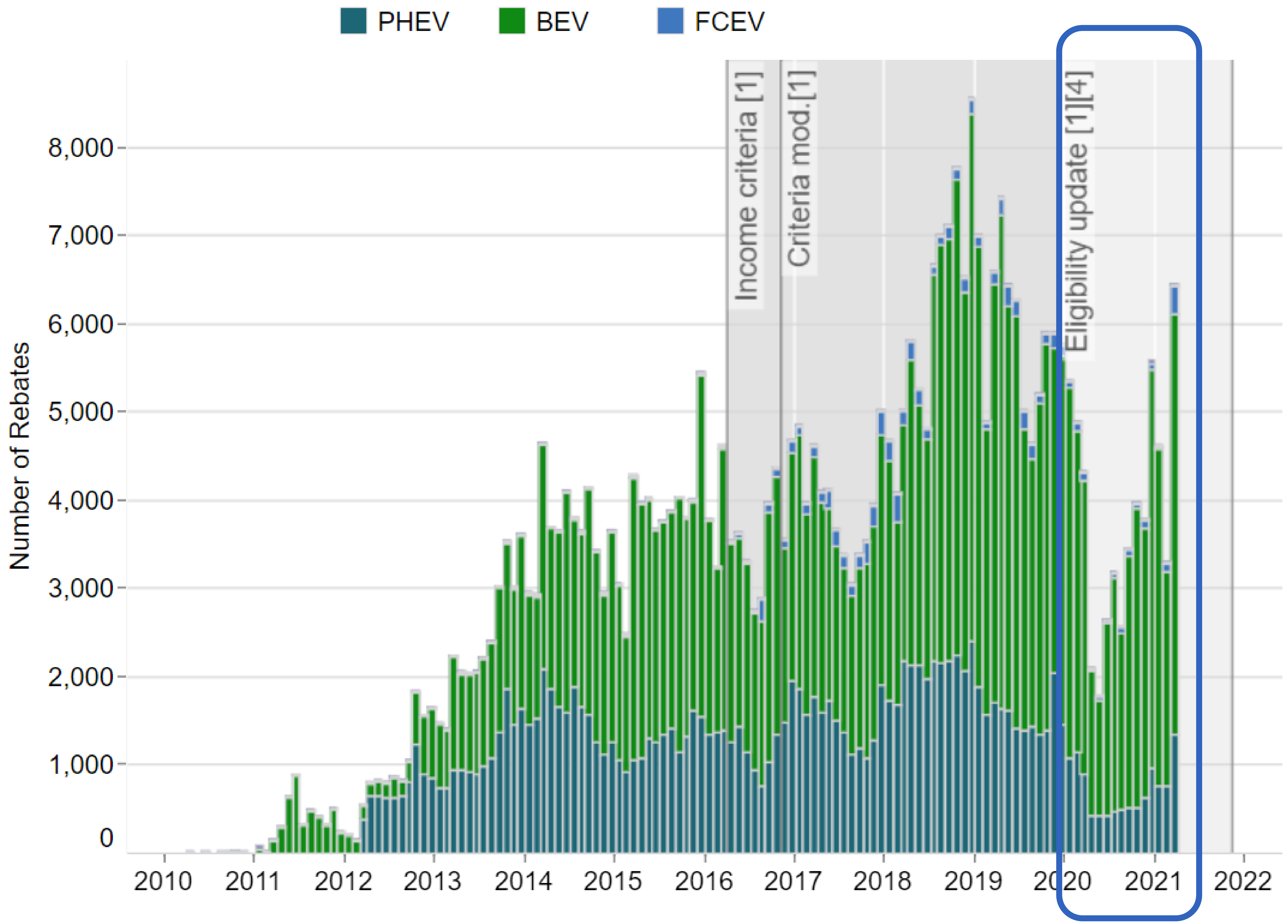
Comparisons: Outputs

Funding Plan

Funding Plan [MY 2019] (CARB 2019)				Current Study [CY 2019]*			
Technology Type	Avg. GHG Reductions Per Mile (grams)	First-Year VMT	Avg. First-Year GHG Reductions Per Vehicle (tons)	Technology Type	Avg. GHG Reductions Per Mile (grams)	First-Year VMT	Avg. First-Year GHG Reductions Per Vehicle (tons)
PHEV	137	14,855	2.0	PHEV	220 (+60%)	13,475	3.0 (+46%)
BEV	242	11,059	2.7	BEV	299 (+24%)	12,724 (avg.)	3.8 (+43%)
FCEV	185	12,445	2.3	FCEV	174 (-6%)	12,445	2.2 (-6%)

* Note: only minor differences (<2%) present in current study results between MY 2019 and CY 2019; CY presented for comparability to other tables and results.

Approved Applications Over Time: CY 2020 Purchases/Leases



With COVID exemptions, rebate applications for CY 2020 purchases/leases for individuals spanned 1/1/2020 – 4/15/2021.

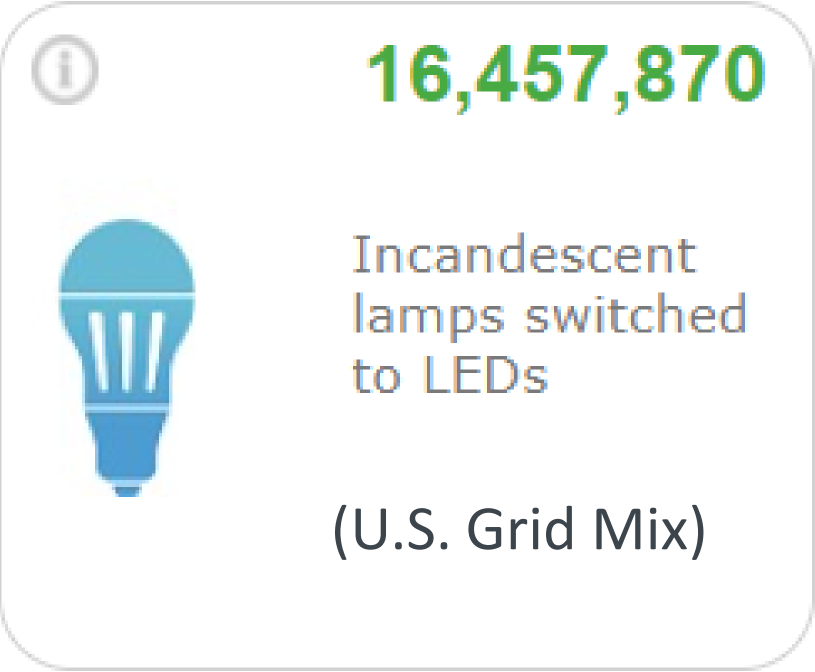
12% applied in 2021.

12/29/21 image from https://cleanvehiclerebate.org/eng/rebate-statistics

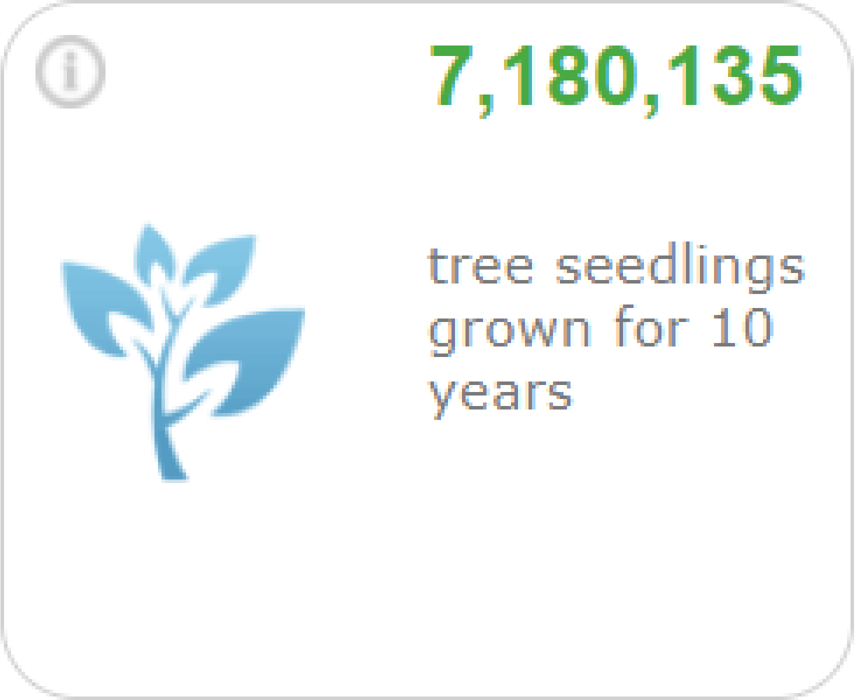
Estimated Greenhouse-Gas Emissions Reductions from *Rebate-Essential* Calendar-Year 2020 Purchases/Leases (draft)

Technology type	Total vehicles	Average first-year GHG reductions per vehicle (tons)	Average warranty-life GHG reductions per vehicle (tons)	Total *Rebate-Essential* warranty-life reductions	Rebate dollars per *Rebate-Essential* warranty-life ton reduced
All	*N* = 37,201 39% Rebate Essential	3.6 tons	30 tons	434k tons	$189/ton

434k tons avoided is the same as…



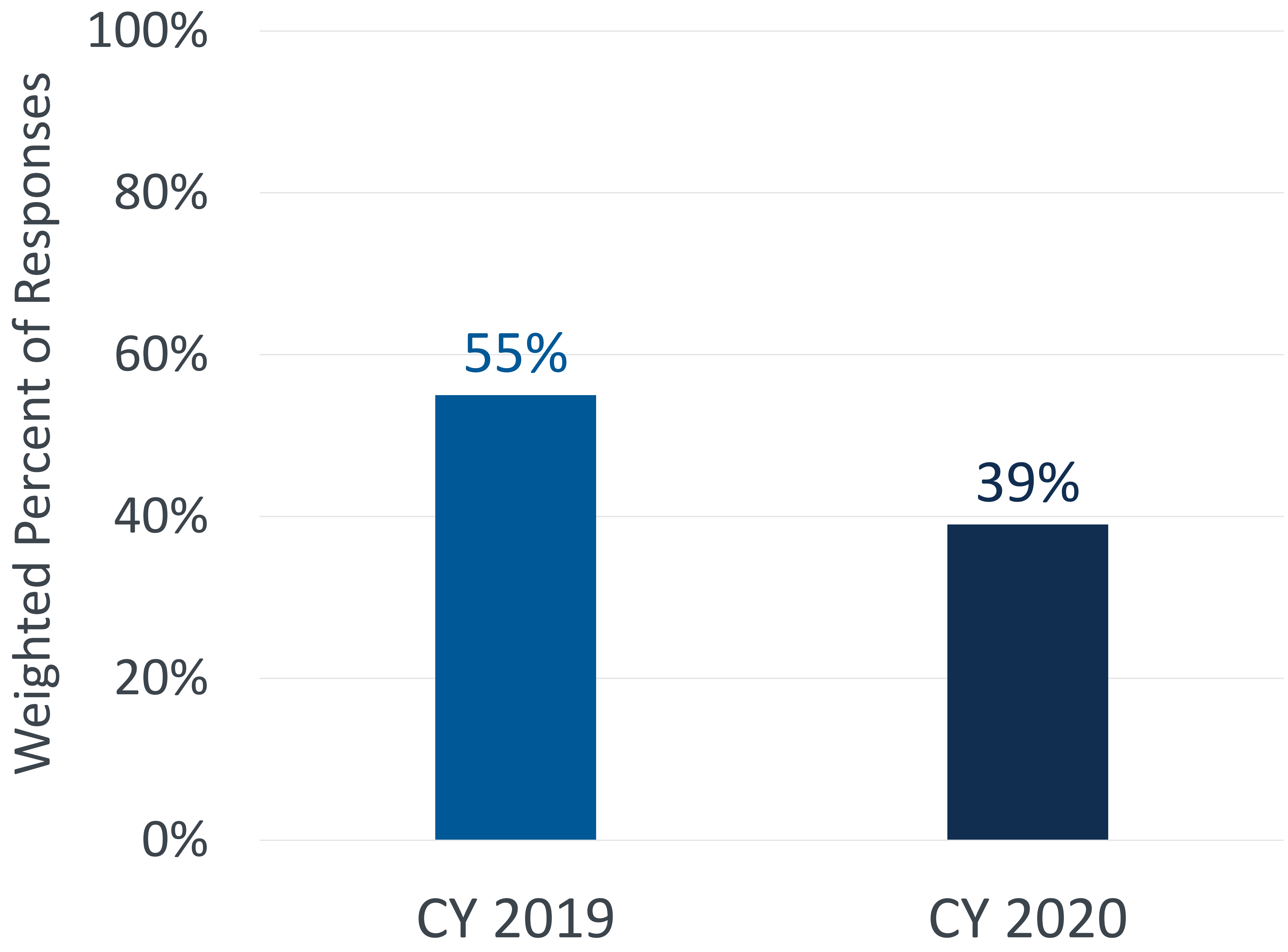
-or-



ton GHGs = metric ton carbon-dioxide-equivalent (CO_2e) emissions.
U.S. EPA GHG equivalency from: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

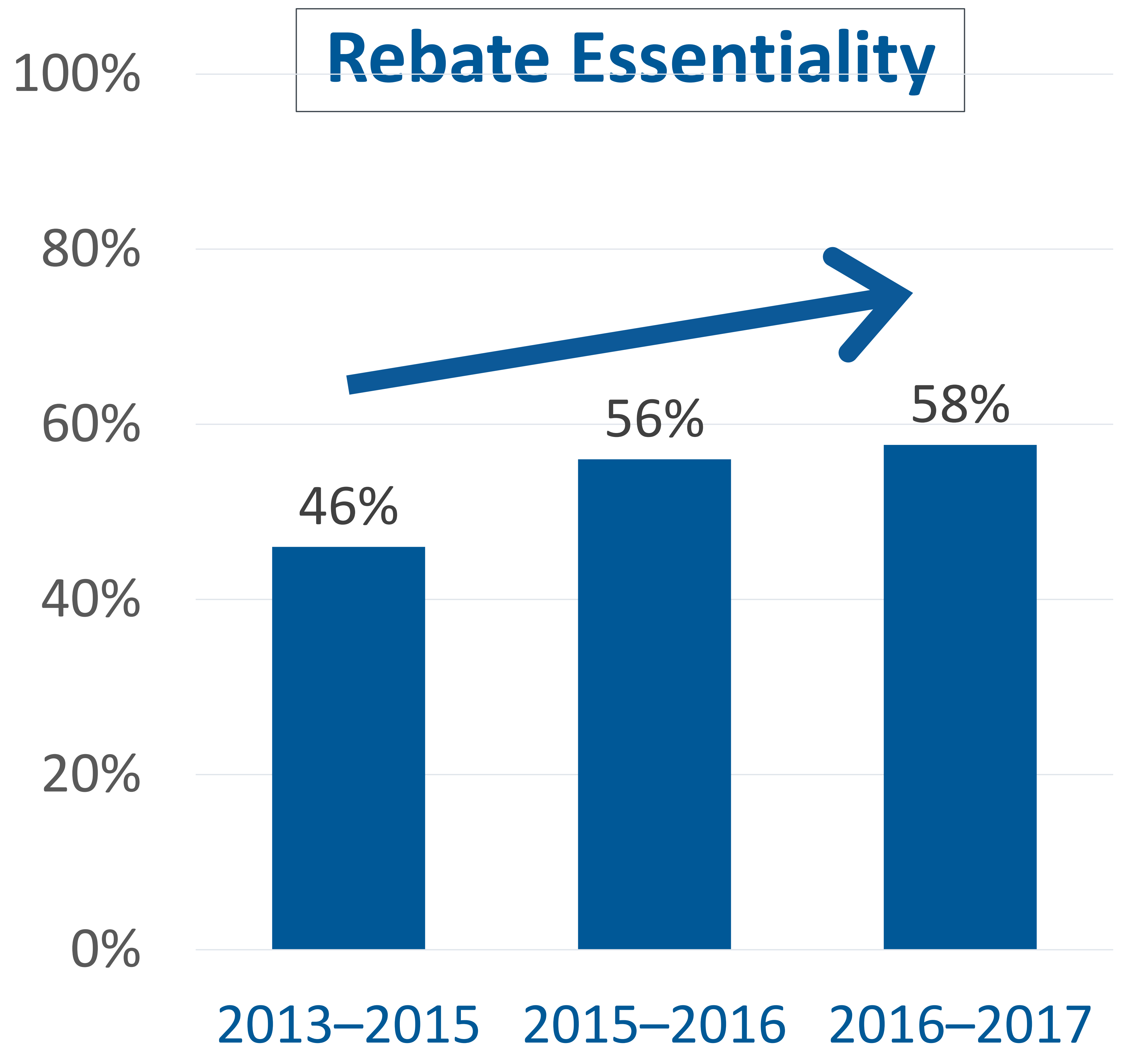
Rebate-Essential Participants: CY 2019 & 2020 Purchases/Leases

Would not have purchased/leased their EV without the state rebate



CVRP Consumer Survey: 2017–2019 edition. Filtered question n = 6,457.
CVRP Consumer Survey: 2017–2020 edition. Filtered question n = 4,418.
Starting 12/2019, PEVs with base MSRP > $60k became ineligible.

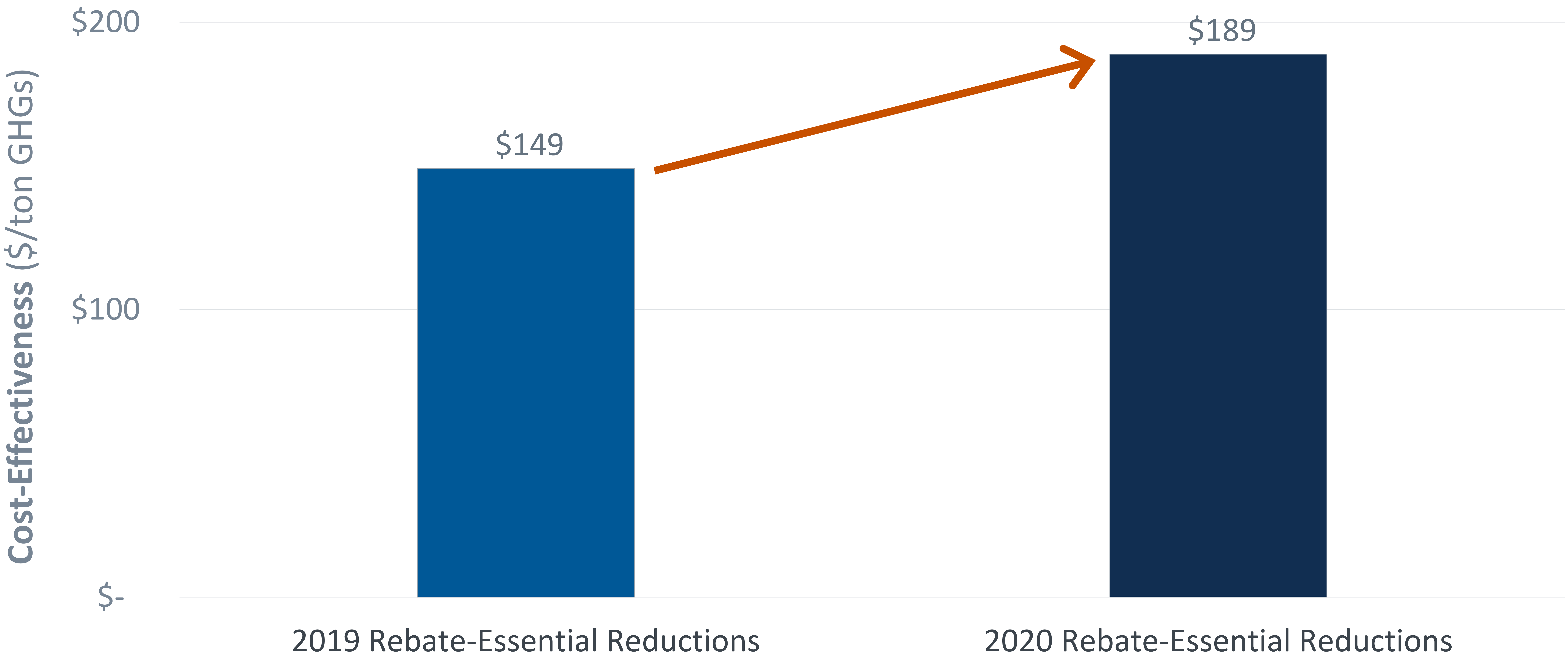
Rebate Essentiality was *Increasing* Over Time



CVRP Consumer Survey. 2013–2015 edition: weighted, n=19,208. 2015–2016 edition: weighted, n=11,457. 2016–2017 edition: weighted, n=9,261

Cost-Effectiveness: Decreased from CY 2019 to draft CY 2020

CALIFORNIA CLEAN VEHICLE REBATE PROJECT



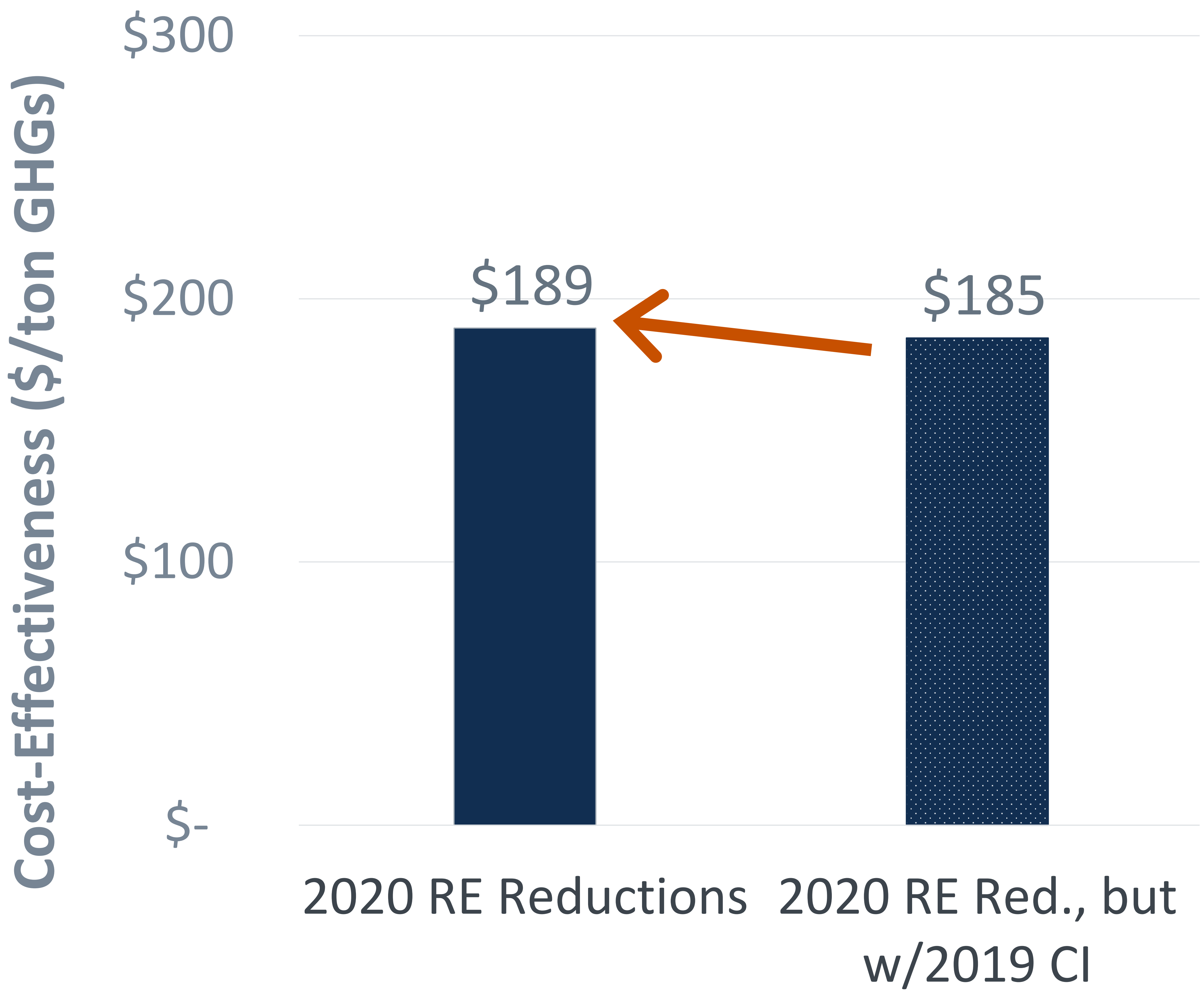
ton GHG = metric ton CO_2e. RE = *Rebate-Essential.* 2020 results based upon draft LCFS inputs.

Good Reasons Exist for Cost-Effectiveness to Worsen

CALIFORNIA CLEAN VEHICLE REBATE PROJECT™

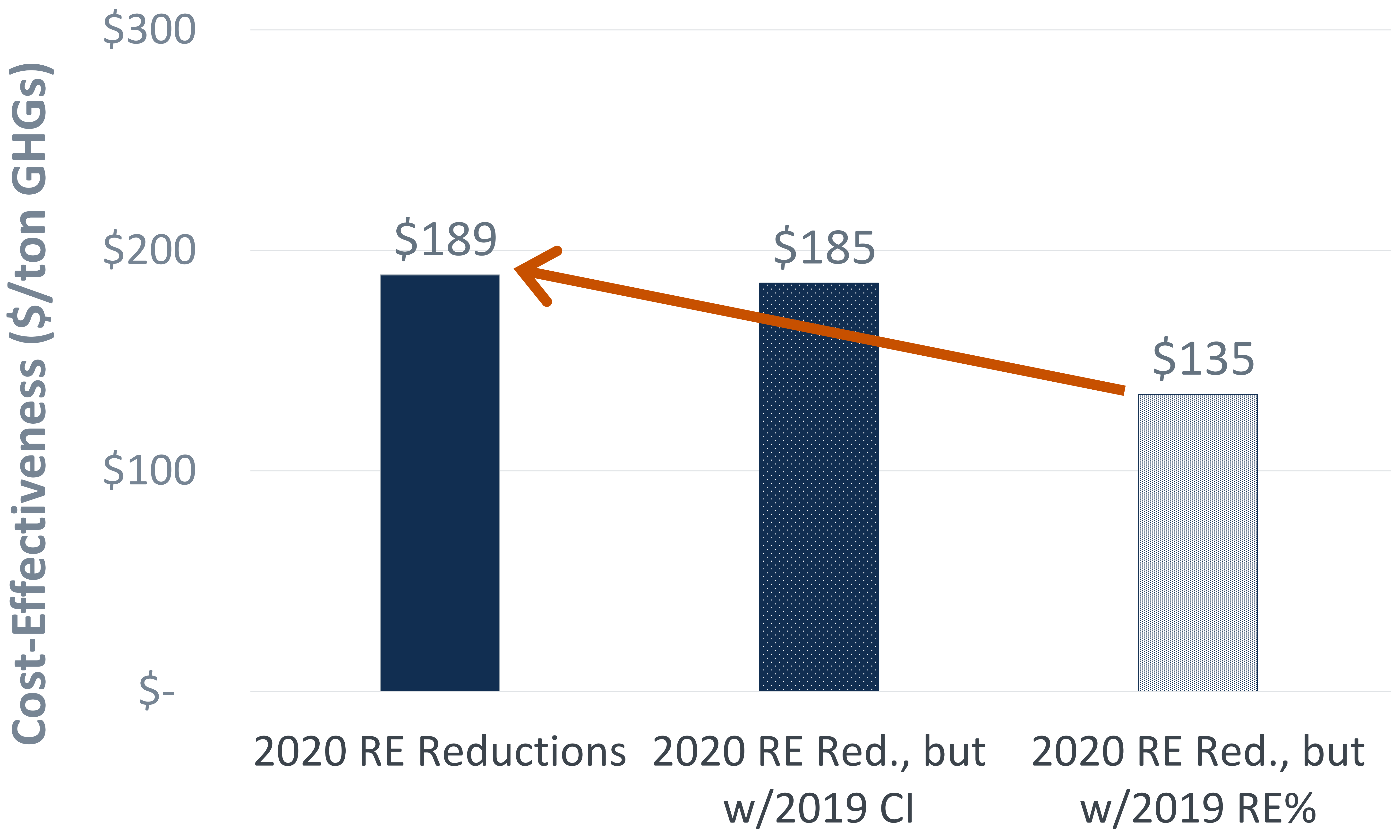
- Greater share of Increased Rebate for Low-/Moderate-Income Consumers
- Greater share of desired technology with higher rebate
- Gasoline improving ("raising the bar")

Improving Gasoline: Decreased Cost-Effectiveness Somewhat (draft)



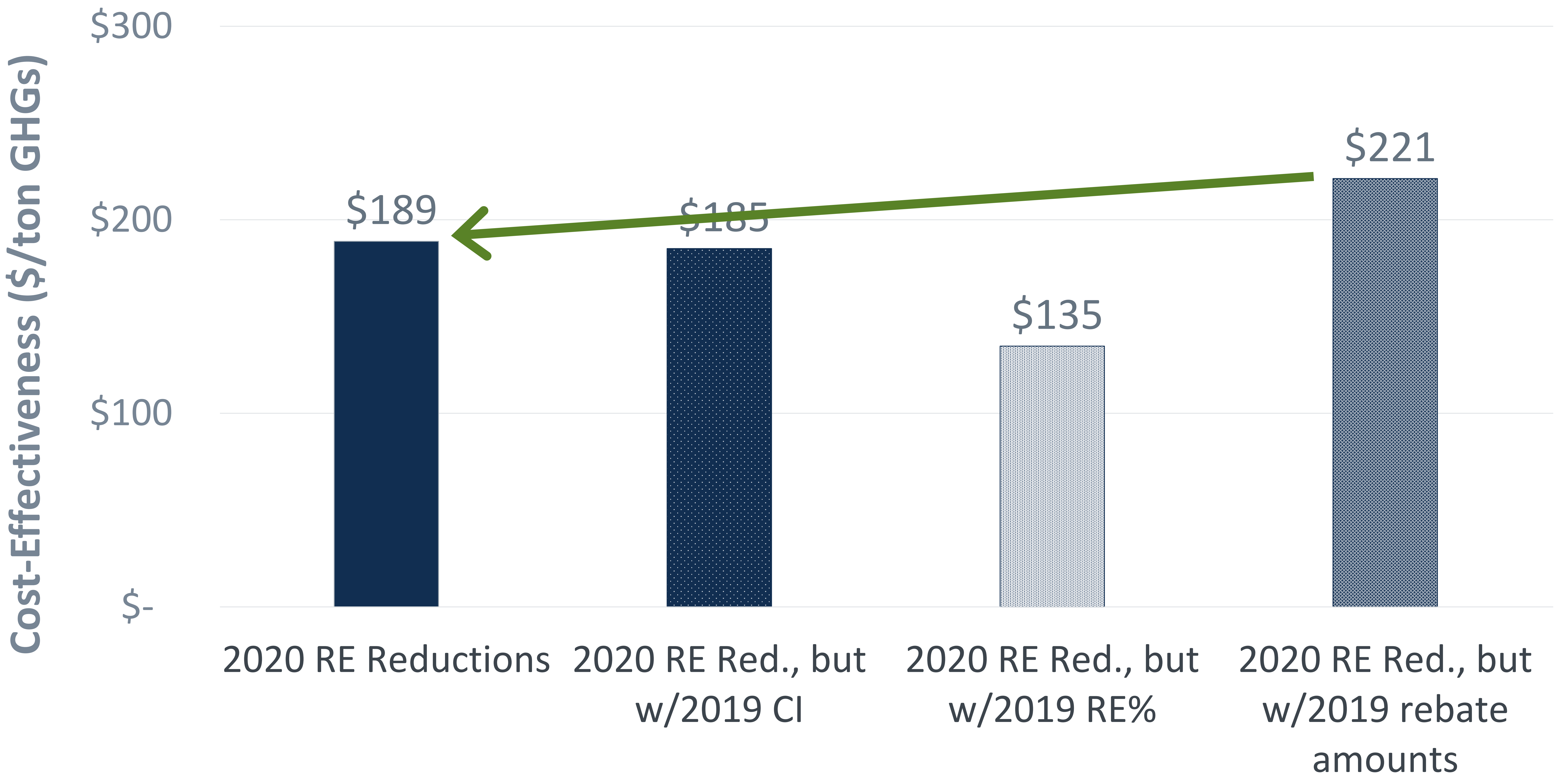
ton GHG = metric ton CO_2e. RE = *Rebate-Essential.* CI = carbon intensity of fuels. 2020 results based upon draft LCFS inputs.

Decreased *Rebate Essentiality*: Decreased Cost-Effectiveness (draft)



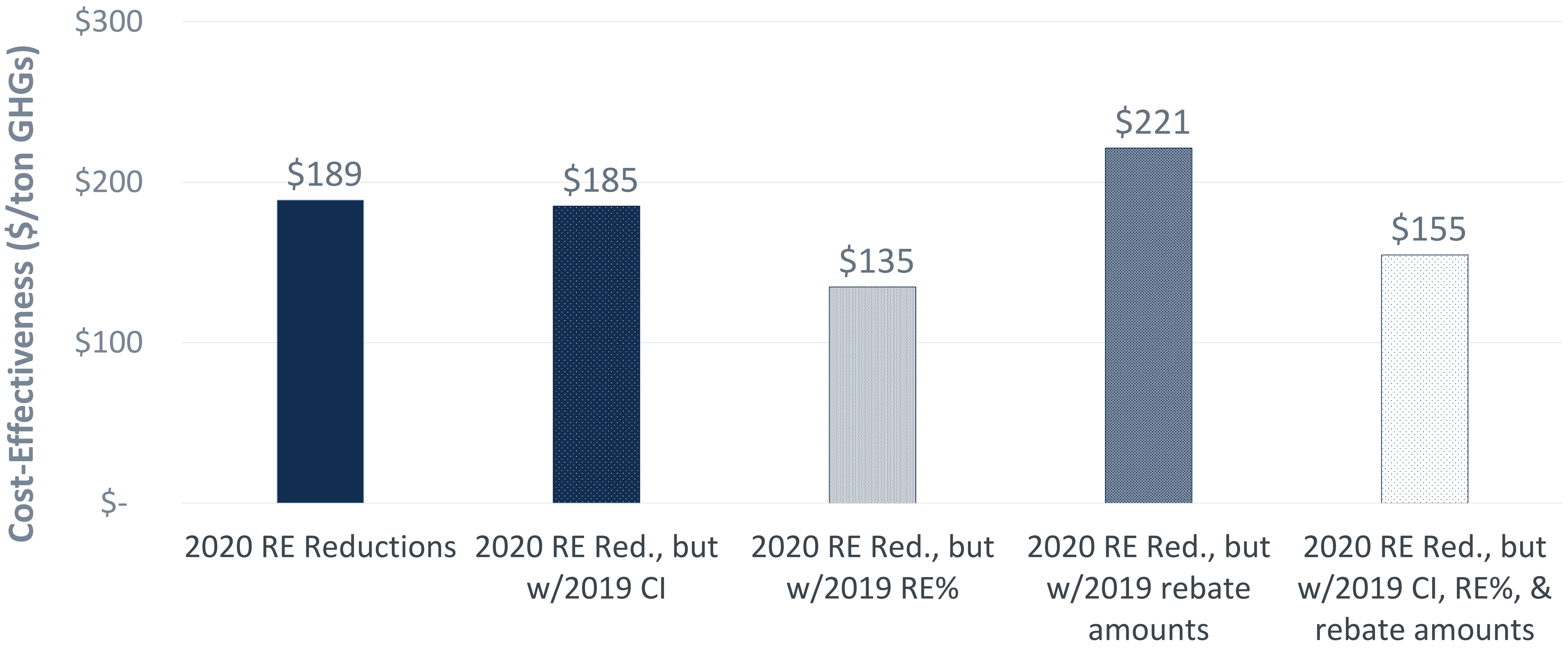
ton GHG = metric ton CO_2e. RE = *Rebate-Essential.* CI = carbon intensity of fuels. 2020 results based upon draft LCFS inputs.

Decreased Rebate Amounts: Increased Cost-Effectiveness (draft)



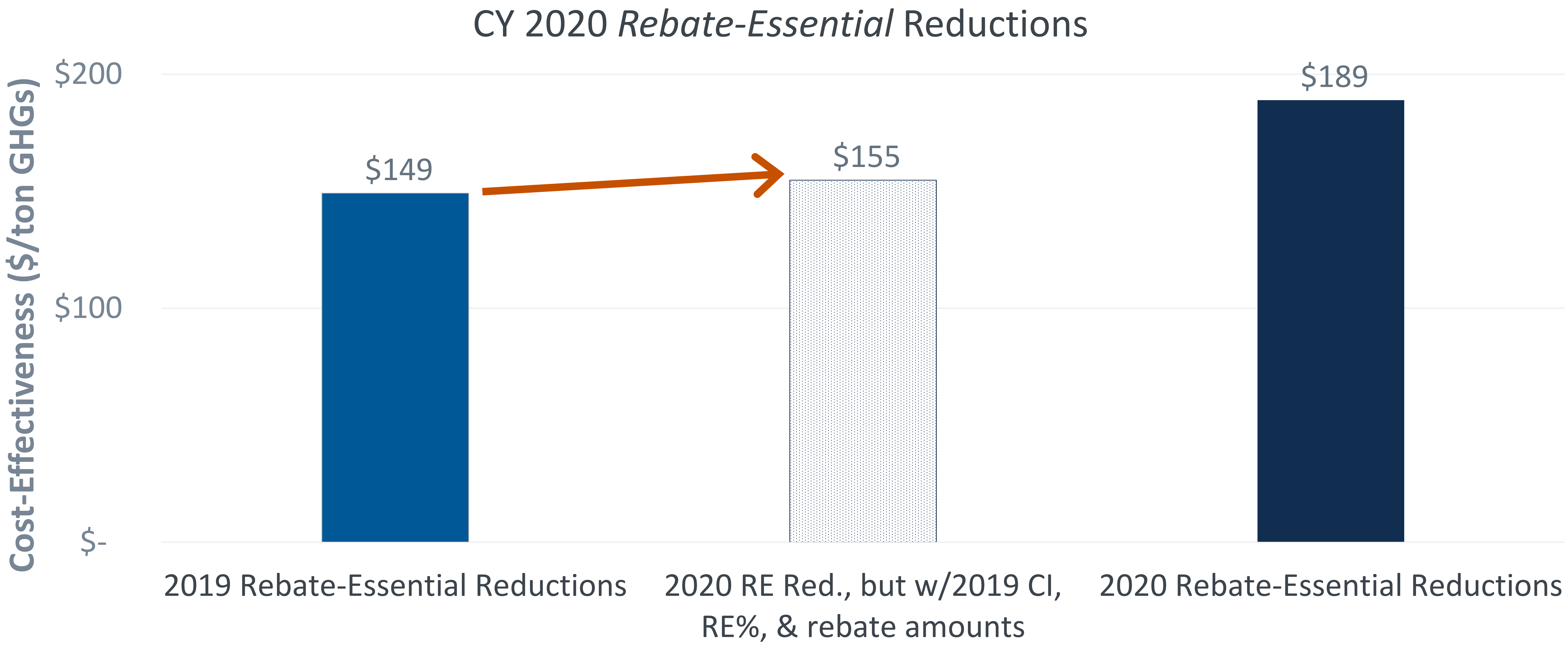
ton GHG = metric ton CO_2e. RE = *Rebate-Essential.* CI = carbon intensity of fuels. 2020 results based upon draft LCFS inputs.

Decomposing the Differences Between 2019 and 2020 (draft)



ton GHG = metric ton CO_2e. RE = *Rebate-Essential.* CI = carbon intensity of fuels. 2020 results based upon draft LCFS inputs.

Changing Vehicle and Rebate Mix: Decreased Cost-Effectiveness (draft)



ton GHG = metric ton CO_2e. RE = *Rebate-Essential.* CI = carbon intensity of fuels. 2020 results based upon draft LCFS inputs.

Rebates: CY 2019 & 2020 Purchases/Leases

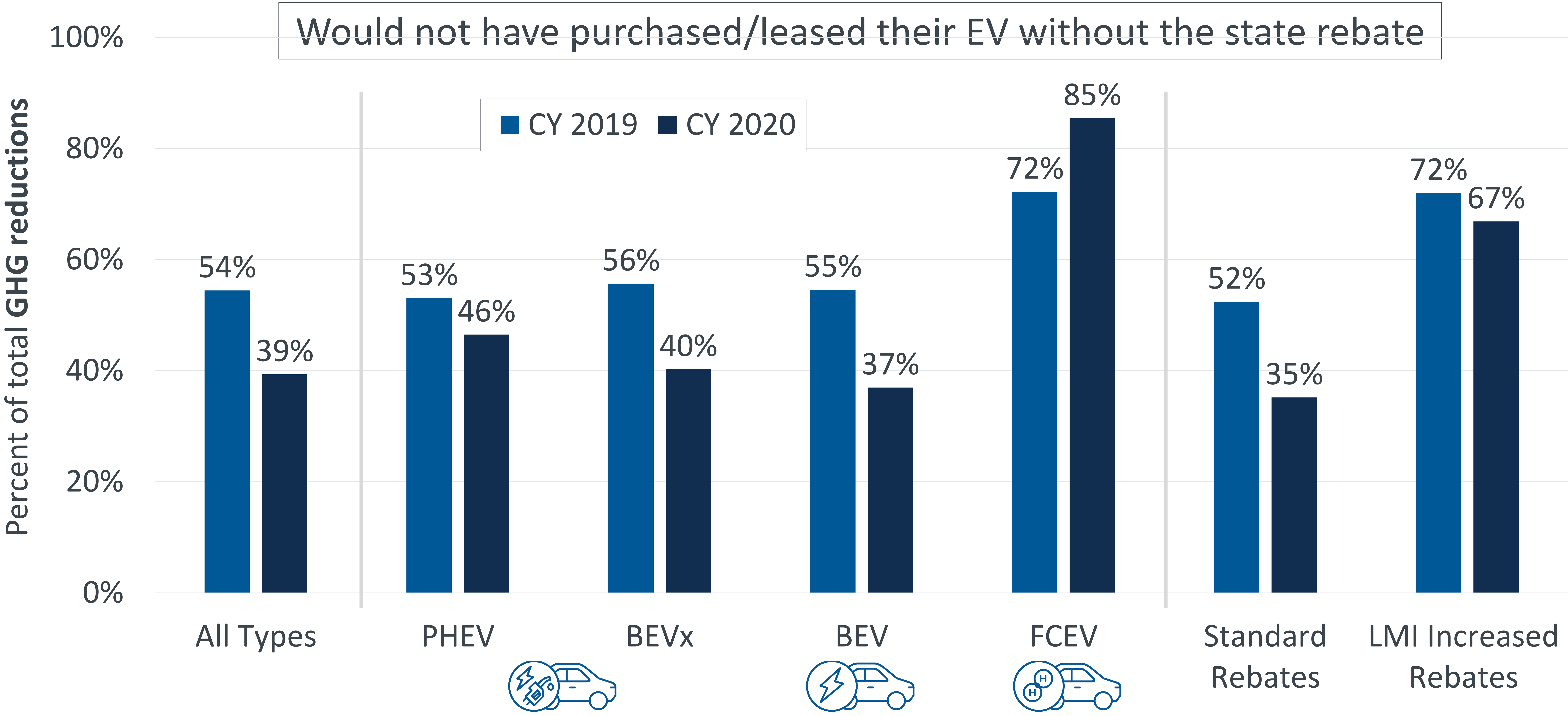
Technology type	2019	2020
PHEV	16,177 (26%)	6,348 (17%)
BEVx	703 (1%)	141 (0.4%)
BEV	44,440 (70%)	29,966 (81%)
FCEV	1,776 (3%)	746 (2%)
Total	**63,096**	**37,201**

Rebate type	2019	2020
Standard Rebates	56,688 (90%)	32,416 (87%)
Lower-Income Increased Rebates	6,408 (10%)	4,785 (13%)
Total	**63,096**	**37,201**

PHEV = plug-in hybrid electric vehicle
BEVx = range-extended battery electric vehicle (BMW i3 REx)
BEV = battery electric vehicle
FCEV = fuel-cell electric vehicle
LMI = Low-/Moderate-Income

Rebate-Essential Reductions: 2019 & Partially Updated 2020

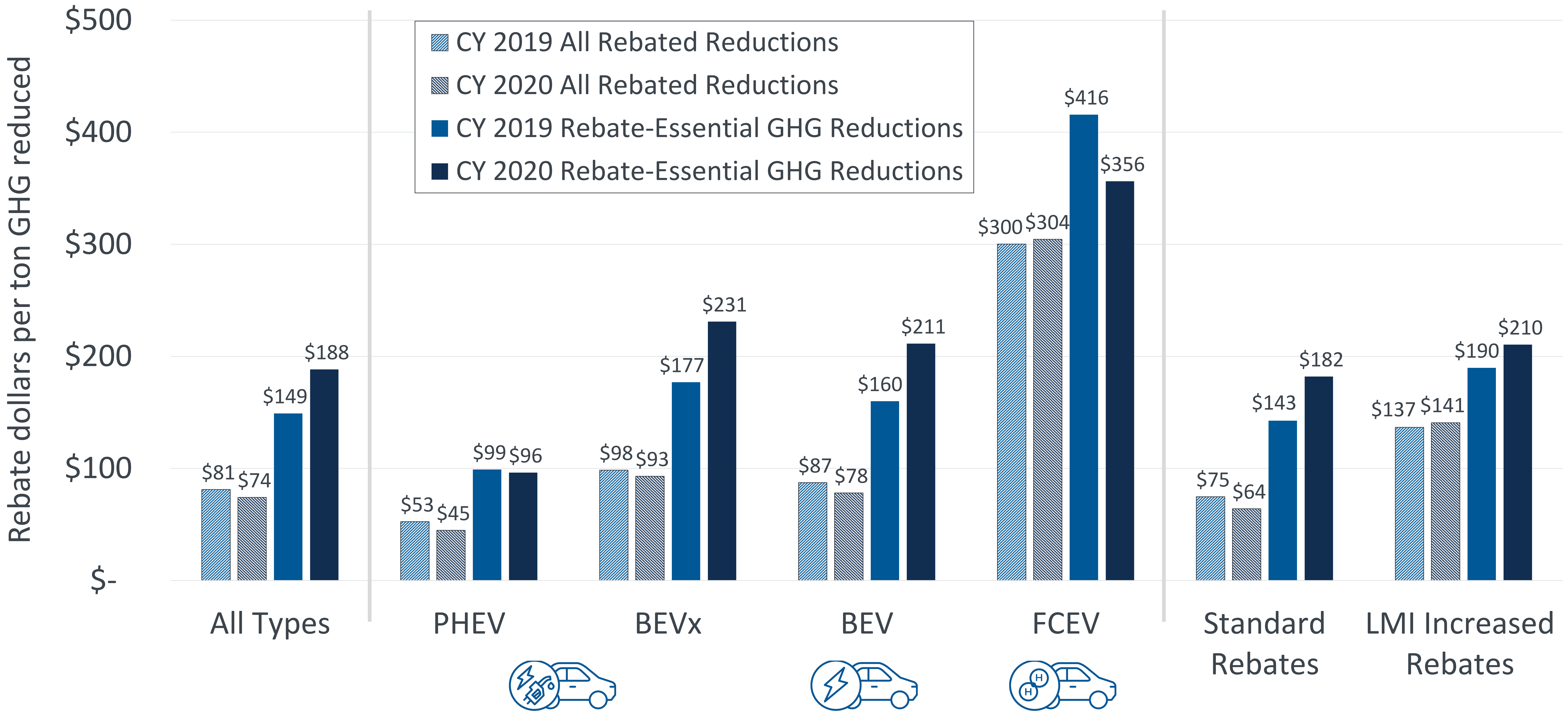
Warranty-Life



LMI = Low-/Moderate-Income

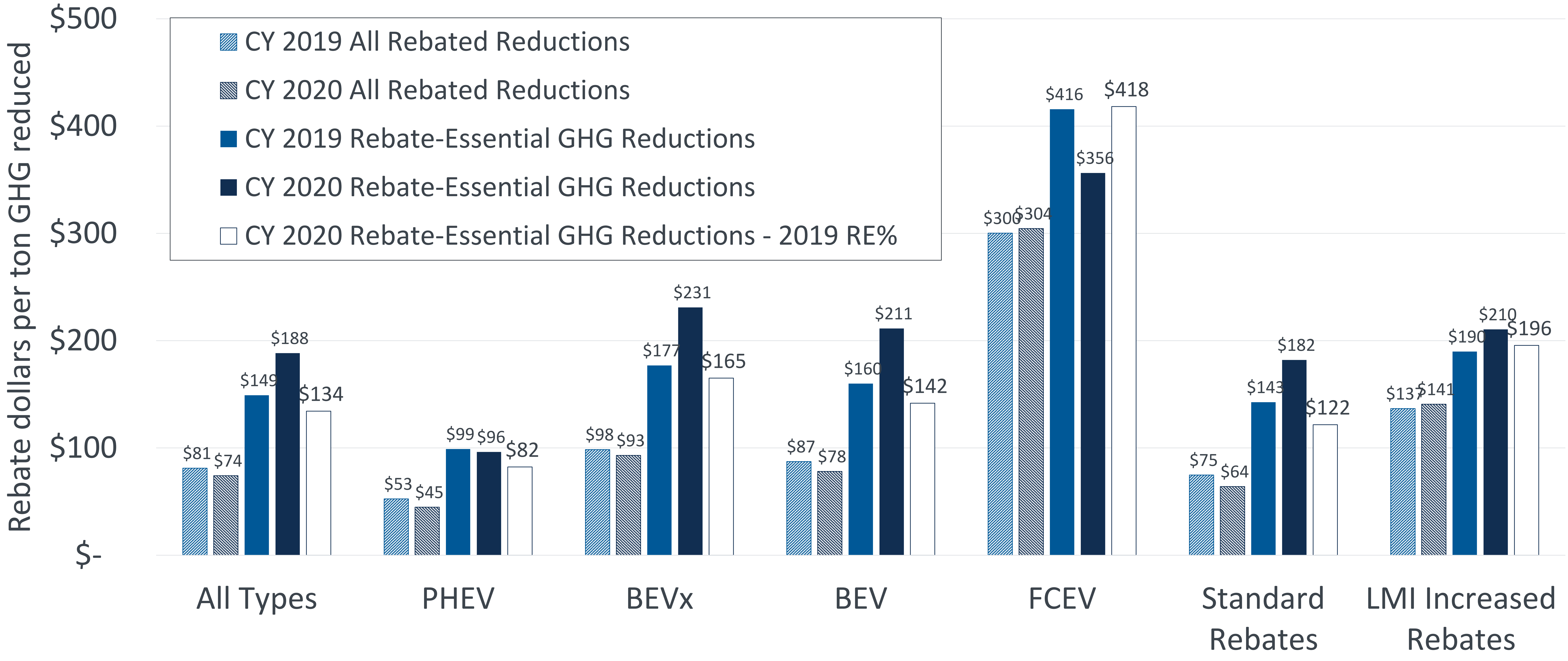
Cost-Effectiveness: 2019 & Partially Updated 2020

Warranty-Life



ton GHG = metric ton of CO_2-equivalent emissions; LMI = Low-/Moderate-Income

Absent Decrease in *Rebate Essentiality*, Trend is Improving Cost-Effectiveness (partially-updated 2020)



Additional Context

Other Presentations With Additional Context

EVs & Consumers Rebated for CY 2019 Purchases/Leases:

- CVRP CY 2019 Data Brief: Vehicle Replacement & Incentive Influence
- CVRP CY 2019 Data Brief: Consumer Characteristics
- CVRP Data Brief: MSRP Considerations
- EV Purchase Incentives: Program Design, Outputs, and Outcomes of Four Statewide Programs with a Focus on Massachusetts

Older, More Polluting Vehicles Replaced by Rebated EVs:

- CVRP CY 2019 Data Brief: Vehicle Replacement & Incentive Influence
- What Vehicles Are Electric Vehicles Replacing and Why?

Additional Select Findings: CY 2019 Rebates (part 1)

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Program design and disruptions shape impacts

Vehicles Rebated

- Predominantly moderate-MSRP models:
  - > 92% with model-minimum MSRP <$40,000 before incentives

Consumers Rebated: Characteristics *and Appropriate Baselines*

- Metrics of race/ethnicity and age becoming comparable to new-vehicle buyers, others trending in right direction
- Home ownership and, in particular, male gender much more frequent among rebated EV consumers
- Household income also higher, but 62% or rebates in CA < $150k, 70% in NY < $200k; different picture than painted by population stats
- New-car buying explains ½ to ⅔ of difference in the income metric between the population and rebate recipients

Paths Forward

- Strategic consumer segments present possible paths toward the mainstream and beyond to increased access

Additional Select Findings: CY 2019 Rebates (part 2)

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Vehicle Replacement

- Increased to 84+%:
  - > 77% were gasoline-fueled vehicles; > half were 5+ years old; > a quarter were 10+ years old
- Indicators of impact tend to be ***increasing***
- PHEVs produced strong replacement rates early, BEVs catching up
- Related research: when compared to buying a *new* non-EV, rebated EVs may be saving >29 tons of GHG emissions per vehicle (12-year life) at costs <$80/ton

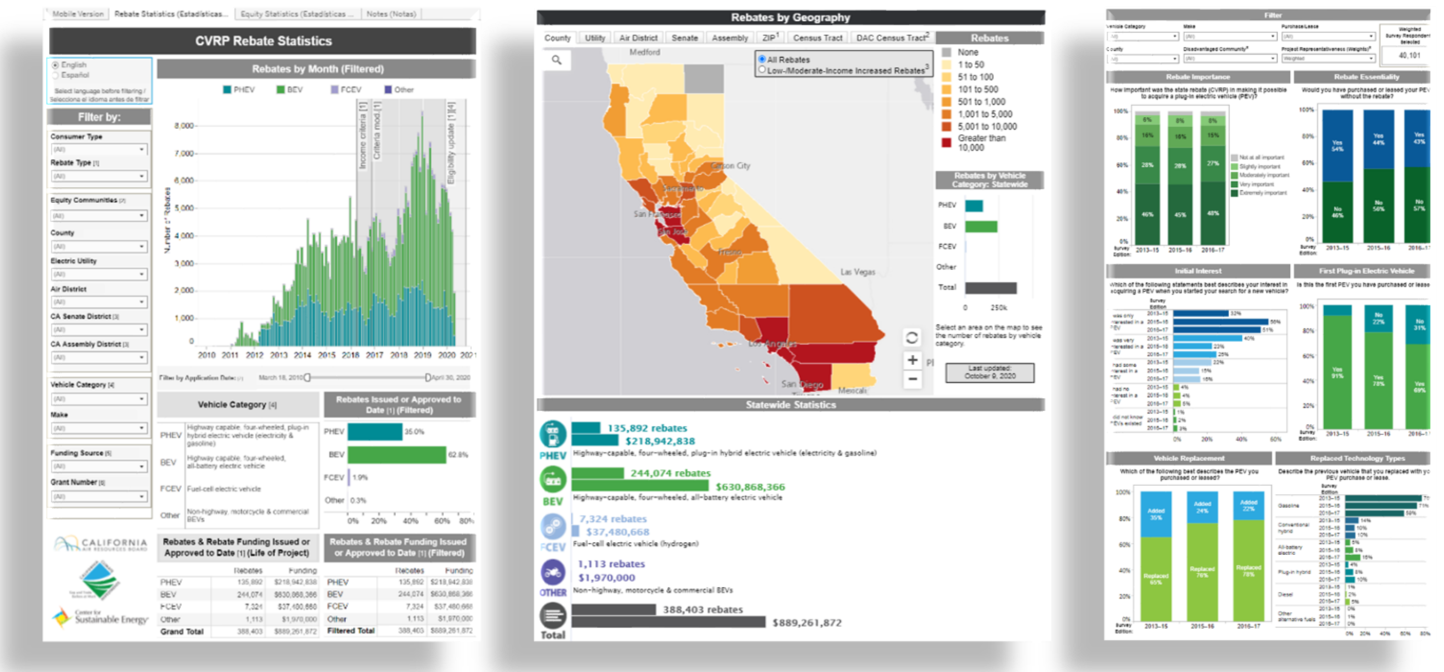
Incentive Influence

- >89% found rebate an important enabler of EV acquisition; half or more would not have purchased/leased without it
- At MSRP greater than $60k, rebate influence decreases substantially
- Attractive offerings (including Tesla products) have somewhat lower *Rebate Essentiality*, but the differences between luxury/non-luxury MSRPs are bigger
- Rebate influence and federal-tax-credit influence are similar
  - Half or more rated federal tax credit an extremely important enabler
  - Down somewhat from 2018 peak before phase out

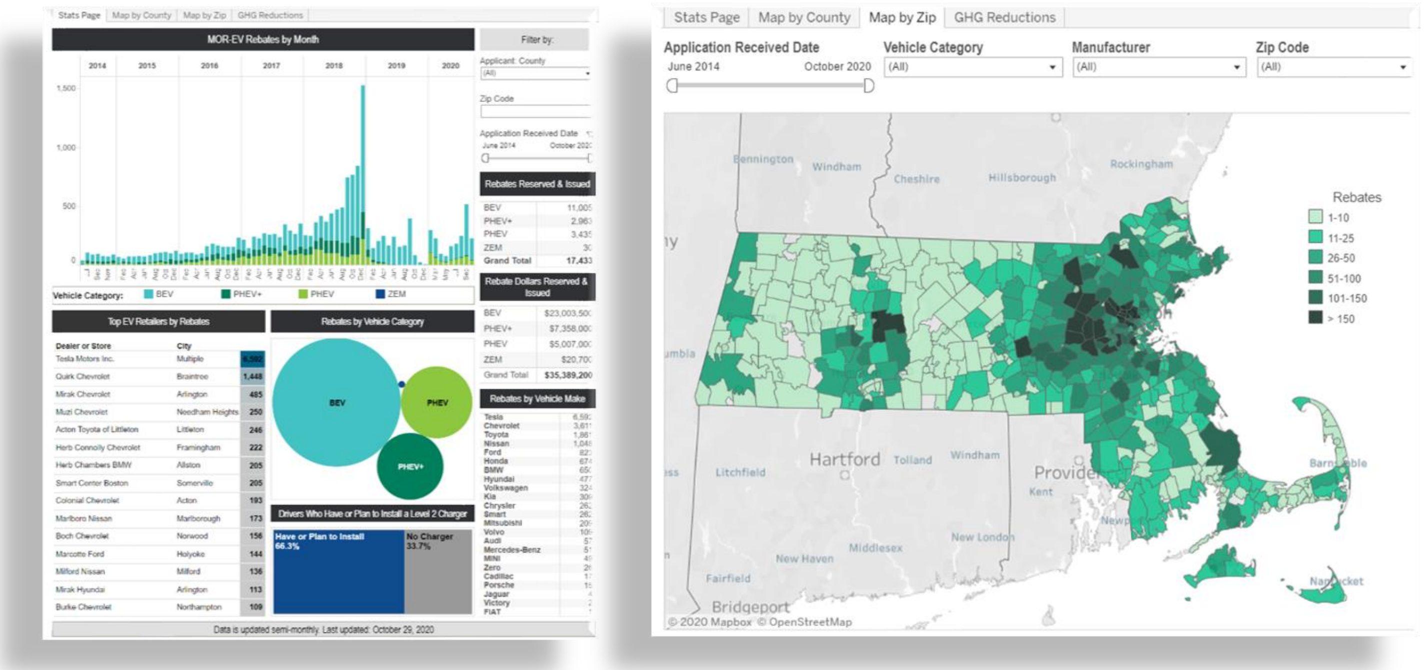
Additional Resources

Where Are EV Rebates Going?
Public Dashboards and Data Facilitate Informed Action

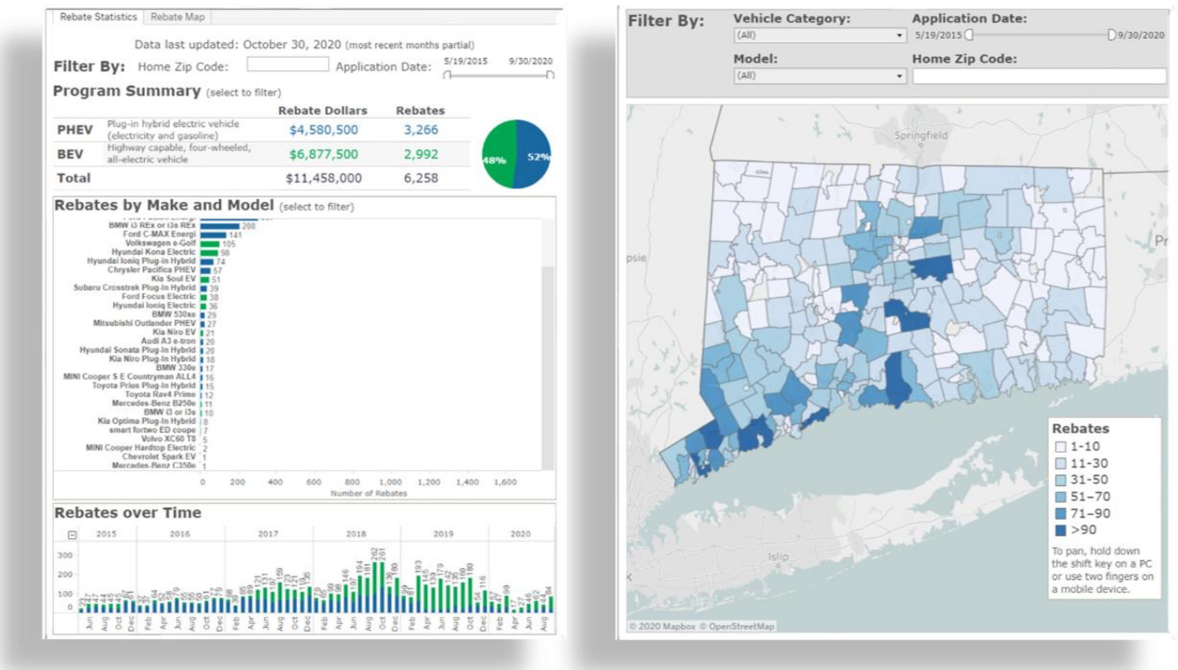
Statewide EV Rebate Programs: CA, MA, CT, NY (OR and NJ dashboards forthcoming)



cleanvehiclerebate.org



mor-ev.org



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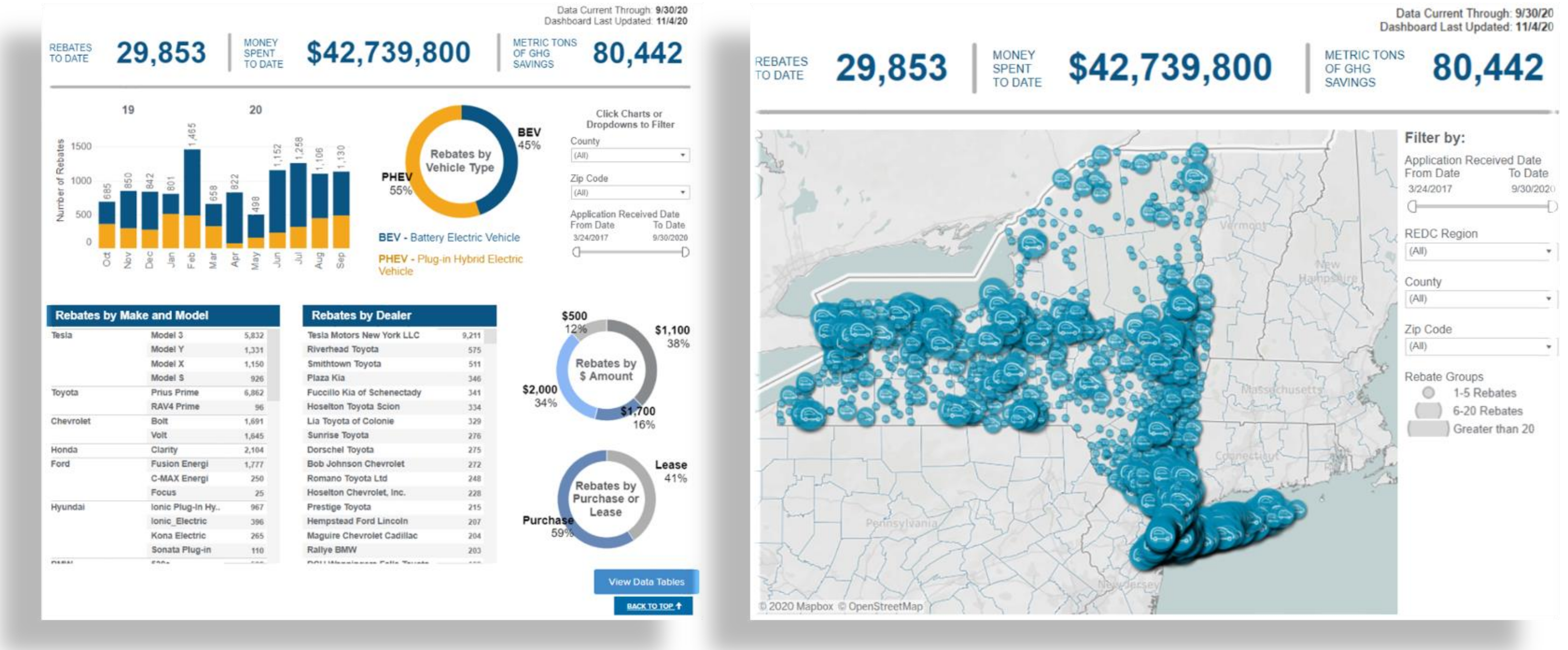

nyserda.ny.gov (dashboards done by NYSERDA)

- > 442,000 EVs and consumers have received > $979 M in rebates
- > 75,000 survey responses being analyzed so far, statistically represent > 319,000 consumers
- Reports, presentations, and analysis growing

As of 11/4/2020

Select Publications (Reverse Chronological, as of 12/21/21)

Center for Sustainable Energy™

- N. Pallonetti and B.D.H. Williams (2022, January). "Evaluating the Cost-Effectiveness of Greenhouse Gas Emission Reductions Associated with Statewide Electric Vehicle Rebate Programs in California and Massachusetts in 2019," in procs. *International Energy Program Evaluation Conference 2022*.
- N. Pallonetti and B. D. H. Williams, "Refining Estimates of Fuel-Cycle Greenhouse-Gas Emission Reductions Associated with California's Clean Vehicle Rebate Project with Program Data and Other Case-Specific Inputs," Energies, vol. 14, no. 15, Jul. 2021.
- B. D. H. Williams and J. B. Anderson, "Strategically Targeting Plug-In Electric Vehicle Rebates and Outreach Using 'EV Convert' Characteristics," Energies, vol. 14, no. 7, p. 1899, Mar. 2021.
- B.D.H. Williams, J.B. Anderson, A. Lastuka, Characterizing Plug-in Hybrid Electric Vehicle Consumers Who Found the U.S. Federal Tax Credit Extremely Important in Enabling Their Purchase, in: 33rd Electr. Veh. Symp., Electric Drive Transportation Association (EDTA), EVS33, and Zenodo, Portland OR, 2020. https://doi.org/10.5281/ZENODO.4021408
- S. Hardman, P. Plötz, G. Tal, J. Axsen, E. Figenbaum, P. Jochem, S. Karlsson, N. Refa, F. Sprei, B.D. Williams, J. Whitehead, B. Witkamp, Exploring the Role of Plug-In Hybrid Electric Vehicles in Electrifying Passenger Transportation, International EV Policy Council, UC Davis Plug-in Hybrid and Electric Vehicle Research Center, 2019.
- B.D. Williams, J. Orose, M. Jones, J.B. Anderson, Summary of Disadvantaged Community Responses to the Electric Vehicle Consumer Survey, 2013–2015 Edition | Clean Vehicle Rebate Project, Center for Sustainable Energy (CSE), San Diego CA, 2018.
- B.D. Williams, J.B. Anderson, Strategically Targeting Plug-in Electric Vehicle Rebates and Outreach Using Characteristics of 'Rebate-Essential" Consumers in 2016–2017, in: 31st Int. Electr. Veh. Symp., Society of Automotive Engineers of Japan, Inc., Kobe, Japan, 2018.
- C. Johnson, B.D. Williams, J.B. Anderson, N. Appenzeller, Evaluating the Connecticut Dealer Incentive for Electric Vehicle Sales, Center for Sustainable Energy (CSE), 2017.
- C. Johnson, B.D. Williams, Characterizing Plug-In Hybrid Electric Vehicle Consumers Most Influenced by California's Electric Vehicle Rebate, *Transp. Res. Rec*. 2628 (2017) 23–31.

Select Presentations (Reverse Chronological, as of 12/21)

Center for Sustainable Energy™

- California Plug-in Hybrid EV Consumers Who Found the U.S. Federal Tax Credit Extremely Important in Enabling Their Purchase
- Data from Statewide Electric Vehicle Rebate Programs: Vehicles, Consumers, Impacts, and Effectiveness
- CVRP CY 2019 Data Brief: Vehicle Replacement & Incentive Influence
- CVRP CY 2019 Data Brief: Consumer Characteristics
- CVRP Data Brief: MSRP Considerations
- EV Purchase Incentives: Program Design, Outputs, and Outcomes of Four Statewide Programs with a Focus on Massachusetts
- What Vehicles Are Electric Vehicles Replacing and Why?
- Electric Vehicle Incentives and Policies
- Proposed FY 2019–20 Funding Plan: Final CVRP Supporting Analysis
- CVRP: Data and Analysis Update
- Cost-Effectively Targeting EV Outreach and Incentives to "Rebate-Essential" Consumers
- Electric Vehicle Rebates: Exploring Indicators of Impact in Four States
- Targeting EV Consumer Segments & Incentivizing Dealers
- Supporting EV Commercialization with Rebates: Statewide Programs, Vehicle & Consumer Data, and Select Findings
- Yale Webinar: Supporting EV Commercialization with Rebates: Statewide Programs, Vehicle & Consumer Data, and Findings
- CVRP Income Cap Analysis: Informing Policy Discussions

CSE Areas of Expertise

Clean Transportation

Adoption of electric vehicles and deployment of charging infrastructure

Built Environment

Advancing energy efficiency and renewable resources

Technology Convergence

Interconnecting systems to achieve decarbonization

https://energycenter.org/

Recommended citation:

B.D.H. Williams and N. Pallonetti (2022). Presentation: “Cost-Effectiveness of Greenhouse Gas Emission Reductions Associated with California’s Clean Vehicle Rebate Project in 2019 (and 2020),” for *First Public Workshop on the Fiscal Year 2022-23 Update to the Three-Year Plan for Light-Duty Vehicles and Clean Transportation Equity Investments.* California Air Resources Board, 10 February 2022.

Questions?: brett.williams@energycenter.org

Related papers and presentations available:

cleanvehiclerebate.org/program-reports

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California Climate Investments
Cap and Trade Dollars at Work

California Air Resources Board