Exploratory Estimation of Greenhouse-Gas Emission Reductions from California's Clean Vehicle Rebate Project

98th Annual TRB Meeting, 16 Jan 2019, Washington, D.C.

Brett Williams, M.Phil. (cantab), Ph.D. – Senior Principal Advisor, Clean Transportation

Nicholas Pallonetti – Analyst (first author)

Thanks also to Kipp Searles, Michelle Jones, Laura Parsons, Jaclyn Vogel, Ryan Bodanyi, and others at CSE

Center for Sustainable Energy®

EV Rebate Design (as of Jan. 2019)

	CALIFORNIA CLEAN VEHICLE REBATE PROJECT	MOR-EV Massachusetts Offers Rebates for Electric Vehicles	CHEAPR Connecticut Hydrogen and Electric Automobile Purchase Rebate	NEW YORK STATE
Fuel-Cell EVs 	$5,000	$1,500	$5,000	e-miles ≥ 120 $2,000 ≥ 40 $1,700 ≥ 20 $1,100 < 20 $500
All-Battery EVs 	$2,500	$1,500	e-miles ≥ 200 $2,000 ≥ 120 $1,500 < 120 $500	
Plug-in Hybrid EVs 	$2,500 (i3 REx) $1,500	BEVx only: $1,500	≥ 45 $1,000 < 45 $500	
Zero-Emission Motorcycles 	$900	$450		
	e-miles ≥ 20 only; Consumer income cap and increased rebates for lower-income households	MSRP ≤ $50k, no fleet rebates	MSRP ≤ $60k FCEVs, ≤ $50k BEVs, PHEVs; dealer assignment; $150 dealer incentive	MSRP > $60k = $500 max.; point-of-sale via dealer

Center for Sustainable Energy

Paper Outline

Disclaimer and Thanks

Abstract

1. Introduction: *Motivation, Previous Work, Contribution & Overview*
2. Methods and Inputs: *Rebated Reductions, Rebate-Essential Reductions, and Summary*
3. Data Summary: *Application, Survey, and Vehicle Registration Data*
4. Results and Sensitivity: *GHG Emissions Reduction Estimates, Sensitivity Analysis*
5. Discussion and Next Steps: *Income Eligibility, Impact of Program Data, Additional Data, Conservatisms, Criteria Emissions*
6. Summary
7. References

Disclaimer and Thanks

This study was conducted to inform the Clean Vehicle Rebate Project (CVRP)

– It does not necessarily represent the views of the Clean Vehicle Rebate Project or the California Air Resources Board

– Nor does it represent a final determination for project-reporting purposes

We thank CARB staff for the opportunity to contribute to, and foster, the conversation

Summary: Results

- Over Project Lifespan (either 2.5 or 3 years per vehicle):
  - 1.9 million tons or 7.4 tons per vehicle
  - 7.0 tons per PHEV, 7.7 tons per BEV
  - 53% from “Rebate-Essential” participants
  - $296 per ton avoided (3.4 kg of CO2e per rebate $)
- Over Vehicle Lifespan (e.g., 6.6 – 11.6 years = average vehicle age):
  - savings increase 2–4-fold, (e.g., to $68/ton)
- Does not include grid decarbonization over time, other factors
- Partial use of project-derived data increased savings by 19–21% (so far)

1. INTRODUCTION

Motivation, Previous Work, Contributions, Overview

1.2 Previous CARB Work in the Literature

Average Emission Factor (EF) Per Mile

Baseline gasoline vehicle

$$EF_{gasoline} = f(carbon\ intensity\ of\ gasoline, fleet\ ave.\ gasoline\ consumption)$$

Low Carbon Fuel Standard (LCFS)

CA Emissions Factors data (EMFAC)

BEV

$$EF_{BEV} = f(fleet\ ave.\ fuel\ consumption, energy\ economy\ ratio, carbon\ intensity\ of\ electricity)$$

LCFS

LCFS

PHEV

40% of VMT on electricity…

The 2017-2018 AQIP Funding Plan provides a description of their quantification methodology for emissions reduction calculations at: https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_1718_funding_plan_final.pdf

Emissions Reductions

per BEV =

$$(EF_{gasoline} - EF_{BEV}) * Annual\ VMT_{BEV} * \#\ of\ BEVs * 3\ years$$

per PHEV =

$$(EF_{gasoline} - EF_{PHEV}) * Annual\ VMT_{PHEV} * \#\ of\ PHEVs * 3\ years$$

The 2017-2018 AQIP Funding Plan provides a description of their quantification methodology for emissions reduction calculations at: https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_1718_funding_plan_final.pdf

1.3 Contributions

1.3 Contribution highlights

- Using disaggregated and project-derived data
  - Fuel economy values corresponding to over 257,000 specific vehicle models rebated
  - Metrics of rebate influence from nearly 40,000 corresponding survey respondents

- Additional context-specific information incorporated in the form of MY-specific CA sales-weighted baseline fuel economy calculations

3. DATA SUMMARY

Application, Survey, and Vehicle Registration Data

3.1–2 Data Summary (PHEV and BEV Rebates to Individuals Only)

CVRP Consumer Survey Data

	2013–2015 Edition	2015–2016 Edition	2016–2017 Edition	Total
Responses	n = 19,361	n = 11,577	n = 8,957	n = 39,895
Weighted to represent*	N = 91,081	N = 45,694	N = 46,838	N = 183,613
Vehicle Purchase/ Leases	Sep. 2012 – May 2015	April 2015 – May 2016	May 2016 – May 2017	Sep. 2012 – May 2017

CVRP Application Data

Total participants assigned	N = 102,997	N = 47,746	N = 106,658	N = 257,401
Vehicle Purchase/ Leases	Mar. 2009 – May 2015	April 2015 – May 2016	May 2016 – Aug. 2018	Mar. 2009 – Aug. 2018

* Along the dimensions of vehicle model, county, and buy vs. lease (raking method)

3.3 Vehicle Registration Data

- Monthly new light-duty gasoline vehicle registrations in California from March 2010 through July 2018
- Used for baseline-vehicle sales-weighted fuel economy calculations (MY 2011–2018)

Registration data licensed from IHS Markit

2. METHODS AND INPUTS

Rebated Reductions, Rebate-Essential Reductions, and Summary

2.3 Summary of Inputs, Sources, and Sensitivity

Vehicle Characteristics

Factor	Rebated vehicle	Baseline vehicle
Drivetrain category	**Values:** {PHEV, BEV} **Source:** rebate application	**Values:** {Gasoline}, consistent with (1)
Model year	**Values:** {MY2009 … MY2019} **Source:** rebate application	**Values:** Same as rebated vehicle, consistent with (1)

References provided at end of presentation

Gasoline Carbon Intensity

Rebated vehicle	Baseline vehicle
Values* 82.8% by weight; CaRFG LHV = 109,786 Btu/gal	**Values** Same as rebated vehicle

* (18), (19) 82.8% hardwired into AFLEET vs. 82.5% in CA-GREET 2.0 used by (1)

Electric Fuel Carbon Intensity

Rebated vehicle	Baseline vehicle
Values* modified CAMX grid from CA-GREET 2.0, combined with GREET1 2018 U.S. emission coefficients **Sensitivity tests**** • Modified CAMX grid from CA-GREET 3.0 draft, • Upper bound: 100% renewable **Sensitivity of reductions** • +1.3% • Upper bound: +36%	n.a.

* (18), (19)
** (20)

Center for Sustainable Energy®

Fuel Economy

Rebated vehicle	Baseline vehicle
Values* Combined city/hwy EPA-adjusted rating for each specific vehicle's model/MY	**Values**** • CA-sales-weighted average of combined city/hwy EPA-adjusted ratings for top 30 gasoline models in MYs 2011–2018 (MY 2018 value used for partial MY 2019); • EPA-adjusted production average for cars for MYs 2009, 2010 **Sensitivity test***** Change to EPA *production* average incl. light-duty *trucks* or ~ [-10 to -15%] / +15% **Sensitivity of reductions** -22.1% / +25.0%

* rebate application for model/MY; (14) for fuel economy values
** calculation using data from (14), (15), (16)
*** (16)

Baseline Vehicle Fuel Economy Value by Model Year

Model Year	Baseline Vehicle Fuel Economy Value (miles per gallon)	Source
2009	25.4	EPA production-weighted
2010	25.8	EPA production-weighted
2011	25.1	EPA/IHS Markit/CSE sales-weighted
2012	27.9	EPA/IHS Markit/CSE sales-weighted
2013	27.9	EPA/IHS Markit/CSE sales-weighted
2014	28.2	EPA/IHS Markit/CSE sales-weighted
2015	28.4	EPA/IHS Markit/CSE sales-weighted
2016	28.7	EPA/IHS Markit/CSE sales-weighted
2017	28.0	EPA/IHS Markit/CSE sales-weighted
2018	28.8	EPA/IHS Markit/CSE sales-weighted
2019	28.8*	EPA/IHS Markit/CSE sales-weighted

*Model year 2018 value used due to limited 2019 data availability
EPA Fuel Economy Trends Report (2009–2010 values): https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100TGDW.pdf
EPA fuel economy data: https://www.fueleconomy.gov/feg/download.shtml
Registration data licensed from IHS Markit

Center for Sustainable Energy®

Annual Vehicle Miles Traveled (VMT)

Rebated vehicle	Baseline vehicle
Values* {PHEVs = 14,855, BEVs = 11,059} **Sensitivity test**** {PHEVs = 11,122 – 15,283, BEVs = 7,916 – 13,494} **Sensitivity of reductions** -27.2% / +14.9%	**Values** Same as rebated vehicle

* (8), (9) in (1)
** (10), (11), (12) in (13)

Center for Sustainable Energy®

PHEV Electric Operation

Rebated vehicle	Baseline vehicle
Values* 40% electric fuel **Sensitivity test**** 15 – 74.5% **Sensitivity of reductions** -7.5% / +10.4%	n.a.

* (17)
** (13)

Center for Sustainable Energy®

BEVx (BMW i3 REx) Electric Operation

Rebated vehicle	Baseline vehicle
Values* 92% electric fuel **Sensitivity test**** +/- 8 percentage points **Sensitivity of reductions** +/-0.1%	n.a.

* (13)
** (13)

Center for Sustainable Energy®

Project-Life Emissions

$$E_{i,project\ \ life} = E_{i,1st-year} \times O_i \quad (3)$$

Where:

O = ownership requirement (either 2.5 or 3 years, depending on rebate project terms)

Rebate Essentiality

Rebated vehicle	Baseline vehicle
Values* {1,0} for those with survey responses; for others, used the average by tech. type for the corresponding program era, ranging 41.3%–63.6% **Sensitivity test** +/- margin of error (ranging from 1.2 to 2.2 percentage points) **Sensitivity of reductions** +/- 2.6%	[applies to case as a whole: emission reductions counted are proportional to rebate-essentiality value (e.g., case excluded if not rebate essential)]

* Survey data (unweighted direct responses and weighted averages)

Weighted Rebate Essentiality by Survey Edition and Vehicle Category*

Rebate Essential: Would not have purchased/leased their EV without rebate

Vehicle Category	2013–15 Edition	2015–16 Edition	2016–17 Edition
All	46%	56%	57%
BEV	50%	61%	64%
PHEV	41%	47%	47%

* Specific to this analysis; see details of trimmed dataset

5. DISCUSSION AND NEXT STEPS

Income Eligibility, Impact of Program Data, Additional Data, Conservatisms, Criteria Emissions

5.3 Next Steps: Additional Project Data

Preliminary Counterfactual Vehicle Analysis

- **Re-assigned counterfactual fuel economy averages based on specific vehicles replaced** (next slide)
- Other response combinations were unchanged (2017 gasoline fuel economy)
- Non-respondents were assigned the average per-vehicle emissions of the new counterfactual fleet (by rebated vehicle category/survey edition)

MY 2017 survey respondents

Rebated EV
Replaced (or will replace) another household vehicle
Additional vehicle to my household fleet
First ever vehicle acquired by my household

Counterfactual Scenario
Purchased/leased this exact vehicle anyway
Purchased/leased a less expensive version of the same model
Purchased/leased a different new PEV
Purchased/leased a used PEV
Purchased/leased a new non-PEV instead
Purchased/leased a used non-PEV instead
Not made any purchase/lease at all

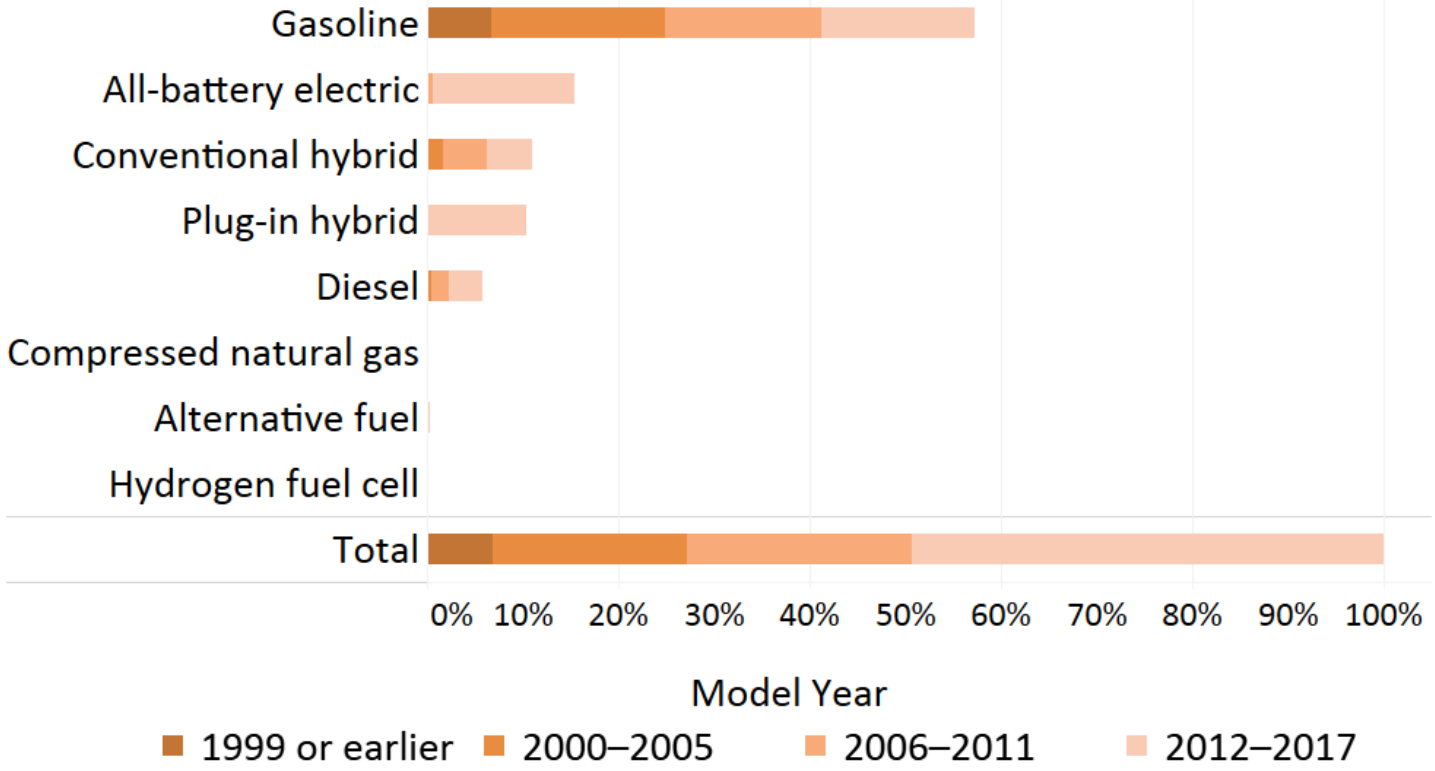
Replaced Vehicle Fuel Economy Assignment

<table>
<tr><th></th><th>Gasoline</th><th>Diesel</th><th>HEV</th><th>PHEV</th><th>BEV</th><th>Flex-fuel/E85</th><th>CNG</th><th>FCEV</th></tr>
<tr><td>MY 1994 or earlier–2010</td><td>MY-specific production-weighted ave. for cars
(“1994 or earlier” assigned MY 1994 value)</td><td colspan="4">2011 CA-sales-weighted ave. fuel economy</td><td colspan="3" rowspan="2">Treated as non-respondents</td></tr>
<tr><td>MY 2011–2017</td><td>MY-specific CA-sales-weighted ave. of top 30 gasoline models</td><td colspan="4">MY-specific CA-sales-weighted ave. of all models</td></tr>
</table>

Additional Project Data: Counterfactual Purchase Behavior

- Result: per-vehicle 1st-year reduction +19% vs. Funding Plan
  - Down from +21%: recently replaced vehicles may be less-emitting than average new gasoline vehicles

What vehicle types have rebates helped replace?
Current Program



CVRP Consumer Survey. ***2016–2017*** edition, **trimmed to start *November 2016*,**
PEV respondents only, weighted, n=4,695

Center for Sustainable Energy®

6. SUMMARY

Summary: Background

Background

- Prior estimates were based upon fleet-average vehicle characterizations as conservative starting point
- We inform that process by utilizing project-specific data through August 2018 (N=257,401 participants) and other forms of disaggregated, context-specific inputs and calculations

Approach

- Use AFLEET (Alternative Fuel Life-Cycle Environmental and Economic Transportation) Tool
- Inputs include: fuel economy, vehicle miles traveled, electric miles, gasoline composition, and grid generation mix

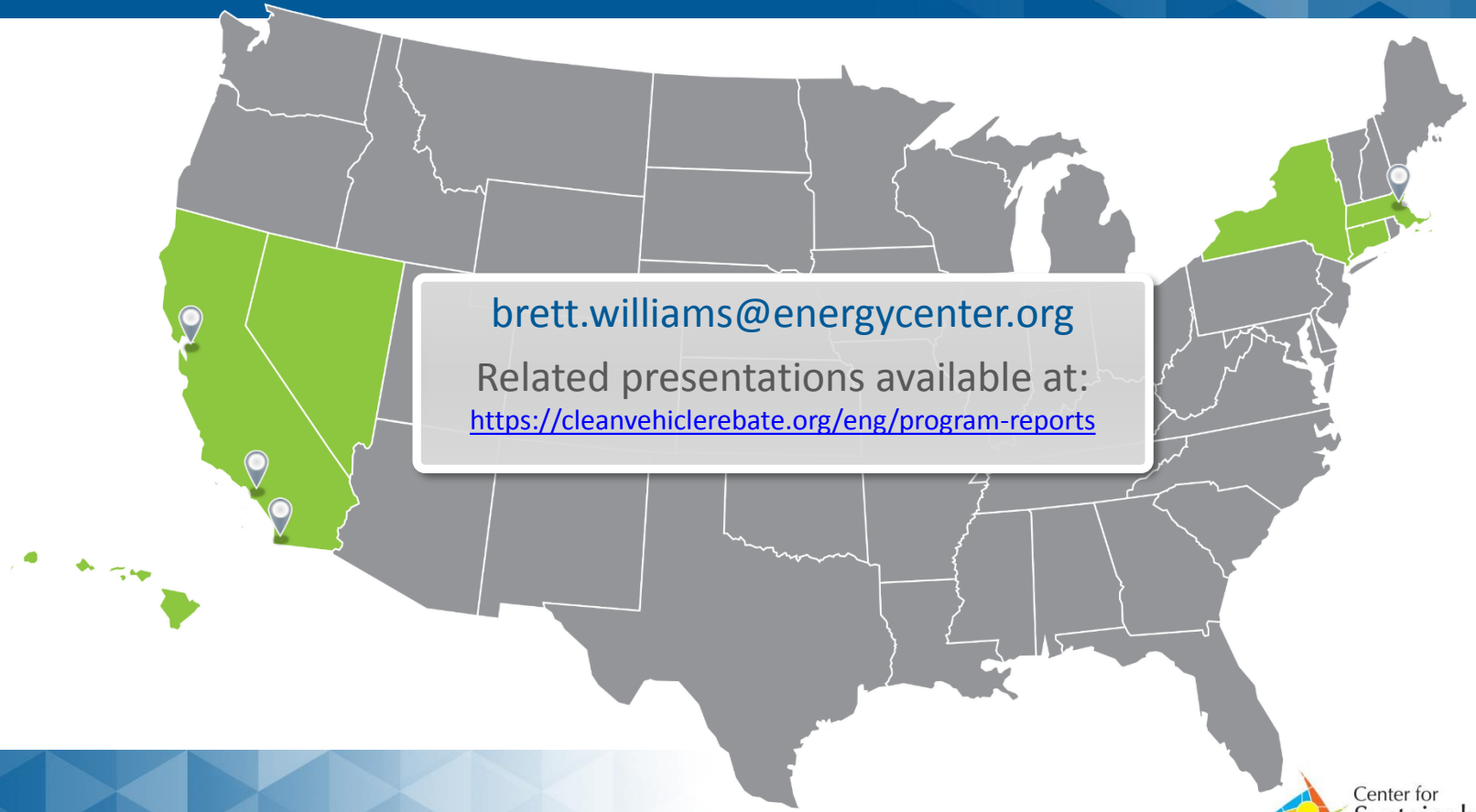
Summary: Results

- Over Project Lifespan (either 2.5 or 3 years per vehicle):
  - 1.9 million tons or 7.4 tons per vehicle
  - 7.0 tons per PHEV, 7.7 tons per BEV
  - 53% from “Rebate-Essential” participants
  - $296 per ton avoided (3.4 kg of CO2e per rebate $)
- Over Vehicle Lifespan (e.g., 6.6 – 11.6 years = average vehicle age):
  - savings increase 2–4-fold, (e.g., to $68/ton)
- Does not include grid decarbonization over time, other factors
- Partial use of project-derived data increased savings by 19–21% (so far)

Summary: Sensitivity Analysis

- Substantial uncertainty remains
  - Summing the impacts of using extreme low values or extreme high values indicates results bounded between -57% and +52%
- Most sensitive to:
  - Baseline fuel economy (-22% to +25%)
  - VMT assumptions (-27% to +15%)
- Upside potential of 100% renewable grid is +36%

Thank you for your attention.



brett.williams@energycenter.org

Related presentations available at:
https://cleanvehiclerebate.org/eng/program-reports

Center for Sustainable Energy®

REFERENCES

References

1. California Air Resources Board. "Proposed Fiscal Year 2017-18 Funding Plan for Clean Transportation Incentives." [Online].; 2017 [cited 2018 July 30. Available from: https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_1718_funding_plan_final.pdf.

2. California Air Resources Board. EMFAC2014 Web Database. [Online].; 2014 [cited 2018 July 30. Available from: https://www.arb.ca.gov/emfac/2014/.

3. California Air Resources Board. LCFS Pathway Certified Carbon Intensities. [Online].; 2018 [cited 2018 July 30. Available from: https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm.

4. California Air Resources Board. Low Carbon Fuel Standard Regulation. [Online].; 2015 [cited 2018 July 30. Available from: https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf.

5. Argonne National Laboratory. AFLEET Tool 2018. [Online].; 2017 [cited 2018 November 30. Available from: https://greet.es.anl.gov/afleet_tool.

6. Walsworth J. Average age of vehicles on road hits 11.6 years.; 2016 [cited 2018 August 14. Available from: http://www.autonews.com/article/20161122/RETAIL05/161129973/average-age-of- vehicles-on-road-hits-11.6-years.

7. Johnson C, Williams B. "Characterizing Plug-In Hybrid Electric Vehicle Consumers Most Influenced by California's Electric Vehicle Rebate. *Transportation Research Record*. 2017 January; 2628.

Center for Sustainable Energy®

References

8. Schey S, Smart J. "Battery Electric Vehicle Driving and Charging Behavior Observed Early in The EV Project." *SAE International Journal of Alternative Powertrains*. 2012; 1(1): p. 27-33.

9. Smart J, Powell W, Schey S. "Extended Range Electric Vehicle Driving and Charging Behavior Observed Early in the EV Project." [Online].; 2013 [cited 2018 July 30. Available from: https://doi.org/10.4271/2013-01-1441.

10. Idaho National Laboratory. "Plug-in Electric Vehicle and Infrastructure Analysis." [Online].; 2015 [cited 2018 July 30. Available from: https://inldigitallibrary.inl.gov/sites/sti/sti/6799570.pdf.

11. Carlson B. "Electric Vehicle Mile Traveled (eVMT): On-road Results and Analysis." [Online].; 2015 [cited 2018 July 30. Available from: http://energy.gov/sites/prod/files/2015/07/f24/vss171_carlson_2015_p.pdf.

12. Nicholas MA, Tal G, Turrentine TS. "Advanced Plug-in Electric Vehicle Travel and Charging Behavior Interim Report." [Online].; 2017 [cited 2018 July 30. Available from: https://itspubs.ucdavis.edu/index.php/research/publications/publication- detail/?pub_id=2692.

13. California Air Resources Board. "California's Advanced Clean Cars Midterm Review, Appendix G: Plug-in Electric Vehicle In-Use and Charging Data Analysis." [Online].; 2017 [cited 2018 July 30. Available from: https://www.arb.ca.gov/msprog/acc/mtr/acc_mtr_finalreport_full.pdf.

14. United States Environmental Protection Agency. fueleconomy.gov. [Online].; 2018 [cited 2018 July 30. Available from: https://www.fueleconomy.gov/feg/download.shtml.

Center for Sustainable Energy®

References

15. IHS Markit. Monthly New Vehicle Registration Data. [Online].; 2018.

16. United States Environmental Protection Agency. "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2017." [Online].; 2018 [cited 2018 July 30. Available from: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100TGDW.pdf.

17. California Air Resources Board. "Proposed Fiscal Year 2016-17 Funding Plan for Low Carbon Transportation and Fuels Investments and the Air Quality Improvement Program, Appendix A – Emission Reductions: Quantification Methodology." [Online].; 2016 [cited 2018 July 30. Available from: https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_fy16-17_fundingplan_appa.pdf.

18. California Air Resources Board. CA-GREET 2.0 Tier 1. [Online].; 2015 [cited 2018 July 30. Available from: https://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet.htm.

19. Argonne National Laboratory. GREET1 2018. [Online].; 2018 [cited 2018 October 22. Available from: https://greet.es.anl.gov/.

20. California Air Resources Board. CA-GREET 3.0 Supplemental Document and Tables of Changes. [Online].; 2017 [cited 2018 July 30. Available from: https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/11062017greet_supp.pdf.

21. Williams B, DeShazo J. Pricing Workplace Charging: Financial Viability and Fueling Costs. Transportation Research Record: Journal of the Transportation Research Board. 2014; 2454: p. 68-75. Available from: https://doi.org/10.3141/2454-09