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California Transportation Electrification Assessment: Phase 1 Final Report

Before the

Public Utilities Commission of the State of California

California Transportation Electrification Assessment

Phase 1: Final Report

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Disclaimer. This Transportation Electrification Assessment Phase I report, prepared by ICF International with analytical support from E3, updates and expands upon previous work on the grid impacts, costs, and private and societal benefits of increased transportation electrification. Utility work groups made up of a cross section of investor owned utilities and municipally owned utilities provided input and consultation for critical aspects of the study. In addition, feedback and comments were solicited and received from the California Energy Commission and the California Air Resources Board. The report's findings and conclusions, however, are the work of ICF.

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Abbreviations and Acronyms

AEO	Annual Energy Outlook
ARB	California Air Resources Board
BEV	Battery Electric Vehicle
CARB	California Air Resources Board
CEC	California Energy Commission
CH4	Methane
CHE	Cargo Handling Equipment
CNG	Compressed Natural Gas
CO2	Carbon Dioxide
CO2E	Carbon Dioxide Equivalent
CPI	Consumer Price Index
CPUC	California Public Utilities Commission
DER	Distributed Energy Resources
DGE	Diesel Gallon Equivalent
EER	Energy Equivalency Ratio
EIA	United States Energy Information Administration
EPA	US Environmental Protection Agency
EVSE	Electric Vehicle Supply Equipment
FCV	Fuel Cell Vehicle
GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
GSE	Ground Support Equipment
GWh	Gigawatt-hour
HOA	Home Owners Association
HP	Horsepower
HSR	High Speed Rail
IOU	Investor Owned Utility
ISOR	Initial Statement of Reasons
kW	Kilowatt
kWh	Kilowatt-hour
LCA	Lifecycle Analysis
LCFS	Low Carbon Fuel Standard
LEV	Low Emission Vehicle
MDU	Multi-Dwelling Unit
MT	Metric Ton
NMOG	Non-Methane Organic Gases
NOx	Oxides of Nitrogen
O&M	Operational and Maintenance

PEV	Plug-In Electric Vehicles
PHEV	Plug-In Hybrid Electric Vehicles
PHEV10	PHEV with 10 miles equivalent all electric range
PHEV20	PHEV with 20 miles equivalent all electric range
PHEV40	PHEV with 40 miles equivalent all electric range
PM	Particulate Matter
ROG	Reactive Organic Compounds
RTG	Rubber Tire Gantry
TE	Transportation Electrification
TEA	Transportation Electrification Assessment
TOU	Time of Use
TRU	Transport Refrigeration Unit
TSE	Truck Stop Electrification
TTW	Tank-To-Wheel
ULETRU	Ultra Low Emission TRU
VOC	Volatile Organic Compounds
WTT	Well-To-Tank
WTW	Well-To-Wheels
ZEV	Zero Emission Vehicle

Executive Summary

The key messages of this report are:

- Transportation electrification(TE) has the potential to provide significant benefits to society and utility customers
- The plug-in electric vehicle (PEV) segment shows particular promise, but increased utility involvement in the PEV market is necessary to accelerate adoption to achieve the maximum grid benefits of PEVs and the goals of the Governor's Zero Emission Vehicle (ZEV) Action Plan[1]
- The lack of a proven, sustainable third-party business model for owning and operating electric vehicle supply equipment (EVSE) is a significant market barrier to increased PEV adoption

Air quality and climate change concerns continue to be major drivers for transportation electrification in California. Electrified technologies have near-zero or zero tailpipe emissions of criteria pollutants, and electricity has much lower carbon intensity than fossil fuels like gasoline and diesel. Despite the environmental benefits of transportation electrification, the technologies still face many barriers. Most notably, electrified technologies often have higher upfront costs and/or require infrastructure investments, such as electric vehicle supply equipment, high load transformers and interconnections, and new recharging and electrical interconnections. In some cases, the barriers to adoption are attributable to misperceptions (e.g., that electrified technologies do not have the power needed to perform the required tasks).

This Transportation Electrification Assessment (TEA): (1) updates previous CalETC estimates of the market sizing, forecasts and societal benefits for each technology to 2030; (2) includes market sizing, forecasting and societal benefits for additional TE technologies; (3) performs a costing analysis of select TE technologies; (4) quantifies the grid benefits from PEVs; and (5) identifies the market gaps, barriers and potential solutions for PEV adoption to achieve the grid benefits.

The forecasting was done for three different cases: "In Line with Current Adoption", "In Between" and "Aggressive Adoption". The "In Line with Current Adoption" case is based on anticipated market growth, expected incentive programs, and compliance with existing regulations, and the "Aggressive Adoption" case is based on aggressive new incentive programs and/or regulations. The "In Between" case is in between the "In Line with Current Adoption" and "Aggressive Adoption" cases and varies by technology. For some technologies this is simply half-way in between and for other technologies this is a discretely separate case. The only exception is the plug-in vehicle (PEV) market penetrations. To avoid making market penetration the focus of the PEV grid benefit study, ICF and CalETC decided to use three different existing PEV penetration scenarios. The "In Line with Current Adoption", "In Between" and "Aggressive Adoption" cases were based on: California Zero Emission Vehicle (ZEV) compliance with a 50/50 split of PEVs and fuel cell vehicles (FCVs), ZEV "likely" compliance per the California Air Resources

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[1] 2013 ZEV Action Plan: A roadmap toward 1.5 million zero-emission vehicles on California roadways by 2025, available online at: http://opr.ca.gov/docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf

Board (CARB), and three times ZEV "likely" compliance, respectively. The detailed forecasting for each case and technology can be found in Appendix A and is summarized in Section 2. The detailed forecasting produced results that show the potential for significant increases in electricity consumption and societal benefits. Table 1 shows the potential electricity consumption and societal benefits in 2030 for the three cases and how these compare to statewide consumption and emission values.

Table 1. Electricity Consumption and Societal Benefits from the Detailed Forecasted Technologies in 2030

Case	Electricity Consumed (Mil kWh/yr)	Petroleum Displacement (Mil GGE/yr)	GHG Emissions Reduced (Mil MT/yr)	PM Emission Reduced (tons/day)	NOx+ROG Emissions Reduced (tons/day)
"In Line with Current Adoption" Case	6,230	558	4.92	0.44	24.8
"In Between" Case	14,300	1,330	11.5	0.73	43.5
"Aggressive Adoption" Case	33,200	3,310	28.9	1.29	71.9
California Statewide Consumption / Emissions	280,561 (Electricity – 2013)[2]	18,800 (Transportation – 2013)[3]	171 (Transportation – 2013)[4]	85 (Transportation – 2012)[5]	2,509 (Transportation – 2012)[6]
Percentage of California Statewide Values	2.2-11.8%	3.0-17.6%	2.9-16.9%	0.5-1.5%	1.0-2.9%

Transportation electrification has small projected criteria pollutant benefits compared to current emissions but significant potential for petroleum displacement and for helping California achieve its GHG emission reduction goals.

Many of these transportation electrification technologies, in addition to achieving significant societal benefits, have operational cost benefits including decreased fuel costs and lower operational and maintenance (O&M) costs. The costing analysis for PEVs, forklifts, truck stop electrification (TSE) and truck refrigeration units (TRUs) employed a benefit-cost ratio, which is the operational benefits (private benefits) and monetized societal benefits divided by the capital costs. A benefit-cost ratio greater than one indicates that the technology has overall lifecycle cost savings for the owner; societal benefit-cost ratio greater than one indicates there are monetized net benefits to society greater than the cost of the technology. The private benefits and cost effectiveness determined in this report are from both a consumer perspective and a TE technology owner and operator perspective.

[2] http://www.energy.ca.gov/2013publications/CEC-100-2013-001/CEC-100-2013-001-CMF.pdf

[3] California 2013 Weekly Fuels Watch Report http://energyalmanac.ca.gov/petroleum/fuels_watch/; all sectors

[4] http://www.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_by_sector_00-12_sum_2014-03-24.pdf

[5] http://www.arb.ca.gov/aqd/almanac/almanac13/pdf/chap213.pdf

[6] California Almanac of Emissions and Air Quality 2013 Edition - Chapter 2 Current Emissions and Air Quality http://www.arb.ca.gov/aqd/almanac/almanac13/pdf/chap213.pdf

Figure 1 below shows that for TE technologies in 2013, TSE has the potential for extremely high total and private benefit-cost ratios but the overall magnitude of the societal benefits (in this case petroleum displacement in 2030) is significantly lower than for PEVs and forklifts, and lower than for TRUs. The dotted line represents a benefit-cost ratio of one.

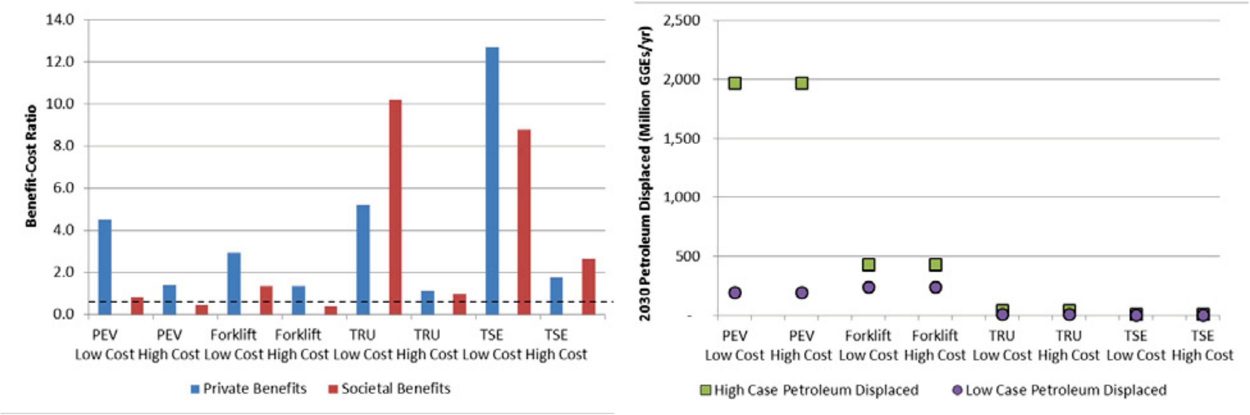

Figure 1. 2013 Benefit-Cost Ratio and 2030 Petroleum Displacement Potential of Select TE Technologies

In addition to the societal benefits from displacing conventional technologies, PEVs also have the potential for significant grid benefits to society and utility ratepayers. If utilities can serve PEV electricity demand with existing infrastructure, this increases the utilization of their existing assets, which could lower electricity rates for all ratepayers. The Phase 2 report will determine the cost effectiveness and value to the utility and ratepayer from PEVs.

To achieve the potential long-term grid benefits of PEVs, it is necessary to increase and maximize the market penetration of PEVs in the near term. ICF, with consultation from a utility stakeholder working group consisting of investor owned utilities and municipally owned utilities, identified the following major market gaps and barriers for PEV market penetration: consumer costs, charging infrastructure deployment, sustainability of third-party ownership of PEV charging equipment, consumer education and outreach, and vehicle features. Table 2 summarizes the major market gaps and barriers and potential solutions.

Table 2. Major Market Gaps and Barriers and Potential Solutions

Market Gaps and Barriers		Potential Solutions
Consumer Costs	• Upfront vehicle costs • Upfront charging infrastructure (EVSE) costs • Vehicle operating costs; need for competitive charging rates for PEVs and shift in traditional billing paradigm	• Increased publicity and continued availability of existing incentives • Creative use of utility LCFS credits or utility developed programs (e.g. battery second life) to reduce the upfront vehicle or EVSE costs • Improved PEV charging rate structures to increase the reduced fuel cost benefits for drivers
Charging Infrastructure	• Lack of information available to single family homeowners seeking to decide between Level 1 and Level 2 charging installation • Little to no progress made in deploying charging at multi-dwelling units; MDU installations are particularly challenging due to technical and logistical issues • Lack of investment in workplace charging infrastructure to date	• Engage MDUs/HOAs, employers and workplace parking providers as a trusted advisor regarding optimal and cost-effective EVSE solutions
Sustainability of Third-Party Ownership of EVSE Networks	• Sustainability of revenue model is frequently challenged and has not been convincingly demonstrated • Demand for non-home charging is unclear due to several factors: vehicle purchasing behavior, consumer willingness to pay for charging, and charging needs/behaviors	• Alternatives to additional public investment in charging infrastructure • Revisiting the CPUC ruling regarding utility investment in charging infrastructure • Improved evaluation of charging infrastructure deployment
Consumer Education and Outreach	• General lack of PEV awareness and knowledge • Total cost of vehicle ownership is poorly understood • Disparate efforts to improve PEV education	• The utility acting as a trusted advisor in the PEV market • Engage with PEV ecosystem partners
Vehicle Features	• Limited vehicle offerings in marketplace	• Modifications to the ZEV program to incentivize the development of PEVs outside of traditional market segments (e.g. subcompacts or midsize sedans)

The primary theme connecting the list of potential solutions is increased utility involvement to help accelerate PEV adoption. This includes increased consumer outreach, education, and incentives for charging infrastructure development, engaging customers by serving as a trusted advisor, and potential involvement in deployment and ownership of EVSE. Such increased utility involvement is an important catalyst for achieving the maximum grid benefits of PEVs. Similar activities could also be applied to other transportation electrification market segments.

1 Introduction

Regional air quality and climate change concerns and the associated federal and state policies continue to be major drivers for transportation electrification (TE) in California. Electrified transportation technologies have near-zero or zero tailpipe emissions and electricity has a much lower carbon intensity than fossil fuels such as gasoline and diesel. Furthermore, the transportation sector's petroleum dependency continues to be a national security concern while exposing consumers and businesses to price volatility. Despite the environmental benefits of transportation electrification, the technologies still face many barriers. Most notably, electrified technologies often have higher upfront costs and/or require significant infrastructure investments including electric vehicle supply equipment (EVSE), high load transformers and new electrical interconnections. Transportation electrification technologies include, but are not limited to on-road vehicles and off-road technologies such as forklifts, truck stop electrification (TSE), transport refrigeration units (TRUs), and cold-ironing at ports.

This Transportation Electrification Assessment (TEA) study (1) updates the market sizing, forecasts and societal benefits (e.g. petroleum displacement, GHG emission reductions and criteria pollutant emission reductions) of transportation electrification (TE) technologies from the previous CalETC Study[7], revising projections out to 2030; (2) includes new market sizing, forecasting and societal benefits for additional TE technologies such as medium and heavy-duty vehicles, high speed rail (HSR), commuter and light rail, and dual mode catenary trucks; (3) performs a costing analysis of select TE technologies; (4) quantifies the grid benefits from PEVs; and (5) identifies the market gaps, barriers and potential solutions for PEV adoption to achieve the grid benefits. Utility work groups made up of a cross section of investor owned utilities (IOUs) and municipally owned utilities (MOUs) were convened to provide input and consultation for critical aspects of the TEA study. In addition, feedback and comments were solicited and received from the California Energy Commission (CEC) and the California Air Resources Board (CARB).

The TEA has been split into two reports: Phase 1 and Phase 2. Phase 1 includes market sizing, forecasts and societal benefits, costing analysis of select TE technologies, a high level discussion of potential grid benefits from PEVs, and identification of market gaps and barriers and potential solutions for PEV adoption. The costing analysis in Phase 1 is from a TE technology consumer perspective and takes into account operational benefits and fuels savings in addition to societal benefits from decreased petroleum consumption, greenhouse gas (GHG), and criteria pollutant emissions. Phase 2 is the detailed modeling and quantification of the grid benefits from PEVs. Phase 2 focuses on the economic and cost effectiveness tests from a utility and overall ratepayer perspective including estimating increases in net revenue for the utilities from PEVs. The Phase 1 report is divided into the following sections:

- Section 1 – Introduction
- Section 2 – Market Sizing and Forecasting
- Section 3 – Costs and Benefits of Select TE Segments

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[7] "Electric Transportation and Goods Movement Technologies in California: Technical Brief," TIAX LLC report for CalETC, revised/updated September 2008.

- Section 4 – Transportation Electrification Grid Benefits
- Section 5 – Market Gaps and Barriers to PEV Market Penetration
- Section 6 – Conclusions

2 Market Sizing and Forecasting

An extensive literature review was undertaken from publicly available documents and documents supplied directly from the utilities, and from the previous CalETC Study[8]. Some of the utilities have performed internal analyses of transportation electrification technologies and those resources and assessments were utilized in the following market sizing. Table 3 below shows the technologies researched in the literature review. Detailed market sizing and forecasting was performed for the technologies in the first and second columns for 2013, 2020 and 2030. Costing analysis (Section 3) was done for the select technologies in the first column. These technologies were selected by ICF with input and agreement from the utility workgroups. For the technologies in the third column, the review did not provide enough additional information for a comprehensive update to the previous assessment. Therefore the market sizing for these technologies was done by utilizing the forecasts from the previous CalETC report (which covered the period from 2010 to 2020) to cover the period from 2013 to 2030. There is not enough information to determine if the original forecasts for these technologies were achieved. However the previous forecasts were done prior to the start of the recession in 2008, likely resulting in delayed implementation of these technologies.

Table 3. Electric Technologies in this Forecast

Detailed Forecasting Update and Cost Analysis	Detailed Forecasting Update	Previous Forecast of 2010 to 2020 used for 2013 to 2030
• Light-Duty PEVs (PHEVs and BEVs) • Forklifts • Truck Stop Electrification (TSE) • Transportation Refrigeration Units(TRUs)	• Shore Power at the Ports • Port Cargo Handling Equipment • Airport Ground Support Equipment (GSE) • High Speed Rail (HSR) • Light (including trolley buses) and Heavy Passenger Rail (e.g. SDMTS[9],BART, LA Metro) • Commuter Rail (Caltrain) • Dual Mode Catenary Trucks on I-710/SR60 • Medium- and Heavy-Duty PEVs	• Lawn and Garden • Sweepers/Scrubbers • Burnishers • Tow Tractors/Industrial Tugs • Personnel/Burden Carriers • Turf Trucks • Golf Carts

The detailed market sizing and forecasting, in addition to the extensive literature review, included contacting industry and government experts (CARB, CEC, and the US Environmental Protection Agency)

[8] "Electric Transportation and Goods Movement Technologies in California: Technical Brief," TIAX LLC report for CalETC, revised/updated September 2008.

[9] http://www.sandag.org/index.asp?projectid=250&fuseaction=projects.detail: ten mile expansion of San Diego trolley system by 2018

to characterize current and future markets conditions and regulatory drivers for each technology. Utility work groups were convened to review the electrification forecasts prior to calculating electricity consumption and societal benefits and performing the cost analysis (Section 3).

The future populations and electricity consumption (and subsequent societal benefits) were estimated for three cases:

- The “In Line with Current Adoption" case is based on anticipated market growth, expected incentive programs, and compliance with existing regulations. For technology that could potentially not be built, like HSR and I710, build/no-build scenarios were considered.
- The “Aggressive Adoption" case is based on aggressive new incentive programs and/or regulations. “Aggressive Adoption” cases are not the hypothetical maximums, but are tangibly aggressive.
- The "In Between" case will fall somewhere in between the “In Line with Current Adoption” and "Aggressive Adoption" cases and will vary by technology. For some technologies it will simply be half-way between the two other cases, but for some technologies (e.g. large projects like high speed rail) a specific “In Between” case was developed. The “In Between” case in this study omits the technologies in the far right column of Table 3 since an “In Between” or medium case was not included in the previous 2007 study.[10]

The forecasts developed in Phase 1 of the study for PEVs will be used in Phase 2 to determine the grid benefits of light duty PEVs. To avoid making market penetration the focus of the PEV grid benefit study, ICF and CalETC decided to use three different existing PEV penetration scenarios: California Zero Emission Vehicle (ZEV) compliance with a 50/50 split of PEVs and fuel cell vehicles (FCVs) (“In Line with Current Adoption” case), likely California ZEV compliance as defined by CARB (“In Between” case) and three times the likely California ZEV compliance ("Aggressive Adoption" case).

While performing the market sizing and forecasting, conventional fuel consumption and criteria pollutant emission factors were gathered. These factors were used to determine GHG reductions, petroleum displacement and criteria pollutant emission reductions from the forecasted electrified technologies. GHG emissions and California based upstream criteria pollutant emission factors were used from California’s State Alternative Fuels Plan (AB1007 analysis)[11], as shown in Table 32. However, the criteria pollutant emission factors for upstream emissions were conservative because they assumed that all of the electricity and refinery emissions occurred with the air basin where the electricity was consumed, when this is not the case in practice. The tables in the follow section detail the resulting market sizing and forecasting and resulting societal benefits (petroleum displacement, GHG emission reductions and criteria pollutant emission reductions). The detailed forecasting for each technology,

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[10] The previous CalETC study contained “Expected” and “Achievable” cases which were converted to low and high cases for this study.

[11] “Full Fuel Cycle Assessment: Well to Tank Energy Inputs, Emissions and Water Impact,” Consultant Report for the California Energy Commission, February 2007. http://www.energy.ca.gov/2007publications/CEC-600-2007-002/CEC-600-2007-002-D.PDF

including regulatory assumptions and data sources and assumptions for calculating societal benefits, can be found in Appendix A.

2.1 “In Line with Current Adoption” Case

The “In Line with Current Adoption” case for many technologies maintains the current population of electrified technologies, includes minimal anticipated natural growth, or achieves minimum compliance with current state and/or federal regulations. Electrification was not assumed to be the only avenue for compliance for regulations where multiple compliance options are available (e.g. anti-idling, ocean going vessels at-berth, TRUs). Table 4 shows the California electric technology population forecasts in the “In Line with Current Adoption” case. TSE penetration is shown as the number of electrified spaces, cold-ironing as the number of electrified ship visits, electrified rail as passenger-miles, and fixed guideway as truck-miles.

The anticipated connected load and resulting annual electricity consumption for populations in the table were calculated for each type of equipment. The data sources and assumptions for electricity load and annual consumptions for each type of equipment can be found in Appendix A. Table 5 shows the resulting annual electricity consumption in 2013, 2020 and 2030.

Table 4. "In Line with Current Adoption" Case Electric Technology Populations in Thousands (Total, Not Incremental)

Electric Technology		Population (in 000s, Total, Not Incremental)		
		2013	2020	2030
PEVs (50/50 FCV/PEV)	BEV	13.6	27.4	60.4
	PHEV	29.9	168	544
Forklifts	Class 1 + 2	42.9	57.2	82.0
	Class 3	51.5	66.9	92.6
Truck Stop Electrification (Spaces)		0.262	0.262	0.262
Transport Refrigeration Units		3.63	5.88	9.31
Shore Power (Ship Visits)		1.94	4.17	6.34
Port Cargo Handling Equipment	Yard Tractors	0	0.318	0.503
	Forklifts	0	0.122	0.193
	Cranes	0	0.022	0.068
Airport GSE		1.26	2.23	2.78
High Speed Rail (Passenger-miles)		0	1,880,000	2,640,000
Light and Heavy Passenger Rail (Passenger-miles)	Light	899,000	1,042,000	1,094,000
	Heavy	1,620,000	1,802,000	1,802,000
Commuter Rail (Passenger-miles)		0	0	0
Dual Mode Catenary Trucks on I-710 / SR 60 (Truck Miles)	I-710	0	0	0
	SR-60	0	0	0
Medium-Duty Vehicles		0.5	4.2	96.5
Heavy-Duty Vehicles		0.5	0.08	8.8
	Subtotal	**145** **2,522,000 (pass miles)**	**336** **2,845,000 (pass miles)**	**904** **2,896,000 (pass miles)**
Lawn and Garden		8,000	8,500	9,000
Sweepers/Scrubbers		27-28	28-30	28-31
Burnishers		101-102	104-104	106-107
Tow Tractors/Industrial Tugs		9	10	12
Personnel/Burden Carriers		37	40	44
Turf Tractors		0	3	7
Golf Carts		74-82	80-92	85-103
	Subtotal	**248-258** **8,000 (L&G)**	**262-276** **8,500 (L&G)**	**275-297** **9,000 (L&G)**

Table 5. “In Line with Current Adoption” Case Electric Technology Electricity Consumption in Million kWh

Electric Technology		Electricity Consumption (Annual Million kWh)		
		2013	2020	2030
PEVs	BEV	40.9	81.2	170
	PHEV	70.5	385	1,195
Forklifts	Class 1 + 2	786	1,048	1,501
	Class 3	271	351	486
Truck Stop Electrification		0.897	1.595	1.91
Transport Refrigeration Units		8.92	14.4	22.8
Shore Power		102	218	330
Port Cargo Handling Equipment	Yard Tractors	0 (2010)	20.5	32.5
	Forklifts	0	0.496	0.785
	Cranes	0	2.36	7.49
Airport GSE		5.9	10.4	13.0
High Speed Rail		0	756	1,051
Light and Heavy Passenger Rail	Light	274	314	332
	Heavy	373	400	400
Commuter Rail		0	0	0
Dual Mode Catenary Trucks on I-710 / SR 60	I-710	0	0	0
	SR-60	0	0	0
Medium-Duty Vehicles		0	25	550
Heavy-Duty Vehicles		0	1	183
Subtotal		**1,930**	**3,630**	**6,280**
Percentage of CA Electricity Consumption – 250,561 GWh (2013)[12]		**0.7%**	**1.3%**	**2.2%**
Lawn and Garden		113	120	128
Sweepers/Scrubbers		9-30	10-31	10-33
Burnishers		57-79	58-81	60-83
Tow Tractors/Industrial Tugs		53-79	62-92	70-105
Personnel/Burden Carriers		75	82	90
Turf Tractors		0	9	20
Golf Carts		84-92	89-104	95-116
Subtotal		**391-468**	**421-510**	**453-555**

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[12] http://www.energy.ca.gov/2013publications/CEC-100-2013-001/CEC-100-2013-001-CMF.pdf

Table 5 shows that even in the “In Line with Current Adoption” case, forklifts have significant electricity consumption. This is due to a relatively mature market with more than 40% market share of electric forklifts without additional incentives or drivers.

Table 6 shows the petroleum and GHG displacement for the “In Line with Current Adoption” case. Petroleum fuel displacement was calculated by determining the annual fuel consumption for the competing conventional fueled equipment combined with the population forecast. Increased use of certain rail systems would displace compressed natural gas (CNG) from transit buses rather than diesel. The quantity of displaced CNG is listed separately from the displaced diesel since CNG is not petroleum based. ICF calculated the GHG emissions displaced by combining petroleum displaced and electricity consumed, using the full fuel cycle GHG emission factors in Table 32.

Table 7 shows the criteria pollutant emission reductions in the “In Line with Current Adoption” case for 2013 2020, and 2030. ICF calculated reductions of criteria pollutant emissions (PM and NOx + ROG/NMOG) based on current regulations for criteria pollutant emissions (e.g. LEV III[13], ULETRU In-Use Performance Standard[14]) and current emission factors for conventional fuels. The California based upstream criteria pollutant emission factors used are shown in Table 32.

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[13] “Low-Emission Vehicle Program - LEV III,” http://www.arb.ca.gov/msprog/levprog/leviii/leviii.htm

[14] http://www.arb.ca.gov/diesel/tru/tru.htm

Table 6. “In Line with Current Adoption” Case Electric Technology Petroleum and GHG Displacement

Electric Technology	**Petroleum Displacement (millions of GGE/year)**			**GHG Displacement (millions of tons/year)**		
	2013	2020	2030	2013	2020	2030
BEVs	5.12	9.96	17.2	0.04	0.09	0.15
PHEVs	11.1	57.9	153	0.10	0.55	1.39
Forklifts	94.0	125	180	0.78	1.11	1.60
Truck Stop Electrification	0.15	0.27	0.33	0.001	0.003	0.003
Transport Refrigeration Units	1.04	1.69	2.67	0.009	0.015	0.024
Shore Power	8.78	18.8	28.5	0.064	0.15	0.23
Port Cargo Handling Equipment	0 (2010)	2.13	3.83	0	0.018	0.032
Airport GSE	0.47	0.83	1.04	0.003	0.007	0.008
High Speed Rail	0	32.8	45.9	0	0.15	0.21
Light and Heavy Passenger Rail	46.4 30.8 (CNG)	51.8 35.4 (CNG)	51.9 37.1 (CNG)	0.49	0.61	0.63
Commuter Rail	0	0	0	0	0	0
Dual Mode Catenary Trucks on I-710 / SR 60	0	0	0	0	0	0
Medium-Duty Vehicles	0	2.7	58.2	0	0	0.5
Heavy-Duty Vehicles	0	0.1	15.4	0	0	0.15
Subtotal	**167 30.8 (CNG)**	**304 35.4 (CNG)**	**558 37.1 (CNG)**	**1.49**	**2.73**	**4.92**
Percentage of 2013 CA Consumption / Emissions 18.8 Billion GGE[15]/171 MMT[16]	**0.9%**	**1.6%**	**3.0%**	**0.9%**	**1.6%**	**2.9%**
Lawn and Garden	0	0	0	0	0	0
Sweepers/Scrubbers	2.9-3.0	3.0-3.2	3-3.3	0.04	0.04	0.04
Burnishers	0.7	0.7	0.7	0.01	0.01	0.01
Tow Tractors/Industrial Tugs	0.54	0.72	0.81	0.01	0.01	0.01
Personnel/Burden Carriers	0.5	0.58	0.64	0.01	0.01	0.01
Turf Tractors	0	2.1	4.5	0.00	0.02	0.05
Golf Carts	0.5	0.5	0.6	0.01	0.01	0.01
Subtotal	**5.1-5.2**	**7.5-7.8**	**10-11**	**0.08**	**0.10**	**0.13**

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[15] California 2013 Weekly Fuels Watch Report http://energyalmanac.ca.gov/petroleum/fuels_watch/; all sectors

[16] http://www.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_by_sector_00-12_sum_2014-03-24.pdf

Table 7. “In Line with Current Adoption” Case Electric Technology PM and NOx + ROG/NMOG Displacement in California (Tons/Day)

Electric Technology	PM (Tons/Day)			NOX + ROG/NMOG (Tons/day)		
	2013	2020	2030	2013	2020	2030
BEVs	0.004	0.01	0.01	0.06	0.11	0.11
PHEVs	0.01	0.03	0.03	0.10	0.50	0.80
Forklifts	0.04	0.05	0.08	2.92	3.92	5.62
Truck Stop Electrification	0.000	0.000	0.001	0.03	0.05	0.06
Transport Refrigeration Units	0.002	0.003	0.005	0.33	0.53	0.87
Shore Power	0.075	0.162	0.246	4.39	9.40	14.3
Port Cargo Handling Equipment	0	0.001	0.002	0	0.05	0.09
Airport GSE	0.001	0.001	0.001	0.08	0.10	0.13
High Speed Rail	0	0.011	0.015	0	0.32	0.45
Light and Heavy Passenger Rail	0.020	0.023	0.024	0.47	0.55	0.56
Commuter Rail	0	0	0	0	0	0
Dual Mode Catenary Trucks on I-710 / SR 60	0	0	0	0	0	0
Medium-Duty Vehicles	0.0	0.0	0.0	0.0	0.1	0.6
Heavy-Duty Vehicles	0.0	0.0	0.03	0.0	0.02	1.33
Subtotal	**0.15**	**0.30**	**0.44**	**8.36**	**15.6**	**24.8**
Percentage of 2013 CA Emissions – 85 TPD PM[17]/ 2,509 TPD NOX +ROG[18]	**0.2%**	**0.4%**	**0.5%**	**0.3%**	**0.6%**	**1.0%**
Lawn and Garden	0	0	0	0	0	0
Sweepers/Scrubbers	0.03	0.022	0.02-0.03	0.58-0.61	0.53-0.57	0.55-0.60
Burnishers	0	0	0	0.04	0.04	0.04
Tow Tractors/Industrial Tugs	0	0	0	0.02	0.02	0.02
Personnel/Burden Carriers	0	0	0	0.07	0.08	0.09
Turf Tractors	0	0	0	0	0.12	0.25
Golf Carts	0	0	0	0.05-0.06	0.06-0.07	0.06-0.08
Subtotal	**0.03**	**0.022**	**0.02-0.03**	**0.76-0.80**	**0.85-0.90**	**1.0-1.1**

2.2 “In Between” Case

The “In Between” case for many technologies is halfway in between the “In Line with Current Adoption” and "Aggressive Adoption" cases except for PEVs, TRUs, cold-ironing, HSR, and fixed guideway. For these identified technologies, specific “In Between” cases were developed. These specific cases can be found in Appendix A. Table 8 shows the California electric technology population forecasts in the “In Between” case for 2013, 2020, and 2030 where TSE penetration is shown as the number of electrified spaces, cold-

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[17] http://www.arb.ca.gov/aqd/almanac/almanac13/pdf/chap213.pdf

[18] California Almanac of Emissions and Air Quality 2013 Edition - Chapter 2 Current Emissions and Air Quality http://www.arb.ca.gov/aqd/almanac/almanac13/pdf/chap213.pdf

ironing as the number of electrified ship visits, electrified rail as passenger-miles, and fixed guideway as truck-miles.

Table 8. "In Between" Case California Electric Technology Populations in Thousands (Total, Not Incremental)

Electric Technology		**Population (in 000s, Total, Not Incremental)**		
		2013	**2020**	**2030**
PEVs ZEV Likely Compliance	BEV	24.1	147	734
	PHEV	29.9	249	1,580
Forklifts	Class 1 + 2	42.9	62.9	101
	Class 3	51.5	66.9	92.6
Truck Stop Electrification (Spaces)		0.262	1.52	2.45
Transport Refrigeration Units		3.63	15.9	67.3
Shore Power (Ship Visits)		1.94	5.48	8.53
Port Cargo Handling Equipment	Yard Tractors	0	0.795	2.64
	Forklifts	0	0.304	0.866
	Cranes	0	0.097	0.308
Airport GSE		1.26	3.00	4.91
High Speed Rail (Passenger-miles)		0	1,880,000	5,900,000
Light and Heavy Passenger Rail (Passenger-miles)	Light	899,00	1,150,000	1,330,000
	Heavy	1,620,000	2,010,000	2,250,000
Commuter Rail (Passenger-miles)		0	386,000	418,000
Dual Mode Catenary Trucks on I-710 / SR 60 (Truck Miles)	I-710	0	30,700	194,000,000
	SR-60	0	0	0
Medium-Duty Vehicles		0.5	6.3	183.7
Heavy-Duty Vehicles		0.5	0.38	23.5
	Subtotal	**156** **2,522,000 (pass miles)**	**559** **3,580,000 (pass miles)**	**2,804** **4,180,000 (pass miles)**

The anticipated connected load and resulting annual electricity consumption for populations in the table above were calculated for each type of equipment. The data sources and assumptions for electricity load and annual consumptions for each type of equipment can be found in Appendix A. Table 9 shows the resulting "In Between" case annual electricity consumption in 2013, 2020 and 2030.

Table 9. "In Between" Case Electric Technology Electricity Consumption in Million kWh

Electric Technology		Electricity Consumption (Annual Million kWh)		
		2013	2020	2030
PEVs	BEV	72	436	2,060
	PHEV	72	568	3,490
Forklifts	Class 1 + 2	786	1,180	1,940
	Class 3	271	351	486
Truck Stop Electrification		2.16	12.1	22.2
Transport Refrigeration Units		8.92	44.4	200
Shore Power		102	287	446
Port Cargo Handling Equipment	Yard Tractors	0	51.3	146
	Forklifts	0	1.24	3.53
	Cranes	0	10.6	33.7
Airport GSE		5.9	14.0	22.9
High Speed Rail		0	756	2,340
Light and Heavy Passenger Rail	Light	274	347	404
	Heavy	373	446	498
Commuter Rail		0	144	156
Dual Mode Catenary Trucks on I-710 / SR 60	I-710	0	82.9	525
	SR-60	0	0	0
Medium-Duty Vehicles		0	38	1,047
Heavy-Duty Vehicles		0	6	446
Subtotal		**1,970**	**4,770**	**14,300**
Percentage of CA Electricity Consumption – 250,561 GWh (2013)[19]		**0.7%**	**1.7%**	**5.1%**

Table 10 shows the petroleum and GHG displacement for the "In Between" case in 2013, 2020, and 2030. Petroleum fuel displacement was calculated by determining the annual fuel consumption for the competing conventional fueled equipment combined with the population forecast. Increased use of a certain rail systems would displace CNG from transit buses rather than diesel. The quantity of displaced CNG is listed separately from the displaced diesel since it does not come from petroleum. ICF calculated the GHG emissions displaced by combining petroleum displaced and electricity consumed, using the full fuel cycle GHG emission factors in Table 32.

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[19] http://www.energy.ca.gov/2013publications/CEC-100-2013-001/CEC-100-2013-001-CMF.pdf

Table 10. “In Between” Case Electric Technology Petroleum and GHG Displacement

Electric Technology	Petroleum Displacement (millions of GGE/year)			GHG Displacement (millions of tons/year)		
	2013	2020	2030	2013	2020	2030
BEVs	9.04	52.8	205	0.08	0.47	1.72
PHEVs	11.2	84.9	450	0.10	0.80	4.09
Forklifts	94.0	139	225	0.78	1.23	2.00
Truck Stop Electrification	0.37	2.07	3.78	0.003	0.020	0.037
Transport Refrigeration Units	1.04	5.26	23.9	0.009	0.048	0.22
Shore Power	8.78	24.8	34.138.6	0.064	0.20	0.31
Port Cargo Handling Equipment	0	5.90	17.2	0	0.050	0.14
Airport Ground Support Equipment	0.47	1.12	1.84	0.003	0.009	0.014
High Speed Rail	0	32.76	102.7	0	0.15	0.49
Light and Heavy Passenger Rail	46.4 30.8 (CNG)	64.1 38.4 (CNG)	71.4 44.0 (CNG)	0.49	0.67	0.76
Commuter Rail	0	6.40	6.93	0	0.031	0.033
Dual Mode Catenary Trucks on I-710 / SR 60	0	5.93	37.5	0	0.043	0.28
Medium-Duty Vehicles	0	4	111	0.0	0.0	1.0
Heavy-Duty Vehicles	0	0	38	0.0	0.01	0.44
Subtotal	**195** **30.8 (CNG)**	**478** **38.4 (CNG)**	**1,430** **44.0 (CNG)**	**1.53**	**3.77**	**11.5**
Percentage of 2013 CA Consumption / Emissions 18.8 Billion GGE[20]/171 MMT[21]	**0.9%**	**2.3%**	**7.1%**	**0.9%**	**2.2%**	**6.7%**

Table 11 shows the criteria pollutant emission reductions in the “In Between” case for 2013 2020, and 2030. ICF calculated reductions of criteria pollutant emissions (PM and NOx + ROG/NMOG) based on current regulations for criteria pollutant emissions (e.g. LEV III[22], ULETRU In-Use Performance Standard[23]) and current emission factors for conventional fuels. The California based upstream criteria pollutant emission factors used are shown in Table 32.

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[20] California 2013 Weekly Fuels Watch Report http://energyalmanac.ca.gov/petroleum/fuels_watch/; all sectors

[21] http://www.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_by_sector_00-12_sum_2014-03-24.pdf

[22] “Low-Emission Vehicle Program - LEV III,” http://www.arb.ca.gov/msprog/levprog/leviii/leviii.htm

[23] http://www.arb.ca.gov/diesel/tru/tru.htm

Table 11. "In Between" Case Electric Technology PM and NOx + ROG/NMOG Displacement in California (Tons/Day)

Electric Technology	PM (Tons/Day)			NOX + ROG/NMOG (Tons/day)		
	2013	2020	2030	2013	2020	2030
BEVs	0.01	0.03	0.04	0.10	0.51	1.15
PHEVs	0.01	0.05	0.06	0.10	0.70	2.02
Forklifts	0.04	0.06	0.09	2.92	4.31	6.93
Truck Stop Electrification	0.000	0.003	0.005	0.03	0.36	0.67
Transport Refrigeration Units	0.002	0.006	0.019	0.33	1.4	5.6
Shore Power	0.075	0.21	0.33	04.30	12.4	19.3
Port Cargo Handling Equipment	0	0.003	0.009	0	0.14	0.39
Airport Ground Support Equipment	0.001	0.002	0.002	0.08	0.14	0.23
High Speed Rail	0	0.011	0.041	0	0.32	1.1
Light and Heavy Passenger Rail	0.019	0.026	0.029	0.47	0.61	0.69
Commuter Rail	0	0.002	0.003	0	0.07	0.07
Dual Mode Catenary Trucks on I-710 / SR 60	0	0.003	0.003	0	0.14	0.71
Medium-Duty Vehicles	0.0	0.0	0.0	0.0	0.1	1.2
Heavy-Duty Vehicles	0.0	0.0	0.09	0.0	0.09	3.54
Subtotal	**0.15**	**0.41**	**0.73**	**8.6**	**22.0**	**45.1**
Percentage of 2013 CA Emissions – 85 TPD PM[24]/ 2,509 TPD NOX +ROG[25]	**0.2%**	**0.5%**	**0.9%**	**0.3%**	**0.8%**	**1.7%**

2.3 "Aggressive Adoption" Case

The "Aggressive Adoption" case for many technologies includes aggressive new incentive programs and/or regulations, especially regulations similar to the mandate at the ports. "Aggressive adoption" cases are not simply the hypothetical maximums, but are tangibly aggressive and anticipate achieving compliance with regulations where electrification is not the only avenue for compliance (e.g. anti-idling, ocean going vessels at-berth, TRUs) solely through electrification. Table 12 shows the California electric technology population forecasts in the "Aggressive Adoption" case where TSE penetration is shown as the number of electrified spaces, cold-ironing as the number of electrified ship visits, electrified rail as passenger-miles, and fixed guideway as truck-miles.

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[24] http://www.arb.ca.gov/aqd/almanac/almanac13/pdf/chap213.pdf

[25] California Almanac of Emissions and Air Quality 2013 Edition - Chapter 2 Current Emissions and Air Quality http://www.arb.ca.gov/aqd/almanac/almanac13/pdf/chap213.pdf

Table 12. “Aggressive Adoption” Case California Electric Technology Populations in Thousands (Total, Not Incremental)

Electric Technology		Population (in 000s, Total, Not Incremental)		
		2013	2020	2030
PEVs 3x ZEV Likely Compliance	BEV	24.1	441	2,200
	PHEV	29.9	745	4,750
Forklifts	Class 1 + 2	42.9	68.7	120
	Class 3	51.5	66.9	92.6
Truck Stop Electrification (Spaces)		0.262	2,790	4,640
Transport Refrigeration Units		3.63	46.1	263
Shore Power (Ship Visits)		1.94	7.58	11.3
Port Cargo Handling Equipment	Yard Tractors	0	1.270	4.030
	Forklifts	0	0.486	1.540
	Cranes	0	0.173	0.547
Airport GSE		1.26	3.77	7.04
High Speed Rail (Passenger-miles)		0	1,880,000	8,330,000
Light and Heavy Passenger Rail (Passenger-miles)	Light	899,000	1,250,000	1,560,000
	Heavy	1,620,000	2,210,000	2,810,000
Commuter Rail (Passenger-miles)		0	422,000	633,000
Dual Mode Catenary Trucks on I-710 / SR 60 (Truck Miles)	I-710	0	76,031	241,000
	SR-60	0	0	315,000
Medium-Duty Vehicles		0.5	16.4	834
Heavy-Duty Vehicles		0.5	0.795	65.8
	Subtotal	**155** **2,520,000 (pass miles)**	**1,400** **3,960,000 (pass miles)**	**8,360** **5,560,000 (pass miles)**
Lawn and Garden		9,300	11,000	14,100
Sweepers/Scrubbers		29	32	35
Burnishers		103	106	109
Tow Tractors/Industrial Tugs		14	16	19
Personnel/Burden Carriers		51	54	57
Turf Tractors		9	18	27
Golf Carts		89	103	117
	Subtotal	**295** **9,300 (L&G)**	**329** **11,000 (L&G)**	**364** **14,100 (L&G)**

The anticipated connected load and resulting annual electricity consumption for populations in the table above were calculated for each type of equipment. The data sources and assumptions for electricity load and annual consumptions for each type of equipment can be found in Appendix A.

Table 13 shows the resulting "Aggressive Adoption" case annual electricity consumption in 2013, 2020 and 2030.

Table 14 shows the petroleum and GHG displacement for the "Aggressive Adoption" case in 2013, 2020, and 2030. Petroleum fuel displacement was calculated by determining the annual fuel consumption for the competing conventional fueled equipment combined with the population forecast. Increased use of a certain rail systems would displace CNG from transit buses rather than diesel. The quantity of displaced CNG is listed separately from the displaced diesel since it does not come from petroleum. ICF calculated the GHG emissions displaced by combining petroleum displaced and electricity consumed, using the full fuel cycle GHG emission factors in Table 32.

Table 13. “Aggressive Adoption” Case Electric Technology Electricity Consumption in Million kWh

Electric Technology		**Electricity Consumption (Annual Million kWh)**		
		2013	**2020**	**2030**
PEVs	BEV	72	1,310	6,170
	PHEV	72.0	1,700	10,500
Forklifts	Class 1 + 2	786	1,310	2,380
	Class 3	271	351	486
Truck Stop Electrification		3.43	22.6	42.4
Transport Refrigeration Units		8.92	14.4	22.8
Shore Power		102	362	551
Port Cargo Handling Equipment	Yard Tractors	0	82.2	260
	Forklifts	0	1.98	6.28
	Cranes	0	18.9	59.9
Airport GSE		5.9	17.6	32.9
High Speed Rail		0	756	3,490
Light and Heavy Passenger Rail	Light	274	380	477
	Heavy	373	494	628
Commuter Rail		0	157	236
Dual Mode Catenary Trucks on I-710 / SR 60	I-710	0	160	722
	SR-60	0	0	945
Medium-Duty Vehicles		0	98	4,753
Heavy-Duty Vehicles		0	12	1,235
Subtotal		**1,970**	**7,300**	**33,200**
Percentage of CA Electricity Consumption – 250,561 GWh (2013)[26]		**0.7%**	**2.6%**	**11.8%**
Lawn and Garden		185	197	209
Sweepers/Scrubbers		10-30	11-34	12-37
Burnishers		58-80	60-82	61-85
Tow Tractors/Industrial Tugs		84-125	97-146	111-167
Personnel/Burden Carriers		104	110	116
Turf Tractors		27	54	81
Golf Carts		100	116	132
Subtotal		**568-651**	**645-739**	**722-827**

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[26] http://www.energy.ca.gov/2013publications/CEC-100-2013-001/CEC-100-2013-001-CMF.pdf

Table 14. "Aggressive Adoption" Case Electric Technology Petroleum and GHG Displacement

Electric Technology	Petroleum Displacement (millions of GGE/year)			GHG Displacement (millions of tons/year)		
	2013	2020	2030	2013	2020	2030
BEVs	9.04	159	614	0.08	1.42	5.15
PHEVs	11.2	255	1,350	0.10	2.40	12.3
Forklifts	94.0	153	273	0.78	1.35	2.40
Truck Stop Electrification	0.59	3.86	7.24	0.006	0.038	0.071
Transport Refrigeration Units	1.04	7.09	35.7	0.009	0.064	0.33
Shore Power	8.78	31.2	47.7	0.064	0.25	0.39
Port Cargo Handling Equipment	0	9.67	30.6	0	0.081	0.26
Airport GSE	0.47	1.41	2.63	0.003	0.011	0.020
High Speed Rail	0	32.8	145	0	0.15	0.63
Light and Heavy Passenger Rail	46.4 30.8 (CNG)	62.8 42.2 (CNG)	79.2 52.2 (CNG)	0.49	0.74	0.91
Commuter Rail	0	7.00	10.51	0	0.034	0.051
Dual Mode Catenary Trucks on I-710 / SR 60	0	14.7	107	0	0.12	0.74
Medium-Duty Vehicles	0	10	503	0	0.1	4.3
Heavy-Duty Vehicles	0	1	104	0	0.01	1.31
Subtotal	**171** **30.8 (CNG)**	**749** **42.2(CNG)**	**3,310** **52.2 (CNG)**	**1.53**	**6.76**	**28.9**
Percentage of 2013 CA Consumption / Emissions **18.8 Billion GGE[27]/171 MMT[28]**	**0.9%**	**4.0%**	**18%**	**0.9%**	**4.0%**	**17%**
Lawn and Garden	5-16	10-29	18-50	0.06-0.09	0.11-0.33	0.20-0.58
Sweepers/Scrubbers	6.0	12	17	0.07	0.14	0.21
Burnishers	3	2.8	2.6	0.04	0.03	0.03
Tow Tractors/Industrial Tugs	20	22.9	26	0.22-0.23	0.26-0.27	0.03-0.31
Personnel/Burden Carriers	21	20	20	0.25	0.24	0.23
Turf Tractors	6.0	12	18	0.06	0.13	0.19
Golf Carts	9.6	14	19	0.12	0.17	0.23
Subtotal	**71-82**	**94-113**	**120-152**	**0.82-0.86**	**1.1-1.3**	**1.4-1.8**

Table 15 shows the criteria pollutant emission reductions in the "Aggressive Adoption" case for 2013 2020, and 2030. ICF calculated reductions of criteria pollutant emissions (PM and NOx + ROG/NMOG) based on current regulations for criteria pollutant emissions (e.g. LEV III[29], ULETRU In-Use Performance

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[27] California 2013 Weekly Fuels Watch Report http://energyalmanac.ca.gov/petroleum/fuels_watch/; all sectors

[28] http://www.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_by_sector_00-12_sum_2014-03-24.pdf

[29] "Low-Emission Vehicle Program - LEV III," http://www.arb.ca.gov/msprog/levprog/leviii/leviii.htm

Standard[30]) and current emission factors for conventional fuels. The California based upstream criteria pollutant emission factors used are shown in Table 32.

Table 15. "Aggressive Adoption" Case Electric Technology PM and NOx + ROG/NMOG Displacement in California (Tons/Day)

Electric Technology	PM (Tons/Day)			NOX + ROG/NMOG (Tons/day)		
	2013	2020	2030	2013	2020	2030
BEVs	0.01	0.10	0.12	0.10	1.54	3.47
PHEVs	0.01	0.14	0.18	0.10	2.09	6.07
Forklifts	0.04	0.06	0.11	2.92	4.70	8.24
Truck Stop Electrification	0.000	0.000	0.001	0.03	0.05	0.06
Transport Refrigeration Units	0.002	0.003	0.005	0.33	0.53	0.87
Shore Power	0.075	0.27	0.41	4.39	15.6	23.8
Port Cargo Handling Equipment	0	0.001	0.002	0	0.05	0.09
Airport GSE	0.003	0.003	0.004	0.08	0.11	0.14
High Speed Rail	0	0.011	0.015	0	0.32	0.45
Light and Heavy Passenger Rail	0.019	0.028	0.036	0.47	0.67	0.85
Commuter Rail	0	0.003	0.004	0	0.07	0.11
Dual Mode Catenary Trucks on I-710 / SR 60	0	0	0	0	0	0
Medium-Duty Vehicles	0.0	0.0	0.0	0.0	0.2	5.4
Heavy-Duty Vehicles	0.0	0.0	0.25	0.0	0.19	9.9
Subtotal	**0.15**	**0.66**	**1.29**	**8.41**	**28.8**	**71.9**
Percentage of 2013 CA Emissions – 85 TPD PM[31]/ 2,509 TPD NOX +ROG[32]	**0.2%**	**0.8%**	**1.5%**	**0.3%**	**1.2%**	**2.9%**
Lawn and Garden	0.07-0.12	0.77-0.87	1.8-2.0	6.7-8.2	10-13	14-20
Sweepers/Scrubbers	0.06	0.09	0.13	1.2	2.1	3.1
Burnishers	0.01	0.01	0.01	0.17	0.17	0.16
Tow Tractors/Industrial Tugs	0.01	0.01	0.01	0.75	0.87	1.0
Personnel/Burden Carriers	0.12	0.11	0.11	2.9	2.7	2.6
Turf Tractors	0.03	0.06	0.09	1.3	2.6	3.9
Golf Carts	0.03	0.04	0.06	1.1	1.7	2.2
Subtotal	**0.33-0.38**	**1.1-1.2**	**2.2-2.4**	**14-16**	**20-23**	**27-33**

[30] http://www.arb.ca.gov/diesel/tru/tru.htm

[31] http://www.arb.ca.gov/aqd/almanac/almanac13/pdf/chap213.pdf

[32] California Almanac of Emissions and Air Quality 2013 Edition - Chapter 2 Current Emissions and Air Quality http://www.arb.ca.gov/aqd/almanac/almanac13/pdf/chap213.pdf

3 Costs and Benefits of Select TE Segments

The following cost and benefit analysis includes both traditional elements (e.g. incremental capital cost, operational cost/savings, and fuel cost/savings) and non-traditional ratepayer benefits including GHG emission reduction, petroleum displacement and criteria pollutant reduction. The methodologies utilized in this section are consistent with those employed by agencies such as the California Energy Commission (CEC), Air Resources Board (ARB) and local air quality agencies to understand the costs and benefits of alternative fuels and emission reduction technologies and programs. Phase 2 will perform a more thorough analysis of the grid benefits from PEVs using CPUC consistent benefit and cost methodologies and considerations including analysis from both a ratepayer and utility perspective. The methodologies employed in Phase 2 will include the avoided cost methodology which has been adopted by the CPUC for evaluating distributed energy resources such as energy efficiency, demand response and distributed generation.

Public Utilities Commission (PUC) Code 740.8 calls for the inclusion of “interests” to ratepayers including activities “that promote energy efficiency, reduction of health and environmental impacts from air pollution, and greenhouse gas emissions related to electricity and natural gas production and use, and increased use of alternative fuels.” [33] In addition, agencies such as the California Energy Commission (CEC) and Air Resources Board (ARB) are shifting to a more comprehensive approach when considering costs and multiple benefits (e.g. State Alt Fuels Plan (AB1007), Vision for Clean Air).Grant programs such as Carl Moyer look to monetize and provide incentives for criteria pollutant emission reductions (e.g. NOx, ROG, PM) and AB118 looks to monetize and reduce GHG emissions and petroleum consumption. Due to transportation electrification’s higher capital costs and lack of a singular focus on one type of reduction, these programs do not reward the comprehensive benefits and operational cost savings of transportation electrification. The benefit-cost ratio was developed to incorporate the full range of societal benefits and operational cost savings. The cost analysis in this section is from the perspective of TE technology consumers.

The benefit-cost ratio categorizes cost elements as either costs or benefits (i.e., savings). Cost savings are characterized as a benefit and incorporated into the numerator. However, there are several trade-offs in this metric as well. For instance, a benefit-cost ratio requires that emission reductions (e.g., tons of GHG reductions) be monetized so that they can be included in the calculation. Monetized health and environmental benefits or damage costs can be controversial and also have their detractors. Both the cost-effectiveness metric and benefit-cost ratio can oversimplify the analysis of technologies. It is also important to consider the magnitude of the benefits.

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[33] PUC Code § 740.8 - “As used in Section 740.3, ‘interests’ of ratepayers, short- or long-term, mean direct benefits that are specific to ratepayers in the form of safer, more reliable, or less costly gas or electrical service, consistent with Section 451, and activities that benefit ratepayers and that promote energy efficiency, reduction of health and environmental impacts from air pollution, and greenhouse gas emissions related to electricity and natural gas production and use, and increased use of alternative fuels.” http://www.leginfo.ca.gov/cgi-bin/displaycode?section=puc&group=00001-01000&file=727-758

The analysis in the following section looks at the benefit-cost ratio for the selected technologies (PEVs, forklifts, TSE and TRUs) and compares them with the magnitude of potential benefits using the 2030 “Aggressive Adoption" case. The cost elements in the analysis include incremental costs (both vehicles and infrastructure), operational and maintenance (O&M) and fuel costs, and monetized societal benefits. Table 16 below shows the factors for monetizing the societal benefits. For each of the emission reduction benefits, the most conservative values (the highest discount rate) were selected for the analysis. The values for 2020 were escalated to 2030 using the consumer price index (CPI)[34] from the U.S. Bureau of Labor Statistics.

Table 16. Factors for Monetizing Societal Benefits

Societal Benefit	Unit	Discount Rate	2013	2020	2030
Displaced Petroleum[35,36]	$/GGE		$0.44	$0.43	$0.42
GHG [37,38]	$/MT	5%	$11	$12	$16
NOx[39,40]	$/ton	7%	$4,675	$5,082	$6,098
PM [41,42]	$/ton	7%	$1,450,038	$1,650,681	$1,977,357
VOC [41,42]	$/ton	7%	$1,118	$1,20	$1,423

For each of the following technologies analyzed, summary tables and figures are presented in the following section for annualized costs, private benefits and monetized societal benefits. The detailed analysis, data sources and assumptions can be found in Appendix B for all technologies.

3.1 Plug-In Electric Vehicles (PEVs)

The analysis for PEVs has been divided into two classes: passenger cars and light trucks. This is due to differences in incremental capital costs and fuel economies between the two classes of vehicles. For each class the analysis includes PHEV10, PHEV20, PHEV40 and BEV for 2013, 2020 and 2030 to account for the differences in gasoline and electricity consumption and cost, and incremental costs between

[34] http://www.bls.gov/cpi/

[35] Leiby, P. Estimating the Energy Security Benefits of Reduced U.S. Oil Imports, ORNL/TM-2007/028, March 2008

[36] EPA RFS Annual Rulemaking, Updated Energy Security Benefits, 2012. EPA-HQ-OAR-2010-0133-0252, Available online at: http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2010-0133-0252

[37] Interagency Working Group on Social Cost of Carbon. 2010. Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866. February. United States Government. http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf

[38] Interagency Working Group on Social Cost of Carbon. Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, United States Government, May 2013.

[39] Diesel Emissions Quantifier Health Benefits Methodology, EPA, EPA-420-B-10-034, August 2010.

Available online: http://www.epa.gov/cleandiesel/documents/420b10034.pdf

[40] EPA/HNTSA, Draft Joint Technical Support Document: Proposed Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, EPA-420-D-11-901, November 2011.

each type of vehicle in each year. The detailed costing analysis, data sources and assumptions can be found in Appendix B.

3.1.1 Passenger Cars

Table 17 and Table 18 below show the resulting private and societal benefit-cost ratios. The private benefit from both a time of use (TOU) rate and a domestic rate are shown separately in the tables below and in Figure 2 and Figure 3. A domestic rate structure is a traditional tiered residential rate structure where the more electricity a household consumes from charging a PEV, the higher the marginal electricity rate no matter when the charging occurs. A TOU rate structure rewards off-peak electricity consumption (e.g. PEV charging) by applying a lower rate than is used during other time periods. The use of a domestic rate reduces the private benefit 7 to13% in 2013 and 16 to41% in 2030. To develop the benefit-cost ratio shown in Figure 2 and Figure 3 for passenger cars, the annual private benefits and monetized societal benefits are divided by the annualized private costs. A private benefit-cost ratio exceeding one means the technology has lifecycle savings. The red line in Figure 2 and Figure 3 delineate a benefit-cost ratio of one (1).

Table 17. TOU Rate Private and Societal Benefit-Cost Ratios

Passenger Cars	PHEV10			PHEV20			PHEV40			BEV		
	2013	2020	2030	2013	2020	2030	2013	2020	2030	2013	2020	2030
Private Benefit-Cost Ratio												
Operational Savings	4.47	7.82	12.53	1.63	3.01	7.49	1.76	3.59	3.84	1.57	3.67	8.89
Societal Benefit-Cost Ratios												
Petroleum Displacement	0.48	0.78	1.10	0.19	0.35	0.82	0.22	0.47	0.50	0.17	0.41	0.96
GHG Emission	0.12	0.22	0.41	0.04	0.09	0.28	0.05	0.12	0.16	0.04	0.10	0.30
NOx	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01
PM	0.22	0.24	0.02	0.13	0.16	0.01	0.18	0.25	0.01	0.16	0.24	0.01
VOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Societal	**0.82**	**1.25**	**1.54**	**0.37**	**0.61**	**1.13**	**0.46**	**0.85**	**0.67**	**0.37**	**0.76**	**1.28**

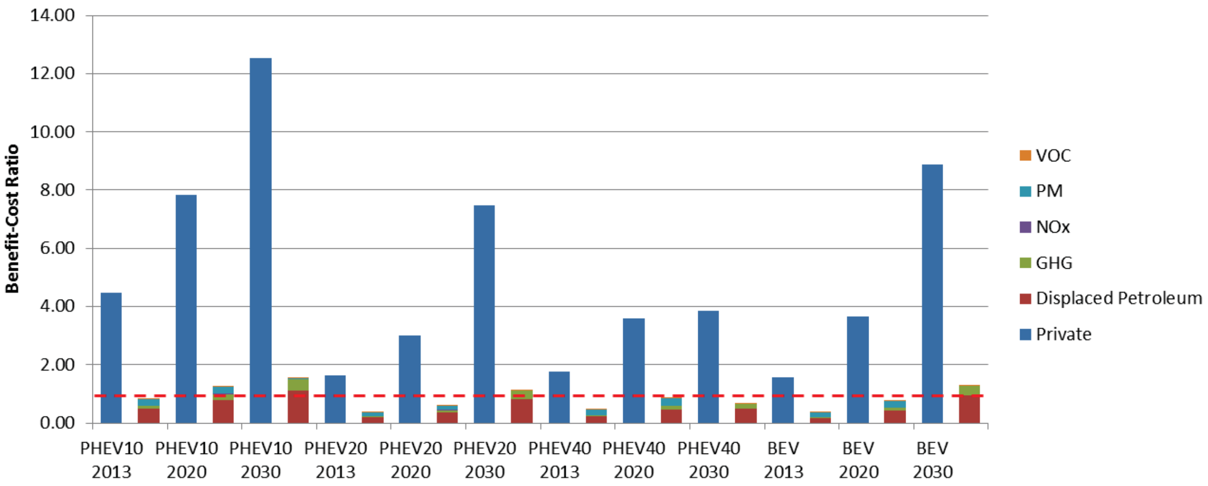

Figure 2. Benefit-Cost Ratio for Passenger Cars - TOU Rate

Table 18. Domestic Rate Private and Societal Benefit-Cost Ratios

Passenger Cars	**PHEV10**			**PHEV20**			**PHEV40**			**BEV**		
	2013	2020	2030	2013	2020	2030	2013	2020	2030	2013	2020	2030
Private Benefit-Cost Ratio												
Operational Savings	4.19	6.97	10.54	1.46	2.43	5.29	1.52	2.67	2.25	1.37	2.78	5.49
Societal Benefit-Cost Ratios												
Petroleum Displacement	0.48	0.78	1.10	0.19	0.35	0.82	0.22	0.47	0.50	0.17	0.41	0.96
GHG Emission	0.12	0.22	0.41	0.04	0.09	0.28	0.05	0.12	0.16	0.04	0.10	0.30
NOx	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01
PM	0.22	0.24	0.02	0.13	0.16	0.01	0.18	0.25	0.01	0.16	0.24	0.01
VOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Societal	**0.82**	**1.25**	**1.54**	**0.37**	**0.61**	**1.13**	**0.46**	**0.85**	**0.67**	**0.37**	**0.76**	**1.28**

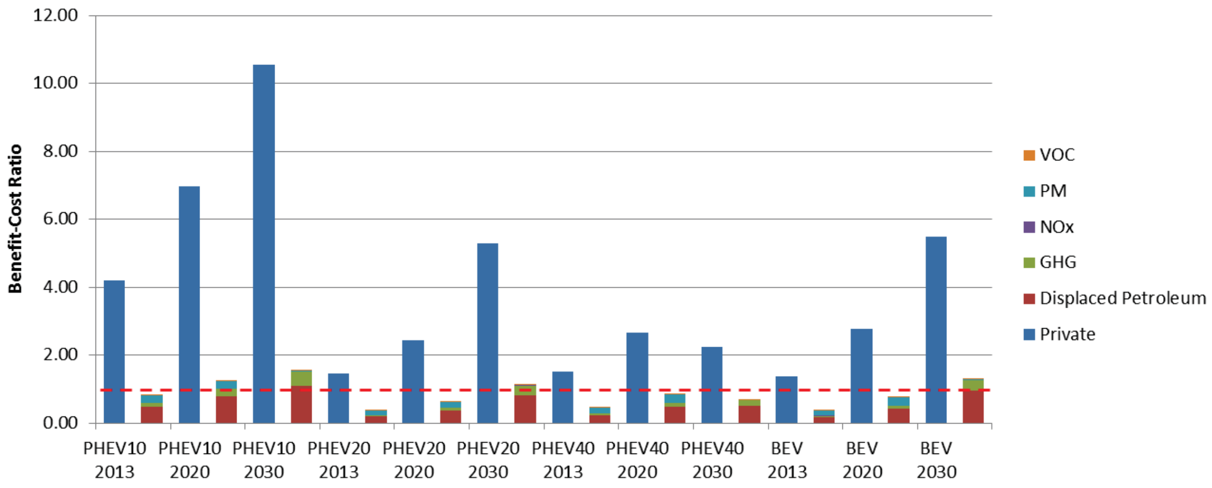

Figure 3. Benefit-Cost Ratio for Passenger Cars - Domestic Rate

Figure 2 and Figure 3 show the private and total benefit-cost ratios for all technologies and classes are above one (the dotted red line) and significantly above one for 2020 and 2030. Figure 2 and Figure 3 also show that for 2013, differences between the benefit-cost ratio from the TOU and domestic rates are much smaller than in 2030. This is due to rate differences of only \$0.065 per kWh in 2010 and \$0.14 in 2030. The ratio differences are also accentuated by the dramatic reduction of the incremental cost (denominator of the ratio) between 2013 and 2030. We can also see that due to increasingly more stringent tailpipe emission standards the 2030 NOx, PM and VOC reductions, and hence their resulting societal benefits, are almost zero.

3.1.2 Light Trucks

Table 19 and Table 20 below show the resulting private and societal benefit-cost ratios. The private benefit of both a TOU rate and a domestic rate are shown separately in the tables below and in Figure 4 and Figure 5. The use of a domestic rate reduces the private benefit 6 to 14% in 2010 and 13 to 33% in 2030. To develop the benefit-cost ratio shown in Figure 4 and Figure 5 for passenger cars, the annual private benefits and monetized societal benefits are divided by the annualized costs. A private benefit-cost ratio exceeding one means the technology has lifecycle savings. The red line in Figure 4 and Figure 5 delineate a benefit-cost ratio of one.

Table 19. TOU Rate Private and Societal Benefit-Cost Ratios

Light-Trucks	**PHEV10**			**PHEV20**			**PHEV40**			**BEV**		
	2013	2020	2030	2013	2020	2030	2013	2020	2030	2013	2020	2030
Private Benefit-Cost Ratio												
Operational Savings	2.96	5.08	7.80	1.33	2.40	4.48	1.30	2.53	2.96	0.96	2.17	3.86
Societal Benefit-Cost Ratios												
Petroleum Displacement	0.33	0.53	0.69	0.16	0.29	0.47	0.17	0.33	0.36	0.11	0.25	0.42
GHG Emission	0.08	0.15	0.27	0.04	0.07	0.17	0.04	0.08	0.12	0.02	0.06	0.14
NOx	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM	0.11	0.11	0.01	0.08	0.09	0.00	0.10	0.12	0.00	0.07	0.10	0.00
VOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Societal	**0.52**	**0.79**	**0.97**	**0.28**	**0.45**	**0.65**	**0.31**	**0.54**	**0.48**	**0.21**	**0.42**	**0.55**

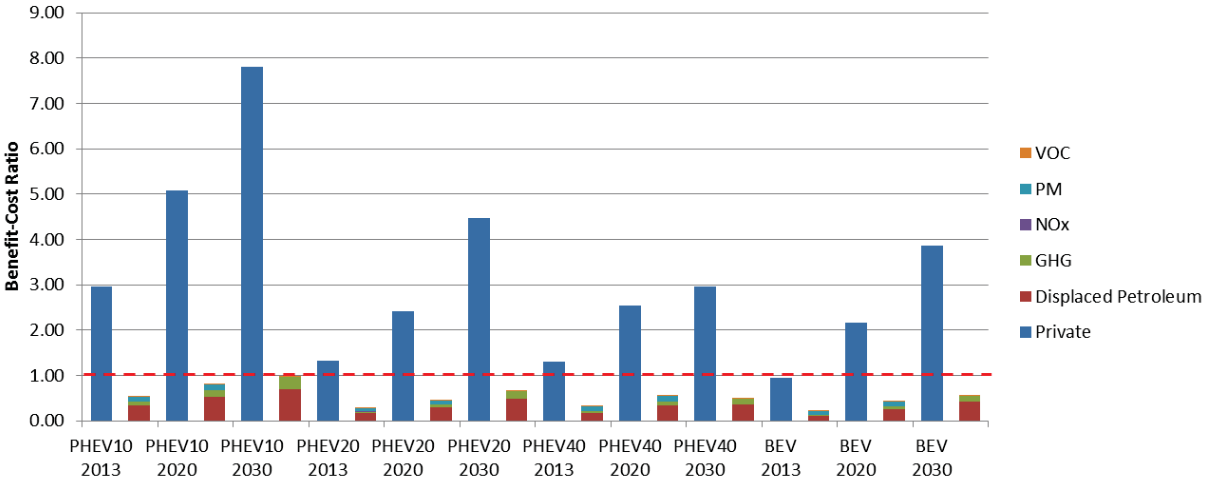

Figure 4. Benefit-Cost Ratio for Light Trucks - TOU Rate

Table 20. Domestic Rate Private and Societal Benefit-Cost Ratios

Light-Trucks	PHEV10			PHEV20			PHEV40			BEV		
	2013	2020	2030	2013	2020	2030	2013	2020	2030	2013	2020	2030
Private Benefit-Cost Ratio												
Operational Savings	2.77	4.56	6.80	1.19	1.99	3.43	1.12	1.95	2.00	0.82	1.68	2.61
Societal Benefit-Cost Ratios												
Petroleum Displacement	0.33	0.53	0.69	0.16	0.29	0.47	0.17	0.33	0.36	0.11	0.25	0.42
GHG Emission	0.08	0.15	0.27	0.04	0.07	0.17	0.04	0.08	0.12	0.02	0.06	0.14
NOx	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM	0.11	0.11	0.01	0.08	0.09	0.00	0.10	0.12	0.00	0.07	0.10	0.00
VOC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Societal	**0.52**	**0.79**	**0.97**	**0.28**	**0.45**	**0.65**	**0.31**	**0.54**	**0.48**	**0.21**	**0.42**	**0.55**

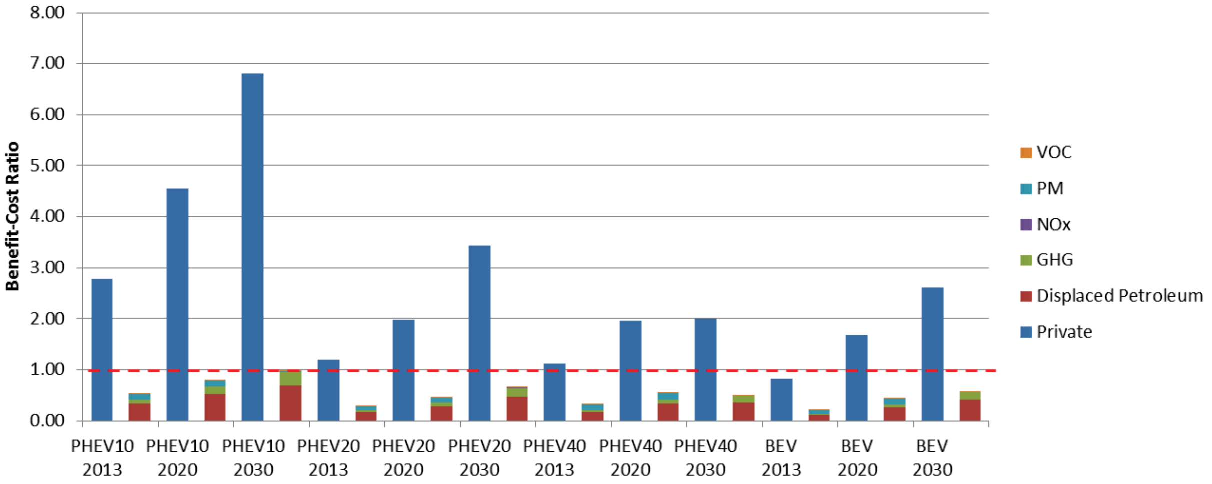

Figure 5. Benefit-Cost Ratio for Light Trucks - Domestic Rate

Figure 4 and Figure 5 show that the private and total benefit-cost ratios for all technologies and classes other than BEVs in 2013 are above one (the dotted red line) and significantly above one for 2020 and 2030. Figure 4 and Figure 5 show that for 2013, differences between the benefit-cost ratio from the TOU and domestic rates are much smaller than in 2030. This is due to rate differences of only $0.065 per kWh in 2010 and $0.14 in 2030. The ratio differences are also accentuated by the dramatic reduction of the incremental cost (denominator of the ratio) between 2013 and 2030. We can also see that due to increasingly more stringent tailpipe emission standards the 2030 NOx, PM and VOC reductions, and hence their resulting societal benefits, are almost zero.

3.1.3 Summary

Table 21 below shows a summary of the TOU benefit-cost ratio for PEV passenger cars and trucks and the "Aggressive Adoption" case in 2030 societal benefits. It is important to understand both the benefit-cost ratio of technology and the technology's potential for total societal benefits. The total benefit cost ratio represents the sum of private plus societal benefits.

Table 21. TOU Benefit-Cost Ratio and Societal Benefits of the "Aggressive Adoption" Case in 2030

PEV	Private B-C Ratio	Societal B-C Ratio	Total	Petroleum Displaced (Mil GGE/yr)	GHG Reductions (Mil MT/yr)	NOx (tons/yr)	ROG (tons/yr)	PM (tons/yr)
PHEV10 - PC	12.53	1.54	14.07	236	2.35	83	220	7.64
PHEV10 - LT	7.80	0.97	8.77					
PHEV20 - PC	7.49	1.13	8.62	316	2.91	146	353	14.5
PHEV20 - LT	4.48	0.65	5.13					
PHEV40 - PC	3.84	0.67	4.52	799	7.00	427	987	43.7
PHEV40 - LT	2.96	0.48	3.44					
BEV - PC	8.89	1.28	10.17	615	5.15	406	860	45.0
BEV - LT	3.86	0.55	4.41					

For each vehicle technology (PHEV10, PHEV20, PHEV40 and BEV), passenger cars have a slightly better benefit-cost ratio from an increase in societal benefits per vehicle while the private benefit-cost ratios are identical. PEVs, as shown in Table 21, and Table 14 and Table 15 in Section 2.3, have the highest potential for petroleum displacement and GHG reductions compared to other electric technologies.

3.2 Forklifts

The analysis for forklifts has been divided into two technologies: 8,000 lb forklifts that displace gasoline and propane lifts and 19,800 lb larger forklifts that displace larger diesel lifts. This is due to differences in incremental capital costs and fuel consumption between the two classes of vehicles. For each forklift the results are for new 2013 forklifts. The detailed analysis, data sources and assumptions can be found in Appendix B.

Table 22 below shows the resulting private and societal benefit-cost ratios. There is a high and low cost for each size lift to demonstrate the ranges of costs found from local dealers. To develop the benefit-cost ratio shown in Figure 6, the annual private benefits and monetized societal benefits are divided by the annualized costs. A private benefit-cost ratio exceeding one (1) means the technology has lifecycle savings. The red line in Figure 6 delineates a benefit-cost ratio of one (1).

Table 22. Forklift Private and Societal Benefit-Cost Ratios

	8,000 lb Low Cost	8,000 lb High Cost	19,800 lb Low Cost	19,800 lb High Cost
Private Benefit Cost Ratio				
Operating Savings	3.49	1.32	2.94	2.21
Societal Benefit Cost Ratios				
Petroleum Displacement	0.56	0.21	0.71	0.53
GHG Emission	0.12	0.04	0.13	0.10
NOx	0.04	0.02	0.04	0.03
PM	0.27	0.10	0.44	0.33
VOC	0.01	0.00	0.00	0.00
Total Societal	**0.99**	**0.37**	**1.32**	**0.99**

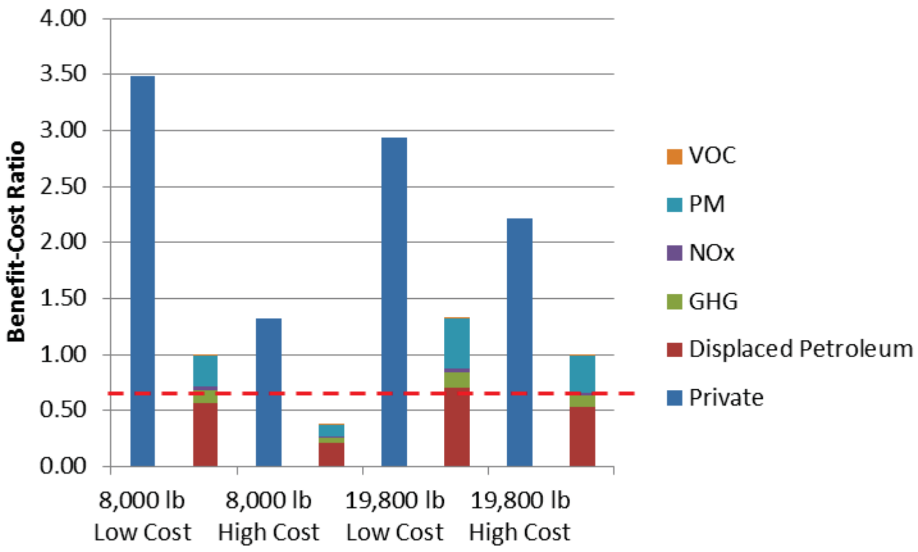

Figure 6. Benefit-Cost Ratio for Forklifts

Figure 6 shows that even the highest costs found when contacting dealers yield positive benefit-cost ratios for both the 8,000lb and 19,800lb forklifts. For the 8,000lb and 19,800 lb forklifts, the largest societal benefits are from petroleum displacement with the next largest monetized benefit from PM reduction.

3.2.1 Summary

Table 23 below shows a summary of the 2030 benefit-cost ratios and "Aggressive Adoption" case societal benefits. It is important to understand both the benefit-cost ratio of the technology and the technology’s potential for total societal benefits.

Table 23. Benefit-Cost Ratio and Societal Benefits of the "Aggressive Adoption" Case in 2030

	Private Ratio	Societal Ratio	Total	Petroleum Displaced (Mil GGE/yr)	GHG Reductions (Mil MT/yr)	NOx (tons/yr)	ROG (tons/yr)	PM (tons/yr)
8,000 lb Lift Low Cost	3.49	0.99	4.48	383	3.41	2,770	58.3	1,610
8,000 lb Lift High Cost	1.32	0.37	1.69					
19,800 lb Low Cost	2.94	1.32	4.26	43.4	0.331	216	6.21	57.8
19,800 lb High Cost	2.21	0.99	3.20					

For both the high and low cost scenarios, 19,800lb forklifts lifts have a slightly better benefit-cost ratio. Forklifts, as shown inTable 23, and Table 14 and Table 15 in Section 2.3, have the second highest potential for petroleum displacement and GHG reductions compared to other electric technologies and are only behind PEVs.

3.3 Truck Stop Electrification (TSE)

The analysis for TSE has been divided into two technologies: plug-in APUs/Shorepower and IdleAir. Plug-in APUs/Shorepower is TSE technology where drivers plug into parking stalls to power their onboard technologies. IdleAir, formerly IdleAire, does not require a truck to plug-in or any truck side capital costs. IdleAire filed for bankruptcy in 2008 and closed in January 2010. Convoy Solutions acquired the former IdleAire assets and launched IdleAir in 2010. The IdleAir system supplies all of the amenities through a unit that attaches to the cab window. For each technology there is a low and high cost from variations in truck side and truck stop infrastructure costs. The results are for new 2013 plug-in APUs and TSE. The detailed analysis, data sources and assumptions can be found in Appendix B.

Table 24 below shows the resulting private and societal benefit-cost ratios. There is a high and low cost for each technology based on variations in plug-in APU and truck stop infrastructure costs. To develop the benefit-cost ratios shown in Figure 7, the annual private benefits and monetized societal benefits are divided by the annualized costs. A private benefit-cost ratio exceeding one (1) means the technology has lifecycle savings. The red line in Figure 7 delineates a benefit-cost ratio of one (1).

Table 24. TSE Private and Societal Benefit-Cost Ratios

All Values are Per Truck Stop	Plug-In APU/ Shorepower – Low Cost	Plug-In APU/ Shorepower High Cost	IdleAir Low Cost	IdleAir High Cost
Private Benefit-Cost Ratio				
Operating Savings	12.72	5.68	3.52	1.76
Societal Benefit-Cost Ratio				
Petroleum Displacement	2.31	1.03	1.40	0.70
GHG Emission	0.53	0.24	0.32	0.16
NOx	1.60	0.71	0.97	0.48
PM	4.31	1.92	2.61	1.30
VOC	0.02	0.01	0.01	0.01
Total	**8.77**	**3.91**	**5.30**	**2.65**

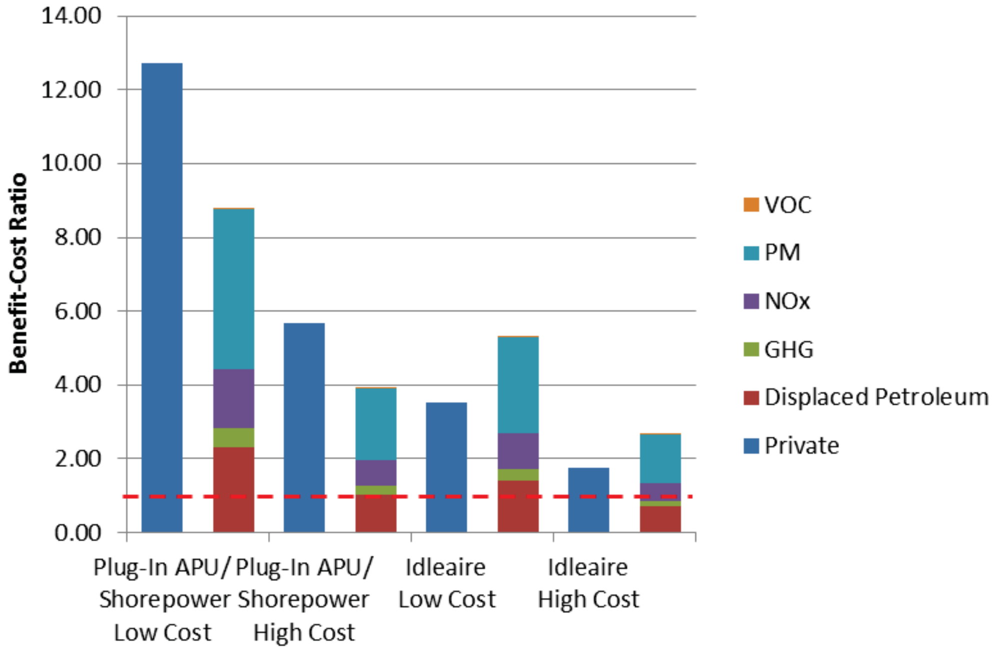

Figure 7. Benefit-Cost Ratio for TSE

Figure 7 shows that even the highest costs yield private benefit-cost ratios of greater than one, with plug-in APU benefit-cost ratios significantly greater than one. The largest monetized societal benefits are from reductions in PM with the next largest from petroleum displacement.

3.3.1 Summary

Table 25 below shows a summary of the 2030 benefit-cost ratio and the "Aggressive Adoption" case in 2030 societal benefits. It is important to understand both the benefit-cost ratio of technology and the technology's potential for total societal benefits.

Table 25. Benefit-Cost Ratio and Societal Benefits of the "Aggressive adoption" Case in 2030

	Private Ratio	Societal Ratio	Total	Petroleum Displaced (Mil GGE/yr)	GHG Reductions (Mil MT/yr)	NOx (tons/yr)	ROG (tons/yr)	PM (tons/yr)
Plug-In APU Low Cost	12.72	8.77	21.49	5.43	0.0513	362	3.16	21.3
Plug-In APU High Cost	5.68	3.91	9.59					
IdleAir Low Cost	3.52	5.30	8.82	1.81	0.0171	121	1.05	7.10
IdleAir High Cost	1.76	2.65	4.41					

For both the high and low cost scenarios, plug-in APU/Shorepower technologies have significantly better benefit-cost ratios. TSE, as shown in Table 25, and Table 14 and Table 15 in Section 2.3, has high benefit-cost ratios and can be implemented in the near-term with positive returns, but the relatively low aggregate societal benefits highlight the limited role TSE can play in contributing to overall emission reduction and petroleum displacement.

3.4 Transport Refrigeration Units

The analysis for TRUs has been divided into four categories: semi in-state, semi out of state, bobtail and bobtail <11 hp. The difference between semi in-state and out of state is whether the TRUs are based within California or out of state. This analysis assumes that while outside out of California, out of state TRUs do not plug-in. The main difference is the number of hours per year the TRU spends within California. The technology for semi, bobtail and bobtail <11 hp categories are the same except for the size of the engines, where semi corresponds to 25-50 hp, bobtail to 25-50 hp, and bobtail <11hp to <11hp engines. For each category there is a low and high cost from variations in TRU and facility side infrastructure costs. The results are for new 2013 TRUs and facility side infrastructure. The detailed analysis, data sources and assumptions can be found in Appendix B.

Table 26 below shows the resulting private and societal benefit-cost ratios. There is a high and low cost for each technology based on variations in TRU and facility side infrastructure costs. To develop the benefit-cost ratio shown in Figure 8, the annual private benefits and monetized societal benefits are divided by the annualized costs. A private benefit-cost ratio exceeding one (1) means the technology has lifecycle savings. The red line in Figure 8 delineates a benefit-cost ratio of one (1).

Table 26. TRU Private and Societal Benefit-Cost Ratios

All Values are Per Facility	Semi In-State Low Cost	Semi In-State High Cost	Semi Out of State Low Cost	Semi Out of State High Cost	Bobtail Low Cost	Bobtail High Cost	Bobtail <11 HP Low Cost	Bobtail <11 HP High Cost
Private Benefit Cost Ratios								
Operating Savings	1.45	1.10	0.25	0.18	5.17	4.50	3.93	3.44
Societal Benefit-Cost Ratios								
Petroleum Displacement	0.47	0.35	0.08	0.06	2.11	1.84	0.98	0.85
GHG Emission	0.10	0.07	0.02	0.01	0.43	0.38	0.21	0.19
NOx	0.37	0.28	0.06	0.05	2.60	2.26	1.00	0.87
PM	0.34	0.26	0.06	0.04	5.02	4.36	1.93	1.68
VOC	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Total	**1.28**	**0.97**	**0.22**	**0.16**	**10.17**	**8.85**	**4.13**	**3.59**

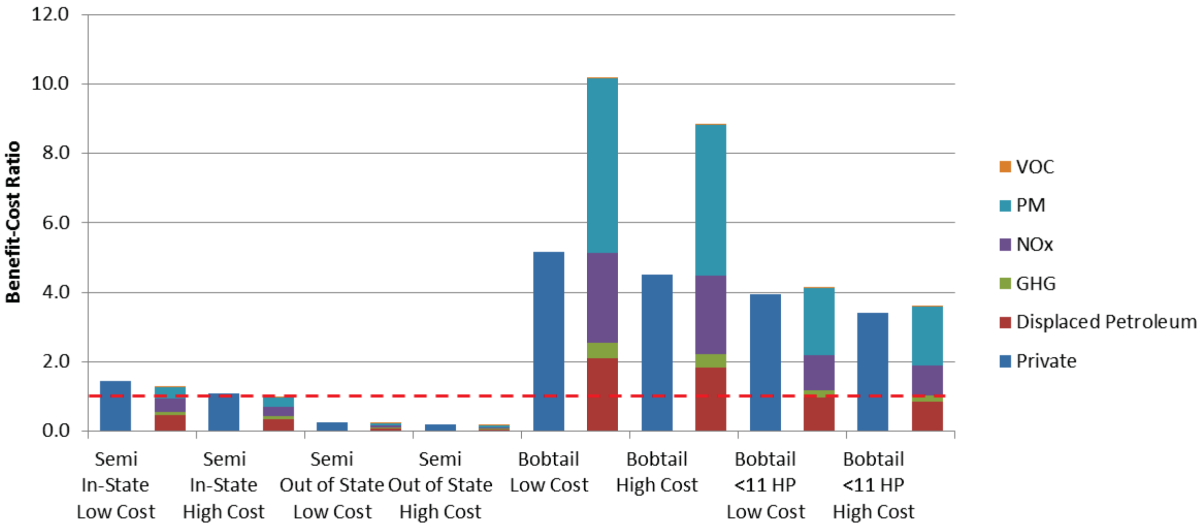

Figure 8. Benefit-Cost Ratio for TRUs

Figure 8 shows that bobtails yield significant private benefit-cost ratios of greater than one but in-state semi TRUs barely achieve private benefit-cost ratios. Semis from out of state do not yield private or total benefit-cost ratios greater than one due to their limited amount of time spent within California. The largest monetized societal benefits are from reductions in PM and NOx with the next largest from petroleum displacement.

3.4.1 Summary

Table 27 below shows a summary of the 2030 benefit-cost ratio and the "Aggressive Adoption" case in 2030 societal benefits. It is important to understand both the benefit-cost ratio of technology and the technology's potential for total societal benefits.

Table 27. Benefit-Cost Ratio and Societal Benefits of the "Aggressive Adoption" Case in 2030

	Private B-C Ratio	Societal B-C Ratio	Total	Petroleum Displaced (Mil GGE/yr)	GHG Reductions (Mil MT/yr)	NOx (tons/yr)	ROG (tons/yr)	PM (tons/yr)
Semi In-State Low Cost	1.45	1.28	2.73	16.7	0.172	1379.6	3.8	43.5
Semi In-State High Cost	1.10	0.97	2.06					
Semi Out of State Low Cost	0.25	0.22	0.46	10.5	0.108	869.3	2.4	27.4
Semi Out of State High Cost	0.18	0.16	0.34					
Bobtail High Cost	5.17	10.17	15.34	4.40	0.0453	564.8	0.4	11.8
Bobtail Low Cost	4.50	8.85	13.34					
Bobtail <11 HP Low Cost	3.93	4.13	8.06	0.0467	0.000474	6.7	0.0	0.1
Bobtail <11 HP High Cost	3.42	3.59	7.01					

For both the high and low cost scenarios, bobtail technologies have significantly better benefit-cost ratios than semis. TRUs, as shown in Table 27, and Table 14 and Table 15 in Section 2.3, have the potential for substantial societal benefits but most would come from semi TRUs that have private benefit-cost ratios just greater than one for in-state or significantly less than one for out of state. The bobtails have high private benefit-cost ratios and can be implemented in the near-term with positive returns, but the relatively low aggregate societal benefits highlight the limited role bobtail TRUs can contribute to overall emission reduction and petroleum displacement.

4 Transportation Electrification Grid Benefits

One of the key concerns about electrification of the transportation sector is the potential impact to the electric grid. If vehicle charging occurs coincident with peak demands, increased loads will drive a need for new investment in generation, transmission and distribution capacity. If charging can be managed to occur primarily in off-peak periods, much of the load will potentially be served with existing infrastructure such that impacts on the electric grid will be significantly reduced and there will be a potential for significant grid benefits.

Evaluating the costs and benefits of transportation electrification on the electric grid has similarities and differences with the evaluation of energy efficiency. The categories of costs and benefits are similar and the definitions of the standard cost tests are the same. The key difference is that energy efficiency provides benefits by reducing load, while transportation electrification provide benefits by increasing load. This notion of increasing load runs counter to long established energy efficiency programs. However, in the case of transportation, increased load provides societal benefits as described in Section 3. Increasing the use of electricity for transportation provides net benefits for both society and utility ratepayers.

The analysis and quantification of the grid benefits of PEVs will be presented in the Phase 2 report, based on the cost-effectiveness test[41] adopted by the CPUC for evaluating distributed energy resources such as energy efficiency, demand response and distributed generation. While the Phase 2 report only looks at the grid benefits from light-duty PEVs, we can assume similar benefits would be seen from medium- and heavy-duty PEVs and off-road electrification.

4.1 Objectives

The grid impact cost-benefit analysis focuses on the cost and benefits of PEVs from the perspective of the utility and its ratepayers addressing three key questions:

1. What are the system costs and impacts associated with increased PEV load?
2. Will increased PEV load cause utility rates to increase or decrease?
3. By how much can dynamic rates and managed charging reduce the costs of serving PEV load?

4.1.1 Grid impacts

The grid benefit analysis provides a much more detailed and robust analysis of distribution grid impacts than has heretofore been published. PG&E, SCE, SDG&E and SMUD all provided detailed data for individual substations and feeders, including:

- Equipment ratings
- Peak day loads and load shapes
- Load growth forecasts

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[41] http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/Cost-effectiveness.htm

- Representative costs of load growth related feeder and substation upgrades
- Geolocation

With this data, we mapped PEV clusters at the Zip+4 level to individual feeders for each of the four utilities. A distribution impact model, developed in Analytica, allows us to model the PEV related load and cost impacts under a variety of vehicle adoption, charging pattern and alternative rate scenarios, which will be presented in the Phase 2 report along with other grid costs.

4.1.2 Ratepayer Benefits

Volumetric rates include both fixed and variable utility costs for delivering electricity to retail customers. The analysis in Phase 2 will show the revenue from PEV charging will exceed the marginal cost of generation to serve the load and the additional costs incurred by the utility to serve PEV load even under the "worst-case" assumptions for grid impacts. We also will show that the GHG reductions from reduced gasoline consumption exceed the emissions associated with increased electricity generation.

4.1.3 Utility Managed Charging

With the shift to off-peak, retail rate revenue is reduced as compared to an unmanaged scenario. The cost of supplying and delivering electricity is also reduced. Across a wide range of scenarios studied, net revenues are still positive with managed charging, but tend to be lower than the unmanaged scenario. Managed charging also reduces the costs to the state as a whole of serving PEV load.

4.1.4 Environmental Benefits

Public Utilities Code section 740.8 characterizes the reduction of health and environmental impacts from alternative-fuel vehicles as in the interest of utility ratepayers (e.g. greenhouse gas and air pollutant reductions). The grid impact analysis in Phase 2 will show the effect of quantifying and including these impacts in utility and ratepayer cost-benefit evaluation.

4.1.5 Vehicle Grid Integration

Managed charging (without vehicle to grid (V2G)) can absorb excess renewable and minimum fossil generation to reduce morning and evening ramps under higher renewable penetration scenarios. An in-depth analysis is beyond the scope of this study, but the analysis in Phase 2 will illustrate how PEVs can support additional renewable generation.

5 Market Gaps, Barriers, and Potential Solutions to Increased PEV Market Penetration

PEV sales have been strong to date, particularly in California: More than 40 percent of all PEVs sold nationally were sold in California through the end of 2013.[42] Despite the near-term successes of PEV deployment, there are still significant markets gaps and barriers that prevent increased adoption and maximization of the associated benefits.

To help address these issues, Governor Brown issued Executive Order B-16-2012 in March 2012 laying the foundation for 1.5 million zero emission vehicles (ZEVs) on California's roadways by 2025. The Executive Order was followed in 2013 by the development of the ZEV Action Plan,[43] prepared by the Governor's Interagency Working Group on Zero-Emission Vehicles. The ZEV Action Plan lays out the following four goals:

- Goal 1: Complete needed infrastructure and planning
- Goal 2: Expand consumer awareness and demand
- Goal 3: Transform fleets
- Goal 4: Grow jobs and investment in the private sector

The goals and associated actions related to planning have been addressed through extensive research, analysis, and outreach in various regions throughout California. For instance, public agencies – primarily air pollution control districts and metropolitan planning organizations (MPOs) – have led planning efforts in California to help achieve PEV readiness. These efforts have focused on a) building codes, b) permitting and inspection, c) zoning, parking rules, and local ordinances, d) incorporating PEV deployment into Sustainable Community Strategies,[44] and e) stakeholder training and education. The underlying principle of these efforts is that consistency in planning at the local and regional level will help simplify and reduce the administrative costs of EVSE deployment.

At the national level, the Transportation Research Board of the National Academy of Sciences released *Overcoming Barriers to Electric-Vehicle Deployment: Interim Report* in 2013. The report focuses on the "infrastructure needs for electric vehicles, the barriers to deploying this infrastructure, and the possible roles of the federal government in overcoming these barriers." The report considers a) customers, manufacturers, and dealers; b) the charging infrastructure; and c) the electric grid.

ICF has drawn from the NAS report as well as confidential interviews with staff at multiple California utilities engaged in this project. We also reviewed an extensive list of other reports and plans related to PEV and charging infrastructure deployment, including but not limited to: EDTA's *Driving Forward: An*

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[42] ICF analysis of national PEV sales data and data from the CVRP.

[43] 2013 ZEV Action Plan: A roadmap toward 1.5 million zero-emission vehicles on California roadways by 2025, available online at: http://opr.ca.gov/docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf

[44] Per SB 375, Steinberg, Statues of 2008.

Action Plan for the Electric Drive Era, Governor Brown's ZEV Action Plan, documents from the Electrification Coalition, the California Plug-in Electric Vehicle Collaborative's *Taking Charge: Establishing California Leadership in the Plug-in Electric Vehicle Marketplace*, the National Petroleum Council's *Advancing Technology for America's Transportation Future*, and the Department of Energy's *EV Everywhere Grand Challenge: Road to Success* report. These documents have served as a useful starting point to identify the critical market gaps and barriers to PEV deployment in California. Some of the issues identified in the interim report are not covered here; however, we have identified what we consider the most salient issues given our understanding of PEV adoption to date, namely:

- Consumer costs
- Charging infrastructure deployment
- The sustainability of third-party owner/operators of PEV charging infrastructure or networks
- Consumer education and outreach
- Limitations on vehicle features

In the following subsections, we identify and characterize gaps and barriers associated with each of these issues. Each subsection concludes with our recommendations as potential solutions to help fill the gaps and overcome the barriers identified. When developing our recommendations and outlining the potential solutions, ICF paid particular (but not exclusive) attention to the role(s) of utilities and public agencies. These recommendations are not meant to minimize the role of other stakeholders (e.g., automobile manufacturers) in developing solutions to increase PEV market penetration.

5.1 Consumer Costs

5.1.1 Identification of the Gaps and Barriers

Upfront Vehicle Costs

Consumers' willingness to pay for new technology, as well as the extent to which they value their convenience will play a large role in PEV deployment. Consumer surveys indicate the manufacturer's suggested retail price (MSRP) of a PEV is of paramount importance, with nearly 70% claiming it is the most important factor in deciding their purchase.[45] Additionally, consumers expect PEVs to be cost-competitive with similar internal combustion engine (ICE) vehicle models, with a majority desiring a sticker price under $30,000.[46] While consumers do acknowledge the higher cost of PEVs and are willing to pay more, the price differential between a PEV and a conventional vehicle or even an HEV remains too high to induce larger volumes of vehicle sales.

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[45] Deloitte Touche Tohmatsu Ltd, "Gaining Traction: A Customer View of Electric Vehicle Mass Adoption in the U.S. Automotive Market," 2010.

[46] Ibid.

Despite a recent survey by Accenture finding that 57% of Americans would consider purchasing a PEV for their next vehicle,[47] consumers' expectations regarding price, range, and charging time are in many cases not met by PEVs available today.[48] These barriers make converting potential consumers into actual purchasers a significant challenge. As discussed previously, vehicle price is the primary barrier to widespread PEV adoption in the near-term. Even with incentives, the initial costs of PEVs generally remain higher than HEVs and ICE vehicles. In a 2011 Los Angeles PEV market survey, for example, more than 80% of respondents said price is an important factor in the decision to purchase a PEV, and 71% believe that "EVs cost too much for what they offer."[49] There have been some decreases in vehicles cost (e.g., Nissan cut the price of the LEAF in 2013 by about $6,400) and over the last year there have been some aggressive leasing offers. PEV adopters' preference and potential doubt over the lifespan of batteries may have contributed to the fact that 50% of PEV placements in California have been financed through leasing.[50] However, there are concerns about the long-term viability of the PEV market if it is dependent on leasing, largely because this may decrease the upfront costs of vehicles, but it does not help the long-term total cost of ownership. For instance, a market reliant on low-priced leasing will require a robust secondary market for PEVs, which will accelerate with 2010 and 2011 PEV leases expiring soon.

Upfront EVSE Costs

Further research is needed to determine which level of charging consumers will ultimately prefer. In single family residences, duplexes, and townhomes, Level 1 charging is readily available and inexpensive and appears to be practical for many PEV users, other than BEV users with daily vehicle miles travelled (VMT) exceeding 40 miles. A Level 2 EVSE could potentially charge a vehicle in a fraction of the time of a Level 1 EVSE, but requires a dedicated space to install the EVSE (in multi-family dwellings) and is considerably more expensive.[51]

Consumer willingness to purchase EVSE depends in large part on the price of the infrastructure in light of the consumer's perceived driving requirements. As charger speed and "intelligence" increase, the expense of the equipment and installation rises commensurately. Currently, a residential Level 2 EVSE is estimated to cost approximately $2,000, including installation; however, survey results show that only 28% of respondents would pay more than $500 for the capability, with the average respondent willing to pay up to $400.[52] Consumer unwillingness to add this additional expense to the purchase of the

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[47] Accenture, "Plug-in electric vehicles: Changing perceptions, hedging bets," 2011.

[48] Deloitte, "Gaining Traction: Will Consumers ride the electric vehicle wave?" *Deloitte Global Services Ltd*., 2011.

[49] Dr. Jeffrey Dubin, et.al, "Realizing the Potential of the LA EV Market," *University of California Los Angeles Luskin Center for Innovation*, May 2011.

[50] Clean Vehicle Rebate Project User Survey, http://energycenter.org/clean-vehicle-rebate-project/survey-dashboard. As a comparison, Experian reports in its State of the Automotive Finance Market report that only 25% of all new vehicle sales were financed through leasing in Q1 2014 (up from 15% in Q1 2009)

[51] This can also contribute to the previous barrier discussed regarding upfront vehicle costs if the purchase of the EVSE is included at ht point of the PEV sales transaction process.

[52] Charul Vyas et al., "Executive Summary: Electric Vehicle Consumer Survey," *Pike Research*, 2012.

vehicle presents a significant barrier to the larger scale deployment of Level 2 EVSE in residences. For instance, Tony Posawatz, formerly the Vehicle Line Director for the Volt and Global Electric Vehicle Development at General Motors (GM) indicated in a presentation that GM has been surprised that "most" Volt drivers have opted for Level 1 charging over Level 2 charging at home. He noted that it takes longer to charge, but that consumers believe the chargers work "well enough" and "suffice for overnight charging".[53] Furthermore, Nissan has reported that 10% to 20% of LEAF buyers are opting for the lower cost Level 1 charging cord set that come with the purchase of the vehicle.

Vehicle Operating Costs

PEV operating costs tend to be significantly lower than those of conventional vehicles. Although this is driven by both the lower cost of electricity compared to gasoline as well as by the lower maintenance costs associated with PEVs, the fuel price differential is the most significant driver for PEV ownership savings. As such, it is critical that utilities provide competitive charging rates for PEVs. The traditional billing paradigm for electricity consumption, however, is not optimized for PEV charging. For instance, domestic rates are generally tiered and penalize higher electricity usage, thereby creating a price barrier for fuel switching (from gasoline to electricity). Furthermore, some whole house on-peak time-of-use (TOU) rates are even higher than the highest domestic tier.[54] In these cases, if a consumer has a non-shiftable load (e.g., air conditioning) that would penalize a switch to a TOU rate, then the consumer is more likely to stay on the standard tiered domestic rate. Finally, a consumer may be interested in moving to a TOU rate for the vehicle to obtain lower energy costs for off-peak charging. However, if it is a separately-metered PEV TOU rate (i.e., a rate specific to the PEV charging load that does not require shifting the rest of the household load), many consumers may pass on this option because of the additional installation cost for separate metering.

5.1.2 Potential Solutions

Ensure availability of incentives

Although PEV adoption to date has been successful in California – with sales nearly double the rate of hybrid electric vehicles when they were first deployed[55] – the availability of new vehicle purchase subsidies remains the most critical incentive available to consumers. Stakeholders in the transportation electrification market need to continue making the case to policy makers that grant money from state programs such as AB 118 should continue to be directed towards vehicle purchases to complement the federal tax credit incentive. Similarly, PEV access to high occupancy vehicle (HOV) lanes should be

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[53] Ernst & Young, Cleantech matters: moment of truth for transportation electrification, 2011 Global Ignition Sessions Report, 2011.

[54] This is not true for all utilities. For both SMUD and SDG&E for instance, this has not been the case to date. SMUD's whole house TOU rate is designed to be revenue neutral and will likely result in a lower bill for residential customers currently in the highest domestic tier rate.

[55] California Center for Sustainable Energy, California Plug-in Electric Driver Survey Results, February 2014. Available online at: https://energycenter.org/clean-vehicle-rebate-project/vehicle-owner-survey/feb-2014-survey.

continued. Apart from the obvious importance of reducing the upfront cost of the vehicle, state-level leadership is required given the scale of the challenge associated with mass light-duty PEV deployment. Regional and local governments simply do not have the spending capabilities of impacting the market significantly.

Apart from vehicle incentives, it is important for utilities and other stakeholders in the PEV ecosystem to identify the incentives that are most successful in impacting vehicle adoption. For instance, a recent survey of PEV buyers by the California Center for Sustainable energy (CCSE) indicated that Plug-in Prius drivers were largely motivated by the availability of the Green Sticker that provides single occupancy access to HOV lanes.[56]

Moving forward, here are two recent developments that should be tracked that may help to diminish the high first cost barrier. First, OEMs and dealerships are implementing creative ways to increase the sales or leases of PEVs, such as low lease rates, low down payments, low interest rate vehicle financing, dealership discounts, free public charging for a limited time, and marketing messages that emphasize the lower fuel costs and incentives. Second, beginning in 2014, many of the PEVs leased in 2010 and 2011 will be rolling off their leases, promising a potentially lower cost used PEV market.

Creative use of LCFS credits

California's Low Carbon Fuel Standard (LCFS) provides utilities with an opportunity to earn credits for selling electricity as a transportation fuel. Per the LCFS regulation, however, utilities must use LCFS credit proceeds to benefit current PEV drivers; furthermore, IOUs have to seek CPUC approval for their plans regarding the use of LCFS credit proceeds. A variety of proposals have been put forth to the CPUC – including vehicle buy-down programs and rate reductions (see Table 28 below). As the market for PEVs evolves and the LCFS credit market matures, utilities should be encouraged to continue to explore opportunities to find innovative mechanisms to spur adoption using LCFS credits that are in line with CARB's LCFS Program requirements. The LCFS program is an excellent opportunity for utilities to explore creative ways to engage consumers.

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[56] California Center for Sustainable Energy, California Plug-in Electric Driver Survey Results, February 2014. Available online at: https://energycenter.org/clean-vehicle-rebate-project/vehicle-owner-survey/feb-2014-survey

Table 28. Descriptions of Utility Programs for Use of LCFS Credits

Utility	Description of Proposal to CPUC
Pacific Gas & Electric	• On-bill credit to PHEV and BEV drivers; credits based on vehicle battery size. • Provide information about availability of credit to customers
San Diego Gas & Electric	• Return credits to drivers under the manner in which they were generated • Provide information about availability of credit on website featuring the credit as an additional benefit for PEV drivers
Southern California Edison	• Propose a Clean Fuel Reward offered to PEV adopters through dealers at the time of vehicle purchase • Provisions for new and used-vehicles (purchase or lease)
Sacramento Municipal Utility District	• Propose a Clean Fuel Reward at the time of vehicle purchase • Support public charging infrastructure investment
Los Angeles Department of Water and Power	• Provide rebates for PEV charging infrastructure

Battery second life

ICF maintains that the development of a robust market for batteries after their useful automotive life will be one of the early indicators of success in the PEV market. As the market for batteries in non-automotive applications develops, there may be a way to monetize the value of the secondary life of batteries and pass those benefits on to consumers at the point of purchase. For instance, in April 2013, the CPUC approved PG&E's request to implement a Plug-In Electric Vehicle Pilot [57] to evaluate whether there is a sufficient business case for light-duty automobile manufacturers to provide grid services from second life batteries and PEVs in service to the utility.

Improve PEV charging rates

Utility rate structures are one of several key decision factors for potential PEV consumers, and can represent the difference between a consumer accruing a return on their investment or realizing a net loss. As noted above, the most significant savings for PEV drivers are from a reduction in fuel expenditures. Utilities should continue to evaluate their rate structures in the context of the potential impact on PEV consumers. These include an analysis of secondary meter options, alternatives to the traditional tiered rate structure, and options for existing or future of TOU rates. For example, SDG&E's VGI Pilot Program application with the CPUC (filed April 11, 2014, A.14-04-014) features a dynamic rate for workplace and MDU settings that reflects grid conditions and the changing cost of energy throughout the day.

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[57] State of California Public Utilities Commission, Advice Letter 4077-E-B, April 2, 2013, http://www.pge.com/nots/rates/tariffs/tm2/pdf/ELEC_4077-E-B.pdf

5.2 PEV Charging Infrastructure Deployment

5.2.1 Identification of the Gaps and Barriers

Charging at single family homes

For the most part, PEV readiness plans have identified the gaps and barriers to residential charging, especially at single family residences, including issues such as expedited permitting. The market gaps and barriers for charging at single family residences are small and likely near-term issues that can be addressed as part of the expected market evolution. For instance, over the last two years, the number of consumers opting for Level 1 charging is indicative of consumer reaction to EVSE pricing and installation: Chevrolet reports that as many as 70% of Volt drivers opt for Level 1 charging and Nissan reports that 10% to 20% of LEAF drivers opt for Level 1 charging. These data are largely consistent with survey data from the Clean Vehicle Rebate Project reported by the California Center for Sustainable Energy.[58] Considering that the EV Project and ChargePoint America–projects funded by the American Recovery and Reinvestment Act (ARRA)–both focused on deploying Level 2 EVSE, including at residences, it is clear that consumers have reacted differently than anticipated. Deciding between Level 1 and Level 2 charging at home may continue to be an issue if potential PEV buyers do not have the tools to assess their charging needs carefully and accurately in the context of their personal travel behavior.

Charging infrastructure at multi-dwelling units

Multi-dwelling units (MDUs) or multi-family units are a commonly identified gap in the PEV market today because little progress has been made in deploying charging facilities at these locations. The degree to which this barrier will have an impact on PEV adoption is more obvious in areas with high population density and high levels of MDUs (e.g., Los Angeles, San Diego, and San Francisco), where there is a strong argument to be made that lack of charging infrastructure will negatively impact long-term PEV adoption. For the most part, until solutions are created to address this gap, consumers living in MDUs are severely constrained in their ability to participate in the PEV market, excluding a major portion of the vehicle buying or leasing market. For example, charging installations (at Level 1 or Level 2) at multi-family units generally have high deployment costs, including trenching, new poles or transformers, and often involve more stakeholders (e.g., Homeowners' Associations (HOAs), property management) than at single family residences.[59] Metering the PEV load and billing users may require potentially complex arrangements if connecting to the premises meter or to the tenant meter is not feasible. Because many MDUs are under commercial rates, it is also possible that vehicle charging may result in bill increases due to commercial rate demand charges, which would apply to the entire facility under that commercial account. These issues continue to make deployment of charging installation at

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[58] California Plug-in Electric Vehicle Owner Survey, February 2014. Available online at: https://energycenter.org/clean-vehicle-rebate-project/vehicle-owner-survey/feb-2014-survey.

[59] For a more detailed overview of the complexities of the MDU issues, please review the California PEV Collaborative document entitled Plug-in Electric Vehicle Charging Infrastructure Guidelines for Multi-unit Dwellings, available online at: http://www.pevcollaborative.org/sites/all/themes/pev/files/docs/MUD_Guidelines4web.pdf.

multi-family units challenging. Finally, HOAs or property managers may have ultimate say over charging infrastructure installations at MDUs; unfortunately, they may not be willing to bear the costs of installation. Even if an HOA or property manager is willing to bear the cost of charging infrastructure installation, they may not understand the operational aspects, such as payment for use or regulating the use of charge points and associated parking spots.

This situation may be exacerbated by the perception that Level 2 networked EVSEs with payment capabilities are essential for all PEV drivers. While residential deployment of Level 2 EVSEs is required to serve those BEVs with a daily VMT that exceeds 40 miles, many PEV users can reliably charge their vehicle at Level 1. A 110 V outlet or a basic EVSE (Level 1 or Level 2) may save several thousand dollars per charge point (payment for the charging transactions may be handled offline through various billing arrangements). Incidentally, Level 1 charging or some types of multi-port Level 2 charging[60] will have less impact on the grid and may avoid demand charges. The number of decisions for the site owner and PEV owner to make can be overwhelming, and no party or website in this space plays the role of helping them understand the many complex options or advocating for the low cost solutions (e.g., avoiding perimeters, trenching, networked charging, demand charges, and utility line drops).

Senate Bill 880 (SB 880, Corbett, Statues of 2012)[61] voids any policies or provisions that prohibit or restrict the installation or use of EVSE in a common interest development with owner-designated parking spaces. However, if property managers and HOAs do not have adequate information and education to help them navigate the different decisions that need to be made, the issues listed above may act as barriers and reduce the likelihood, or at least slow down the process, of deploying charging infrastructure at these properties.

Workplace charging

Most analysts agree that after residential charging, the next most likely place for PEV drivers to charge their vehicle will be at workplaces, largely because of the long dwell times. Unfortunately, the majority of away-from-home charging installations deployed today have not been at workplaces, and instead have been at public parking locations that typically have shorter parking durations. It appears that the costs of the EVSE and installation costs continue to be the most significant challenges to EVSE deployment at workplaces.[62] By definition, workplace charging does not offer the everyday reliability of charging at home (and as such may have only limited impact on PEV adoption), but workplace charging

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[60] For example Level 2 charging with multiple ports can be either sequenced or throttled so that the total load per station does not exceed 6.6 kW (or less).

[61] Senate Bill 880 (Corbett), Common interest developments: electric vehicle charging stations. Available online at: http://leginfo.ca.gov/pub/11-12/bill/sen/sb_0851-0900/sb_880_bill_20120229_chaptered.pdf. Note that SB 880 was signed into law as an urgency statute to clean up Senate Bill 209 (Corbett); more specifically, SB 880 was intended to 1) correct constitutional flaws posed by SB 209, 2) resolve a conflict with Civil Code Section 1363.07 and 3) correct ambiguities within the language of SB 209.

[62] California Plug-in Electric Vehicle Collaborative, Amping up California Workplaces: 20 Case Studies on Plug-in Electric Vehicle Charging at Work, 2013. Available online at: http://www.evcollaborative.org/sites/all/themes/pev/files/WPC_Report4web.pdf

provides an opportunity to extend significantly the eVMT of many PEVs. PHEVs, such as the Toyota Prius Plug-in or the Ford C-Max Energi, carry a battery that may not have the capacity to cover the driver's daily VMT. Those drivers may have to rely on gasoline to complete their daily driving unless workplace charging is available.

Other away-from-home charging

Other away-from-home charging is distinguished from residential and workplace charging by generally shorter parking durations, and covers a wide range of situations where a PEV driver could potentially charge when away from home and/or work. Within this category, there are different sub-categories specific to the venue type –such as retail parking lots, on-street parking, airport long- and short-term parking, cultural and recreational centers, etc. We distinguish these locations based on dwell times in Table 29 below, and provide broad categorization as well as the likely charging method at these locations.

Table 29. Example of Charging Type based on Purpose

Dwell Time	Typical Venues	Charging Rate	Purposes	Use
Short < 1.5h	Supermarket, big box retailers,	At the retailer's discretion	Opportunistic top-off charging Increase foot traffic Unlikely to serve an actual need because of likely proximity with home	Weekly
	Highways / Freeways	DCFC	For BEVs only Extend eVMT on longer (non-commute) trips	Occasional
Medium 1.5–6 h	Shopping Centers, Cultural/ Sports Centers	Combination of L1 for PHEVs and L2 for BEVs	Extend eVMT	
Long >6 h	Airport Parking (long-term)	L1		
	Hotels /Convention Centers/Theme Parks	Combination of L1 for PHEVs and L2 for BEVs		

As increasing numbers of away-from-home EVSE are deployed in California by an array of providers, it will be important for charging providers to ensure that there are multiple ways for consumers to access their EVSE networks without holding multiple memberships or paying unnecessary premiums. While California passed SB 454 in 2013 to require networks to offer one-off charging transactions to non-members, pricing of these transactions is not regulated and could potentially be used to circumvent the new law. However, it is important to note that any entity can install EVSE, and not all installations require a service provider.

5.2.2 Potential Solutions

In addition to the recommendation to revisit the CPUC ruling prohibiting utility investment in charging station infrastructure (discussed in more detail in Section 5.3 below), ICF highlights the recommendations related to charging infrastructure noted in the following sections.In general, utilities can help develop awareness about the multiple charging options available to residential and commercial customers. Unlike other industry players that may not find it in their best business interest, utilities could conduct programs to demonstrate low cost/low complexity charging solutions that also benefit the grid and ratepayers. These may help remove perceived barriers to deployment of charging infrastructure and show a pathway for adopters to follow.

Engage MDUs/HOAs, employers, and workplace parking providers

There is considerable overlap between the barriers to deploying charging infrastructure at multi-family units and at workplaces. It is important that utilities, as trusted energy advisors, engage these stakeholders in meaningful discussions to help identify optimal solutions for consumers/drivers, HOAs, employers, and other parties interested in providing MDU or workplace charging.

It is also important to note that workplace charging is more complicated than simply the employer-employee-utility interface. There are opportunities to provide charging infrastructure near commuter exchanges, which involve local and regional transit agencies, or to provide charging infrastructure at parking structures in which the employer is not necessarily the owner.

Utilities have a critical role to play in this space and can help ease the burden that has been borne by early market entrants, who have spent a significant amount of time educating potential site hosts:

- City CarShare for instance, has been at the forefront of EVSE deployment in the Bay Area to support the PEVs in its fleet. Their role is relevant because their fleet of PEVs require non-residential charging as a base. City CarShare has sought to install EVSE at a variety of locations and have been engaged with an array of parking providers to help expand the deployment of PEVs in its carsharing fleet. City CarShare reports it may take up to four months to educate these stakeholders about the issues associated with EVSE. Because this can be a significant barrier to deployment, utilities can play an important role through engagement and education.
- Daimler's car2go launched the first all-electric car share program in the US in San Diego in 2011-2012. As it launched its all-electric fleet, it was dependent on city of San Diego parking ordinances being changed. SDG&E played a critical role in supporting car2go by working with the City of San Diego and the EV Project to help deploy charging infrastructure to support the electric fleet.

Engagement with employers and workplace parking providers today is also important because in the near- to mid-term future, widespread workplace grid-integrated charging could serve as an opportunity to provide lower cost charging by taking advantage of those times during the year when there is surplus energy production, particularly from renewable energy resources, that occur during the typical work day. This could increase overall system efficiency and avoid the installation of additional storage capabilities.

5.3 Third-Party Ownership of Charging Infrastructure

5.3.1 Identification of the Gaps and Barriers

The previous section focused on the general deployment of charging infrastructure at residences, workplaces, and publicly accessible locations. This section addresses the role of third-party EVSE owners and network operators in California's PEV charging industry. By way of background, the CPUC ruled that IOUs cannot own EVSE at customers' facilities because it found that utility ownership of EVSE is unlikely to provide safety advantages or reduce customer service costs. Furthermore, the CPUC made the assumption that the IOUs may negatively impact what is referred to as the electric vehicle service provider (EVSP) market; however, this ruling was not evidentiary based and did not include an examination of the viability of the EVSP business models (Phase 2 of Rulemaking 09-08-009).

This section explores the challenges that third-party owners and operators of EVSE face in the PEV charging market, namely:

- The underlying revenue model for EVSE is based on the resale of electricity, a commodity that is inexpensive compared to the high cost of infrastructure for PEV charging.
- The demand for non-home charging is unclear due to a variety of variables, including BEV vs. PHEV deployment, battery technology, availability of free charging, consumer willingness to pay, and driver behavior (e.g., non-residential dwell time and daily VMT).

Table 30 below includes an overview of the services that PEV charging industry participants provide:

Table 30. Services Provided by PEV Charging Industry Participants

Market Participant	Brief Description
Hardware Manufacturer / Equipment Retailer	Manufactures the EVSE that is installed; may be branded or unbranded. Manufacturers may also sell their equipment directly to market or to network managers/operators (i.e., retailer).
Installers / Maintenance providers	Installs EVSE; in some cases installers also provide routine maintenance for the equipment.
Charging station owner / host	Entity that owns or hosts the equipment, such as a retail outlet. May also resell electricity to PEV driver.
Charging Station Network Operator	Has the ability to connect, control, and monitor charging stations on its network; generally provides metering capability. Collects payment from users (potentially on behalf of charging station owners); may also resell electricity to PEV driver.
System operator	The California Independent System Operator (ISO) provides open and non-discriminatory access to the state's wholesale transmission grid. There are several Publicly Owned Utility-based organizations that provide system operations as well.
Utility provider	Electrical utilities in California–including investor- and publicly-owned utilities.

For the purposes of this report, a third-party owner/operator is broadly defined as an entity that owns and/or operates PEV charging equipment (i.e., Level 1, Level 2, or DC fast charging EVSE) or sells/leases the charging equipment and sells the network transaction services. In either case, the third-party owner/operator is neither a utility nor the vehicle owner. In the context of the table above, this includes charging station owners and charging station network operators. In some cases (e.g., eVgo Network), the owner and operator of the charging station is the same organization. In other cases, the charging station network operator acts as an agent of the charging station owner. The latter bears the investment risk by paying for the installation. It owns the equipment and sets pricing. Meanwhile, the charging station network operator collects revenues from users, withholds a fee and remits the balance to the charging station owner.

It is also important to mention that an EVSE is not a gasoline pump. Not only does an EVSE deliver much cheaper transactions, it does so at a much slower pace than a gasoline pump. This has major implications for the business model for away-from-home charging and is a paradigm shift for vehicle users compared to gasoline vehicles. While drivers may be willing to wait for a few minutes to fill up their tanks, the longer time associated with charging will likely mean that drivers seek to complete other activities while their PEV is charging (e.g., work, shop, sleep, etc.). In addition, unless a PEV driver actually needs to charge away from home, the cost of charging and the required charging time will play a major role in the decision to use out-of-home charging. As a result, out-of-home charging is likely to be mostly opportunistic, and will likely occur if the cost is less than the cost of charging at home and/or less than the cost of gasoline (and if the PEV driver can spare the time). This significantly limits the price elasticity of demand as out-of-home charging competes with home charging (unlike gasoline stations which do not have any competing models).

Sustainability of revenue model

The high costs of the infrastructure to provide publicly accessible EVSE make it difficult to earn a profit because the commodity (i.e., electricity) being sold is comparatively inexpensive. Publicly accessible installations of Level 2 EVSE can cost in excess of $10,000 in some cases; whereas DC fast charge EVSE installations can cost in excess of $150,000. As a result of these high costs, many industry observers and market analysts believe that investing in publicly accessible charging infrastructure may be predicated on an unsustainable revenue model if the charging transactions are the sole source of revenue and the only business driver to deploy charging stations. The National Academy of Sciences (NAS) report,[63] for instance, states that the high cost of installing public charging stations and the minimal revenue obtained from providing electricity present challenges for developing business models.

ICF conducted a breakeven analysis of non-home EVSE ownership for Level 2 (AC) and DC fast charging. We assumed an installed cost of approximately $10,000 for a Level 2 EVSE and $100,000 for a DC fast charge EVSE.[64] Our analysis also included electricity costs, including the energy charge, customer charge

[63] National Academy of Sciences, *Overcoming Barriers to Electric-Vehicle Deployment: Interim Report,* 2013.

[64] EVSE deployment costs can vary significantly, especially for public installations. The costs presented here are representative of ICF's recent research as it relates to Level 2 and DC fast charging equipment. It is worth noting,

(assuming several EVSE per meter), demand charges, and peak demand pricing. For the purposes of our analysis, the EVSE was assumed to be installed at either a small facility with demand less than or equal to 200 kW (e.g., a parking facility or small office building) or a medium facility with demand greater than or equal to 200 kW (e.g., a large office building, grocery store, or hotel). The breakeven analysis considered operations, maintenance, and networking costs for both types of equipment. Our analysis also assumed that the third-party EVSE provider opted into California's Low Carbon Fuel Standard (LCFS) program as a regulated party selling electricity as a transportation fuel in order to generate potentially valuable credits. A discount rate of 7% was employed.

The results were calculated as breakeven pricing – defined as the price per charging event that an EVSE provider would need to charge in order to break even on the initial investment by a given year of operation. Note that these estimates assume no profits generated for the EVSE provider prior to the breakeven year. The profit in any year will depend on operating costs and revenue generated from charging events; however, the initial capital investment for EVSE–including hardware and installation–would be recouped by the breakeven year. There are other analyses that seek to determine the cost per unit of electricity that an EVSE provider would have to charge in order to turn a profit of a particular percentage in a given year. It is important to reiterate that this analysis makes no assumptions about profitability. Our analysis indicates that:

- Even at an assumed charging level of up to 6.6 kW, the breakeven pricing for Level 2 EVSE is similar to standard residential rates, and much higher than TOU residential rates that utilities generally offer to customers who own a PEV (which are as low as $0.06/kWh for overnight charging). For instance, the breakeven pricing indicates that for an EVSE provider to have its investment paid off in five years—without any profit—it would need to charge $0.26 to $0.43 per kWh, depending on the rate schedule. Although the cost on a per gallon of gasoline equivalent is competitive with gasoline at a cost of $2.35 to $3.86 per gallon, it is much higher than the residential rates that drivers may be charged.
- The breakeven pricing for DC fast charging EVSE is highly sensitive to energy demand charges. If one assumes that an EVSE provider, for instance, is responsible for 50 days of demand charges – with a maximum demand from DC fast charging EVSE estimated at 45 kW – then the breakeven pricing can change dramatically. It can increase the breakeven pricing for a 5-year payback by nearly a factor of three.
- In almost every scenario modeled by ICF, the breakeven pricing in a reasonable timeframe (defined here as less than five years) is considerably higher than what consumers are likely to pay for residential charging. The breakeven pricing in the out years (e.g., 8 to 10 years), indicates that there are scenarios that can offer a rate competitive with residential charging. However, it

however, that there are Level 2 installations that can cost significantly more or less than $10,000 depending on local conditions. Similarly, there are DC fast charging installations that can cost significantly more or less than $100,000 depending on local conditions. Regardless of these variations, the costs employed in the revenue model fairly represent EVSE deployment costs for the purposes of our assessment.

is difficult to make the case that a private stakeholder will make investments with a ten-year payback in mind.

The sustainability of investing in and owning publicly accessible charging stations will come under increasing scrutiny if public agencies seek to scale back the role of government-funded projects. For instance, we have witnessed several high profile failures in the charging infrastructure market to date. Most notably, ECOtality's bankruptcy and 350 Green's financial and legal troubles; both organizations received significant levels of public funding. Better Place, although they did not spend any public funds during their deployment projects, is another high profile failure in the charging infrastructure market. Apart from these individual failures, there are other signs in the market place that should give public agencies pause about committing additional funding, including companies withdrawing from the market and significant consolidation. For instance, Siemens announced in 2013 that it was withdrawing from the public charging infrastructure business.

Despite these challenges in the market for charging infrastructure, many industry players continue to advocate for increased public spending on publicly accessible EVSE as a way to solve the sustainability conundrum. Some stakeholders speak of a gap of up to $1 billion in funding for publicly available EVSE by 2020. These discussions of funding gaps are complemented by commentary such as the following from the Director of Electric Vehicles at Schneider Electric: "We still have to put in pervasive EV charging infrastructure within cities that allows people to identify that the infrastructure exists out there." Meanwhile, others such as BMW Board Member Herbert Diess have commented that "this public infrastructure is not really very important because most people are charging their cars at home".[65] Given the extent to which PEV drivers have adapted their charging behavior to their driving behavior–as evidenced by the larger-than-expected proportion of PHEV and BEV drivers using Level 1 charging, for instance–it is increasingly difficult to make the case that high levels of public investment in publicly available EVSE infrastructure are warranted.

The demand for non-home charging is unclear

Despite there being consensus that PEVs will continue to increase their share of the light-duty vehicle market, it is unclear what the demand will be for non-home charging. This market is impacted by variables such as the vehicle type or architecture that consumers purchase, consumer willingness to pay for charging, and driver behavior. These factors are particularly important because the PEV charging industry needs to demonstrate how it is taking steps to provide the pricing and technology to influence charging decisions that demonstrate advancement toward the vehicle-grid integration (VGI) that the CPUC recently outlined in a white paper.[66]

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[65] Ward's Auto, January 20, 2014 " BMW Exec Sees Little Need for Public Charging" (http://goo.gl/EMtQQM)

[66] CPUC, Energy Division Staff White Paper, Vehicle-Grid Integration: A Vision for Zero-Emission Transportation Interconnected throughout California's Electricity System, November 2013. Available online at: http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M080/K775/80775679.pdf.

Vehicle purchasing behavior

It is unclear what type of vehicles–BEVs or PHEVs–consumers in the various regions of California will be more likely to purchase in the future. The distribution of vehicle types will have a significant impact on business strategies in the EVSE market as most BEVs do not need any out-of-home charging on a daily basis (because their battery range typically covers more than the daily VMT) and current PHEVs do not have DC fast charging connectors.

Our analysis makes credible assumptions about the split between PHEVs and BEVs; however, this estimate carries considerable uncertainty. For instance, OEMs are generally making more significant investments in PHEVs, as indicated in a recent survey of automotive executives.[67] There has been a drop in executives' interest (from 2013) in battery technologies with increased interest in internal combustion engine (ICE) downsizing and optimization. Furthermore, 24% of survey respondents identified plug-in hybridization and battery vehicles with range extenders as their main investment over the next five years compared to just 9% of respondents identifying pure battery electric vehicles. Finally, 35% of survey respondents reported that PHEVs are the most likely to attract consumer demand by 2019. Meanwhile, just 17% and 14%, respectively, responded that battery vehicles with range extenders and pure BEVs will attract consumer demand, by 2019.

Conversely, the improvement in battery technology has the potential to change consumer preferences: Although most BEV models available today have a range of about 100 miles or less–including the Nissan LEAF, Chevrolet Spark, Ford Focus Electric, and Mitsubishi iMiEV– the potential for battery technology improvements leading to longer vehicle ranges, or simply the decision by OEMs to offer larger batteries, may translate into improved attractiveness and an increased market share for BEVs. The increased availability of non-home charging may also influence the demand for BEVs, as well as increase eVMT for PHEVs.

Consumer willingness to pay for charging

Industry estimates indicate that about 20% of non-home charging stations collect a fee for charging.[68] As a result, there is little data available to understand consumer willingness to pay for away-from-home charging. A recent Navigant survey, for instance, found that 40% of respondents had a high degree of interest in public charging. When those respondents were asked how much they would be willing to pay for a 15-minute charge that provides 6 to 7 miles of range, more than 20% of them indicated that they would only use this service if it was free. The rest of the results – including ICF's analysis of the equivalent electricity pricing – are shown in Table 31 below.

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[67] KMPG, *Global Automotive Executive Survey 2014*, Available online at: http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/global-automotive-executive-survey/Documents/2014-report.pdf

[68] Number attributed to Pasquale Romano, CEO of ChargePoint in a CNBC article entitled Payback is a switch: Business Case for EV Charging. Accessed online in April 2014 at http://www.cnbc.com/id/101388967.

Table 31. Consumer Willingness to Pay Survey Results and Equivalent Pricing

Willing to Pay for 15-Minute Charge; Range of 6-7 miles	Percentage of Respondents	Equivalent Electricity Pricing
free	23%	--
< $1	29%	<$0.43/kWh
$1 to $2	29%	$0.43-$0.87/kWh
$2 to $3	11%	$0.87-$1.30/kWh
$3 to $5	5%	$1.30-$2.17/kWh
>$5	3%	>$2.17/kWh

For the equivalent electricity pricing, ICF assumed total energy delivered of 2.3 kWh based on a 0.35 kWh/mi efficiency of electric drivetrains and a range of 6-7 miles.

These types of surveys provide valuable insights; however, they lack a critical feature such that the results are skewed: Survey respondents are not provided equivalent pricing for residential charging. The survey implicitly assumes that the respondents would not understand how much they are paying for residential charging and would make decisions for publicly accessible EVSE based on some arbitrary assumption of convenience and willingness to pay. ICF posits, however, that one of the most significant areas of uncertainty moving forward is the amount that consumers will be willing to pay when they become increasingly accustomed to attractive TOU rates at residences or even modest residential rates when charging at Level 1. Other analyses of the viability of third-party ownership/operation of PEV charging networks overlook another critical factor, which is comparing the cost of a public charging event to the price of gasoline. Deloitte, for instance, makes this comparison in an analysis it conducted regarding the breakeven costs of EVSE installation and operation.[69] This comparison may make sense in the context of discussion about PEV adoption; however, as PEV drivers become accustomed to paying at-home charging rates, the comparative focus will likely shift away from electricity prices vs. gasoline prices and shift towards residential electricity rates vs. non-home electricity rates.

Charging needs and behavior

It is largely unclear where, when, and for how long PEV drivers will seek to charge their vehicles when away from home. Many publicly available EVSE have very low utilization rates: The EV Project generally reports utilization rates well below 10%. To some extent, this is the result of providing free charging stations and associated installation costs. The sites selected for The EV Project were not always vetted for maximum utilization; rather, they focused on willing hosts and potentially high profile locations (e.g., City Halls).

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[69] Deloitte, *Plugged In: The Last Mile*, Available online at: http://www.deloitte.com/assets/Dcom-UnitedStates/Local%20Assets/Documents/Energy_us_er/us_er_PluggedInLastMile_June2013.pdf

Based on the National Household Travel Survey, the average driver makes three trips per day with an average of 9.7 miles for each trip; 80% of all trips are less than 15 miles. These numbers suggest that most BEV drivers (whose electric range varies from 62 miles, for the Mitsubishi iMiev, to 265 miles, for the Tesla Model S) do not need to charge outside their home on most days (i.e., out-of-home charging will lead to load shifting, not load increase). PHEV drivers, using a vehicle with an electric range of 10 to 40 miles depending on the model, may find it worthwhile to charge out of home to extend their eVMT and avoid using gasoline. However, if the cost of charging is too high, or if charging cannot take place while conducting other activities, such as working or shopping, PHEV drivers have the option of using their gasoline-powered range extender and foregoing charging out-of-home.

5.3.2 Potential Solutions

Alternatives to additional public investment in charging infrastructure deployment

To date, public agencies have made significant investments in PEV charging infrastructure. The US Department of Energy (DOE), using funds allocated as part of ARRA, spent more than $130 million on programs to deploy charging infrastructure. Public agencies in California–including the California Energy Commission (CEC) and air pollution control districts–issued match funding to support ARRA-funded programs, and made their own investments with additional public funding for other statewide and regional deployment programs. The CEC, air pollution control districts, and metropolitan planning organizations (MPOs) have made varying levels of commitment to continue funding charging infrastructure deployment for the near-term future.

Given the uncertainty in the charging infrastructure marketplace, ICF recommends that public agencies seek alternatives to additional public investment in charging infrastructure. This will help reduce public agencies' exposure to failed endeavors and potentially stranded assets. These alternatives should have an increased focus on "no regrets" solutions such as make-readies and EVSE deployment in areas where it is needed the most, notably at MDUs and workplaces.

Revisit ruling regarding utility investment in charging infrastructure

There are early signs that benefits are being left on the table by limiting utility investment in charging infrastructure, a topic which will be explored and quantified further in the Phase 2 report. Given the legitimate concerns regarding the sustainability of third-party owner/operators of PEV charging networks, ICF recommends revisiting the CPUC ruling regarding utility investment in charging infrastructure. The Assigned Commissioner's recent Scoping Memo and Ruling (Scoping Memo)[70] indicates that the CPUC is willing to take up this issue. The Scoping Memo outlines 13 issues that are to be addressed in Phase 1 over the next 18 months, including the following:

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[70] R.13-11-007, Phase 1 Scoping Memo, July 16, 2014, available online: http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M098/K861/98861048.PDF

2. Should the Commission consider an increased role for the utilities in PEV infrastructure deployment and, if so, what should that role be? If the Commission should consider utility ownership of PEV charging infrastructure, how should the Commission evaluate "underserved markets" or a "market failure" pursuant to D.11-07-029? What else should the Commission consider when evaluating an increased role for utilities in EV infrastructure deployment?

Based on ICF's research as part of our light-duty PEV market assessment, the answer to the first part of the first question is "yes". We arrive at that answer by considering, for instance, that California utilities have a history of forwarding services to society that are not typically cost-effective, such as early renewable energy installations and energy efficiency measures. There are analogous concerns with the nascent PEV charging infrastructure market that utilities should be able to help address.

The second part of the first question (i.e., the role for utilities in PEV infrastructure deployment) is much more nuanced. In this case, ICF is informed by interviews with each of the utilities–both IOUs and MOUs–conducted as part of this project regarding the potential role(s) for utilities in the charging infrastructure market. The key takeaway from our interviews was that while there was unanimity regarding an increased role for utilities in PEV charging infrastructure deployment, the role and strategy that each utility will pursue is considerably different. With that in mind, ICF recommends that utilities be afforded flexibility in their ability to engage in the charging infrastructure market. The role(s) of the utility should reflect the dynamic nature of the PEV and charging infrastructure markets to date. The solutions that will accelerate deployment of PEVs and charging infrastructure consistent with the ZEV Program and Governor Brown's ZEV Action Plan are not uniform across utilities (whether they be IOUs or MOUs). In other words, the solutions that will be required to achieve the targets of the ZEV Program and the goals of the ZEV Action Plan in 2025 are much different than those that are required to support the nascent market today. The risk of narrowly defining the role of utilities based on our understanding of the market today may well impede the ability of utilities to help provide the solutions needed in the future.

As the CPUC considers evaluating an increased role for utilities, they should consider factors such as the following, recognizing that these factors should be researched expeditiously and within the timeframe of the Phase 1 proceedings as they relate to the Guiding Principles and Current Program Issues:

- A market assessment (informed by existing literature) of the PEV/EVSE ecosystem including a review of revenue models, installation, maintenance and equipment costs, market performance, and EVSE utilization in various deployment schemes.
- A review of PEV driver behavior to date – including VMT, eVMT, location of charging, common charging rates, vehicle types (PHEVs vs. BEVs given that the vehicle architecture impacts policy planning), consumer satisfaction surveys, and EVSE host site owner/manager satisfaction surveys.

These considerations will enable the CPUC to assess current market performance, to determine objectively if it is feasible to facilitate and accelerate PEV charging infrastructure deployment via utility involvement, and to identify the potential role(s) for utilities moving forward.

The CPUC’s recent white paper on vehicle grid integration (VGI) also influences our recommendation to revisit the ruling regarding utility investment in charging infrastructure. The CPUC has outlined a vision whereby solutions are developed that achieve grid optimization through grid integrated charging. This requires technology and pricing that leads to or influences PEV customers' charging decisions (e.g., location, rate of charge, frequency and duration of charging and staying plugged in). In order to accomplish this, steps need to be taken to explore VGI further. Since utility rates are cost based, for example reflecting grid conditions such as capacity and energy, the utility is ideally suited to lead the developmental effort toward VGI, especially if this creates increased long-term performance assurances. Accordingly, an increased role for utilities in VGI possibilities requires revisiting the potential for utility investment in charging infrastructure.

The potential of utility investment in charging infrastructure should help facilitate the first recommendation of exploring alternatives to additional public investment in charging infrastructure deployment. Furthermore, there is a philosophical question regarding efficiency of capital that must be considered in this equation. Grant funding from programs like the Electric Program Investment Charge (EPIC) and the Alternative and Renewable Fuel and Vehicle Technology Program are ultimately funded by ratepayers. Both of these programs, to some extent, have helped or likely will help subsidize potentially unsustainable third-party ownership of PEV charging networks – so which approach is the most societally efficient? Utility investment in PEV charging infrastructure does not preclude a role for non-utility market participants since EVSE hardware, installation, operation and maintenance, and network systems will still need to be procured.

Finally, the CPUC's decision primarily reflects a concern for preserving the nascent EVSP market with the finding that "the benefits of utility ownership of electric vehicle service equipment do not outweigh the competitive limitation that may result from utility ownership".[71] As the PEV market is now in its fifth year, and more is known about the gaps and barriers that limit adoption, utilities are in a unique position to support the PEV market and reap the value of the PEV load more than any other industry players. If utilities were authorized to undertake and committed to implementing initiatives that help bridge critical gaps and barriers, competiveness in the marketplace could not only be preserved, but even encouraged by the resulting increased demand for charging products and services. This would probably be welcome news for a sector that has seen several prominent players file for bankruptcy in recent months.

Improved evaluation of charging infrastructure deployment

One of the critical aspects of The EV Project, originally led by ECOtality and recently assumed by CarCharging Group, is the reporting on EVSE utilization. Unfortunately, there is a gap in the reporting done to date between the utilization data and the costs of EVSE (including installation, maintenance, etc.). Furthermore, there has been little reporting on the utilization of EVSE infrastructure funded by other sources–including the CEC and air pollution control districts in California. Anecdotal evidence

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[71] Alternative Fueled Vehicles OIR, Phase 2 Decision, July 14, 2011, page 82.

suggests that the original deployment of EVSE has been less-than-optimal (e.g., focusing on siting EVSE in places where it is inexpensive to install rather than where it is most likely to get utilized the most). Moving forward, and assuming that public entities continue to provide some funding (e.g., grants) for deployment, it will be important for public agencies to identify evaluation metrics, as part of the funding process, that quantify the impact in terms of net results (e.g., reducing the cost of EVSE through increased production and passing value along to the host). It is often difficult to evaluate the cost-effectiveness of funding initiatives after the money has been spent due to the absence of provisions for the recipient to report adequately on information required to conduct a proper evaluation. To the extent that public agencies can incorporate evaluation into the process at the outset of funding, the more valuable the evaluation will be, especially if results are readily available for policy makers and market participants. The Metropolitan Transportation Commission (MTC) in the Bay Area, for instance, is evaluating grants received under the Climate Initiatives Program. An evaluation contractor has been working with the grantees since the inception of the project, enabling a rigorous accounting of benefits (e.g., GHG emission reductions) and lessons learned. This type of ex ante evaluation is unusual; transportation programs are generally subject to ex post evaluations or no evaluations at all. The utility sector is accustomed to programmatic evaluations through energy efficiency programs, for instance, and can play a critical role in promoting similar levels of evaluation in the PEV ecosystem.

5.4 Consumer Education and Outreach

5.4.1 Identification of the Gaps and Barriers

The introduction of new technologies like PEVs requires careful coordination and continuous outreach to consumers to deliver high-level messaging at the local and regional levels to highlight PEV availability and benefits, including total cost of ownership as well as environmental, health, and community benefits. Furthermore, it is important to communicate on a frequent basis the direct financial and nonfinancial benefits to drivers including tax credits, grants, and the PEV driving experience (e.g. fast acceleration and quiet vehicle operation) and the differences associated with fueling from the grid rather than from a gas station.

Lack of PEV Awareness and Knowledge

Except for high-level messaging, there is a general lack of awareness of PEVs in the consumer market today. For instance,

- Navigant reports that the awareness of EVs other than the LEAF and Volt among survey respondents is less than 25%. Even with the Volt and LEAF, only 44% and 31% are extremely familiar or somewhat familiar with these vehicles, respectively.
- Disappointingly, the numbers from Navigant's 2013 survey are not too dissimilar from those reported in a 2010 survey by Ernst & Young. Ernst & Young found that 62% of respondents had never heard of PHEV technology or have heard of it but don't know what it is. Similarly, 40% of respondents have never heard of PEV technology or had heard of it but don't know what it was.

- Even in the San Francisco Bay Area, one of the top markets for EVs, a survey of City CarShare members showed that only 47% of respondents were very familiar or somewhat familiar with EVs. (Note: at the time, City CarShare only had about 10 PEVs in its fleet). Other responses to the survey indicate that consumers may not be as familiar with PEVs as these surveys indicate. For instance, respondents were asked to identify specific PEV model names. Despite 84% of respondents saying they considered themselves at least “slightly familiar” with PEVs, nearly 20% of respondents identified a vehicle that was neither a BEV nor a PHEV. Rather, the respondents regularly identified an HEV (e.g., Toyota Prius) or a small fuel efficient car such as the SmartCar.

Total Cost of Ownership

Consumers’ unwillingness or hesitancy to pay for the additional upfront cost of PEVs (as discussed previously) is coupled with an undervaluation of fuel savings. Ideally, consumers would have an idea of the payback period for the purchase of a PEV – the period of time required for the consumer to recoup the incremental cost of the vehicle–or would understand the total cost of ownership. These values are dependent on variables such as the price of gasoline, the price of electricity, the price of the vehicle, the cost of maintenance, resale value, and the availability of purchasing incentives. Unfortunately, research has shown that consumers generally undervalue future fuel savings and capture only the potential benefits of more fuel efficient vehicles that accrue over a period of two to four years, when actual ownership is two to three times longer than that.[72] In other words, even if the present value of fuel savings over a vehicle’s lifetime outweighs the difference in initial cost, it typically will not be enough to convince consumers to pay more up front.[73]

Calculating the total cost of ownership may prove complex to most customers, as there are limited data available regarding the resale value of PEVs (due to the low volume of sales and limited historical data available in a nascent market).

Finally, consumer concern about the life of the batteries, despite OEM vehicle warranties, will likely continue to limit the resale PEV market until the batteries' lifespan and their residual value in their post-automotive life are clearer.

Improved PEV Education

The familiar aspects of car ownership – such as vehicle pricing, fuel pricing, vehicle range, availability of refueling infrastructure – changes with PEV ownership. Consumers and property owners can often have a difficult time finding the practical and concrete information required to make an informed purchase. PEV ownership often requires a better understanding of vehicle availability, charging options, networking needs, installation costs, contractors capable of performing the installation, etc. There is abundant information available online; however, it is often in multiple places – at the utility website, or with air pollution control districts, permitting departments, OEMs, etc. There are information

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[72] D. Greene and S. Plotkin, “Reducing Greenhouse Gas Emissions from U.S. Transportation,” *Pew Center on Global Climate Change*, 2011.

[73] Indiana University, “Plug-in Electric Vehicles: A Practical Plan for Progress,” *Indiana University*, 2011.

aggregators that have started to emerge and assume a leading role (e.g., goelectricdrive.com); however, as previously stated, awareness about PEVs remains low, an indication that content and traffic to these sites could be improved.

5.4.2 Potential Solutions

Utility as trusted advisor in the PEV market

Utilities have a critical role to play when communicating with consumers about the benefits of PEVs. As PEVs can be part of greater customer engagement about their energy consumption, utilities should expand their advisory role in this area. Utilities have a 30-plus year history of serving as trusted advisors with other end-users, including in the deployment of energy efficient technologies (e.g., air conditioners, lighting, refrigerators, etc.). Furthermore, the Electric Power Research Institute (EPRI) reports that a synthesis of multiple surveys of potential PEV drivers indicates that there is a strong belief that it is the utility's role to develop charging infrastructure and educate consumers.[74]

Most utilities in California are already engaged in initiatives related to PEV deployment – including through coordination with Clean Cities groups, involvement with the California Plug-in Electric Vehicle Collaborative, or with other local/regional efforts. Continuing engagement in these types of initiatives is critical to the success of PEV adoption. Furthermore, it helps bolster the case for utilities to serve as a trusted advisor. Utilities should continue involvement with existing initiatives and identify new opportunities where available. Of particular note, the Bay Area's MTC recently launched the EV Outreach Program under the Climate Initiatives Program with the intent to encourage Bay Area residents to experience PEVs first-hand via two dozen ride-and-drive events while integrating with social media.

While many utilities[75] are educating customers about PEVs, the previously mentioned CPUC ruling limits the scope of education and outreach activities by IOUs with a prohibition of "mass marketing" and a requirement "to target customers with an interest in Electric Vehicle" (rather than the broader segment of automobile intenders). This ruling effectively prevents IOUs from engaging in broader educational initiatives aimed at the general public regarding PEVs and the benefits of fueling vehicles from the grid.

In addition to the information utilities already provide (e.g., PEV rates, environmental and societal benefits), utilities could provide critical and reliable tools about PEVs (e.g., to help customers

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[74] Multiple EPRI reports including: a) Characterizing Consumers' Interest in and Infrastructure Expectations for Electric Vehicles: Research Design and Survey Results (2010), b) Southern Company Electric Vehicle Survey: Consumer Expectations for Electric Vehicles (2011), c) TVA Electric Vehicle Survey: Consumer Expectations for Electric Vehicles (2011), and d) Texas Plugs In: Houston and San Antonio Residents' Expectations of and Purchase Intentions for Plug-In Electric Vehicles (2012).

[75] It is worth noting that as part of the requirements for utilities earning credits under California's LCFS (participation in the LCFS program is voluntary), utilities must commit to educating the "public on the benefits of EV transportation (including environmental benefits and costs of EV charging as compared to gasoline)." The regulation suggests public meetings, EV dealership flyers, utility customer bill inserts, radio and/or television advertisements, and webpage content.

understand the total cost of ownership or choose the charging level needed based on their driving behavior). As noted in the Ernst & Young report, when utilities decide where they want to sit in the emerging ecosystem (and in the case of IOUs, where they are *allowed* to sit), a stable value chain is likely to emerge. As such, the long-term success of (light-duty) vehicle electrification depends on meaningful utility engagement. Plus, considering that a typical call to a utility's call center about PEVs may lead to a conversation about rates, metering, billing, information resources, PEVs at homes with solar energy and other related topics, the utility is ideally suited as the "first stop" for a PEV inquiry.

Engage with PEV ecosystem partners

Outside of existing initiatives, utilities should continue to seek opportunities to engage with PEV ecosystem partners to educate consumers about the benefits of PEV ownership. These include engagement with automobile manufacturers (OEMs), dealers, and private and public fleets, government agencies, and PEV charging industry market participants.

5.5 Vehicle Features

5.5.1 Identification of the Gaps and Barriers

Limited offerings

Over the last several years, about 63% of Californians' new light duty vehicle purchases have been automobiles, with the balance characterized as light trucks. In 2013, the top ten selling vehicles in California were the Toyota Prius, Honda Civic, Honda Accord, Toyota Camry, Toyota Corolla, Ford F-Series, Honda CRV, Nissan Altima, Toyota Tacoma, and the BMW 3-Series.[76] The PEVs available today are in somewhat similar vehicle classes as these top-ten sellers, with a focus on the subcompact segment (e.g., the Toyota Prius) and the standard midsize (e.g., Honda Accord). There are fewer offerings in the larger vehicle classes, including sedans, vans, pickup trucks and SUVs, with the Toyota RAV4 PEV the only offering outside of the light-duty automobile category.

These types of limitations on PEV options, such as vehicle size and payload capacity, restrict potential purchasing opportunities. Consumers tend to purchase new vehicles that are similar to those that they are replacing and PEV equivalents are limited across many market segments.

5.5.2 Potential Solutions

Modify Zero Emission Vehicle Program

CARB's ZEV Program (as of 2018) uses a system of credits generated by OEMs based on the range of the vehicle. The number of credits are awarded based on the zero emission miles that can be traveled – with a minimum of 50 miles (on Urban Dynamometer Driving Schedule, UDDS) earning 1 credit and 350 miles (UDDS) earning 4 credits. Transitional ZEVs, like PHEVs, can earn up to 1.25 credits, depending on the zero emission VMT potential of the vehicle.

[76] CNCDA, California Auto Outlook, Vol 10, Number 1, February 2014.

Although the success of the ZEV program is ultimately driven by VMT with no tailpipe emissions, basing the program's accounting system exclusively on vehicle range may preclude the development of PEVs in some vehicle classes. The market reality is that consumers do not buy vehicles because of their range – they buy vehicles because of their attributes. To incentivize OEMs to produce vehicles outside of the traditional PEV market segments (e.g., subcompact or midsize sedans), CARB might consider a multiplier for ZEV credits in market segments that are underrepresented in various vehicle offerings. CARB has taken significant measures in the updated regulatory proceedings to simplify the ZEV program; as a result, a simple multiplier based on a multi-year (e.g., 3 years) market assessment of vehicle segments may be advisable. Additionally CARB might consider encouraging PHEVs with substantial electric VMT capability as a way to expand ZEV offerings.

Appendix A: Calculation Methodology and Assumptions for Detailed Forecasting, Fuel Consumption and Emissions of TEA Segments

The first step in calculating the electricity consumption societal benefits is to estimate the future populations of each electric drive technology. The population forecasting included an extensive literature review of current and future market conditions, contacting industry and government experts (including CARB, CEC and EPA) and using a utility work group to review the electrification forecasts prior to calculation of benefits and costs. As discussed in Section 2, the future populations and electricity consumption were estimated for three cases, described as:

- "In Line with Current Adoption" is a low case based on anticipated market growth, expected incentive programs, and compliance with existing regulations. For technology that could potentially not be built, like HSR and I710, build/no-build scenarios were considered.
- "Aggressive Adoption" is a high case based on aggressive new incentive programs and/or regulations. "Aggressive adoption" cases are not simply the hypothetical maximum, but are tangibly aggressive.
- "In Between" is a medium case that will fall somewhere in the middle of the low and high cases and will vary by technology. For some technologies it will simply be half-way while for some technologies while other technologies have more direct medium cases.

After developing population forecasts, it is necessary to determine consumption levels for electricity and conventional fuels displaced. These consumption levels are used to determine GHG and criteria pollutant emission reductions. For gasoline, diesel, CNG and electricity, it is necessary to also take into account the upstream criteria pollutant emissions from electricity and petroleum production and refining. Each technology has specific criteria pollutant combustion emission factors but the upstream factors are constant for each type of fuel. Table 32 below shows the upstream criteria pollutant emission factors for conventional fuels (AB 1007)[77] and electricity. The electricity emission factors are based on 78.7%[78] natural gas combined cycle in 2013 and 67%[79] in 2020 and 2030, with the balance being renewable electricity. GHG emission factors are from the Low Carbon Fuel Standard for each fuel except for the 2020/2030 electricity pathway which is based on 67% natural gas combined cycle and 33% renewables. These factors include the full fuel cycle and do not include emissions associated with vehicle or battery manufacturing. Electricity production outside of urban areas has much less significant impact on human health (e.g. criteria air pollutants).

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[77] "Full Fuel Cycle Assessment: Well to Tank Energy Inputs, Emissions, and Water Impact", Consultant Report for the California Energy Commission, February 2007. http://www.energy.ca.gov/2007publications/CEC-600-2007-002/CEC-600-2007-002-D.PDF

[78] 78.7% based on LCFS marginal electricity pathway

[79] 67% based on RPS requirement for 33% renewables

Table 32. Upstream Emission Criteria Pollutant and GHG Emission Factors

Fuel, Unit	NOx (g/unit fuel)	ROG (g/unit fuel)	PM (g/unit fuel)	GHG (g/unit fuel)
RFG3 (E10), gallon	0.116	0.509	0.0046	11,442
Diesel, Gallon	0.188	0.471	0.0081	13,182
Natural Gas, DGE	0.094	0.027	0.017	9,144
Electricity (2013), kWh	0.041	0.0087	0.0049	377
Electricity (2020/2030), kWh	0.035	0.0074	0.0042	305

In general, emission reductions are calculated by determining the displaced emissions from the reduced petroleum consumption and subtracting the emissions from electricity production. The specific methodologies for determining the populations, electricity consumed and societal benefits for each technology are provided below.

Each type of vehicle and electrification technology has a different level of electricity consumption and efficiency compared to conventional technologies. Table 33 below shows the annual kWh consumption per unit for each technology (except for rail) analyzed in this section and the corresponding energy equivalency ratio (EER). The EER is the ratio of conventional fuel energy to electricity energy for the same work.

Table 33. Annual Electricity Consumption and EER for Each Technology

Electrification Technology	Annual Electricity Consumption (kWh/yr)	EER
PHEV10 (PC/LT)	1,006 / 1,326 (2013)	4.05 - electric; 1.5 – gasoline (2013) 3.4 - electric; 1.5 – gasoline (2020) 3.0 - electric; 1.4 – gasoline (2030)
PHEV20 (PC/LT)	2,012 / 2,652	4.05 - electric; 1.5 – gasoline (2013) 3.4 - electric; 1.5 – gasoline (2020) 3.0 - electric; 1.4 – gasoline (2030)
PHEV40 (PC/LT)	3,079 / 4,058	4.05 - electric; 1.5 – gasoline (2013) 3.4 - electric; 1.5 – gasoline (2020) 3.0 - electric; 1.4 – gasoline (2030)
BEV (PC/LT)	2,968 / 3,912	4.05 (2013) 3.4 (2020) 3.0 (2030)
Forklift (8,000lb / 19,000 lb)	18,312 / 52,080	3.8 / 2.5
TSE (per space)	3,423	5.64
e-TRUs (Semi / bobtail / 11hp bobtail) (per TRU)	3,180 / 2,448 / 938	3.9
Shore Power – Container (per berth)*	6,136,000	2.86
Shore Power – Reefer (per berth)*	3,311,000	2.86
Shore Power – Cruise (per berth)*	28,620,000	2.86
Shore Power – Tanker (per berth)*	3,570,000	2.86
CHE – Yard Tractor	64,600	2.9
CHE – Forklift	4,075	4.5
CHE – RTG Crane	109,000	4.0
Airport GSE	4,670	2.65
Dual Mode Catenary Trucks	17,000-20,000	2.1-2.4
MD PHEV	5,500 – 6,800	3.4
MD BEV	8,200 – 11,000	3.4
HD PHEV	12,000 – 17,000	2.7
HD BEV	22,000 – 131,000	2.7
* - Assumed 60% berth occupancy		

Plug-In Electric Vehicles (PEVs). To avoid making market penetration the focus of the PEV grid benefit study, ICF and CalETC decided to choose three different existing PEV penetration scenarios: California Zero Emission Vehicle (ZEV) compliance with a 50/50 split of PEVs and fuel cell vehicles (FCV), California

ZEV program “likely” compliance as defined by CARB, and three times the California ZEV “likely” compliance.[80] The population projections include a breakdown of PHEVs/BEVs, but ICF and CalETC further developed a breakdown of the PHEVs among PHEV10, PHEV20 and PHEV40. In addition each technology was divided between passenger cars (PCs) and light-trucks (LTs). Table 34 below shows the population percentage breakdown for PHEV and BEV between technology and class. The percentages for PHEVs and BEVs separately total 100%.

Table 34. PEV Fleet Breakdown by Technology and Class

Vehicle Class	2013	2020	2030
PHEV 10 – PC	25%	22%	16%
PHEV10 – LT	0%	4%	12%
PHEV20 – PC	25%	22%	16%
PHEV20 – LT	0%	4%	12%
PHEV40 – PC	50%	43%	31%
PHEV40 – LT	0%	5%	14%
BEV – PC	100%	93%	77%
BEV – LT	0%	7%	23%

The forecasts used for the analysis are for populations of PEVs. ICF used retirement factors from the Argonne National Laboratory VISION Model[81] for the AEO 2013 reference case to develop a fleet turnover model and determine the annual sales required by year from 2012 – 2030 to achieve the vehicle population forecasts. The combination of VISION annual fuel economy of auto ICE and LT ICE for conventional vehicles and auto HEV, LT HEV, auto EV and LT EV (PHEV gasoline VMT is assumed to be at HEV fuel economy) for each model year and population turnover model were used with the annual VMT in Table 35 to determine petroleum displaced and electricity consumed. The factors from Table 32 were combined with the vehicle fuel economies shown in Table 36 to determine fuel consumed and GHG emission reductions.

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[80] The ZEV regulation does not require a certain number of ZEVs by 2030; it requires about 4,200,000 ZEV credits. ZEV credits earned per vehicle in 2030 can vary tremendously (e.g. 0.5 for some types of PHEVs and 4.0 for fuel cell EVs). This can result in many compliance pathways from fewer than 1 million cumulative PEVs in 2030 to more than 3 million.

[81] ANL VISION Model http://www.transportation.anl.gov/modeling_simulation/VISION/index.html

Table 35. Gasoline and Electric VMT and Energy Consumption

Vehicle Type	VMT		eVMT		Energy Consumption (kWh)					
	Daily	Annual	Daily	Annual	Daily			Annual		
					Res	NonRes	Total	Res	NonRes	Total
PHEV10	41	14,965	10	3,650	2.8	0.7	3.5	1,022	256	1,278
PHEV20			20	7,300	5.6	1.4	7	2,044	511	2,555
PHEV40			30.6	11,169	8.6	2.1	10.7	3,127	782	3,909
BEV	29.5	10,768	29.5	10,768	8.3	2.1	10.3	3,016	754	3,770

The VISION fuel economies are based on the fuel economies from AEO and apply an on-road loss factor for each vehicle and technology category. For example, Table 36 below shows the ICE, HEV and EV fuel economy for 2013, 2020 and 2030. The analysis for electricity and petroleum consumption utilized the fuel economies for all years from 2011 to 2030. The vehicle fuel economies in the table below combined with the annual VMT above result in slightly different annual electricity consumption, shown in the table above.

Table 36. Vehicle Fuel Economies

Fuel Economy (mi/GGE)	2013	2020	2030
Auto ICE	28.8	34.7	42.8
Auto HEV	43.0	50.9	62.0
Auto EV	117	117	129
LT ICE	21.8	25.2	31.8
LT HEV	33.6	36.7	48.9
LT EV	88.4	94.4	113

Criteria pollutant emission reductions were calculated by determining the gasoline VMT from Table 35 and vehicle population, and using LEV III emission regulations to produce grams per mile emission factors for NMOG+NOx and PM. Table 37 below shows the selected emission factors for vehicles purchased in 2013, 2020, and 2030. Emission factors were calculated for each sales year from 2011 to 2030.

Table 37. Gasoline VMT Criteria Pollutant Emission Factors

Emissions (g/mi)	2013	2020	2030
PM	0.01	0.0051	0.001
NMOG+NOx	0.119	0.074	0.03

Forklifts. The forklift forecast is based on the ITA Market Intelligence report[82] which includes annual sales from 1988 to 2012 of electric rider (Class 1 and 2), motorized hand (Class 3), and internal combustion engine (Class 4 and 5) forklifts. Based on an estimate of 3,159 operating hours per year per forklift and an estimated lifetime of 24,000 hours for electric forklifts and 21,000 hours for conventional forklifts, forklift lifetimes of 8 and 7 years were estimated for electric and conventional forklifts, respectively. Using the sales data and the estimated lifetimes, US populations were estimated for 1997 to 2012. Based on US Census population data, California is approximately 12.12% of the United States and it is assumed that a similar percentage of US forklifts are in California. This is the same methodology used by CARB in the Low Carbon Fuel Standard to determine the quantity of electric forklifts when determining LCFS credits.

Pre-recession (1997 to 2007) annual increases in forklift (Class 1, 2, 4, and 5) sales were used to project total forklift populations from 2012 to 2020 and 2030. For the “In Line with Current Adoption” case the annual growth rate from 1997-2012 of electric rider populations was used to determine populations of electric riders in 2020 and 2030. It is also assumed that all electric forklifts are within the <120 horsepower (hp) category. For the "Aggressive Adoption" case, it was assumed that a similar mandate for shore power at the ports was instituted and 60% of Class 1, 2, 4, and 5 forklifts by 2020 and 80% by 2030 would be electric. It is assumed in the "Aggressive Adoption" case that <120 and 120 to 175 horsepower forklifts would be replaced with electric. Based on CARB 2009 forklift populations by horsepower category, the incremental populations of electric forklifts were divided between <120 hp (86.1%) and 120 to 175 hp (13.9%) where electric forklifts designated as <120 hp displaced gasoline and LPG forklifts and 120-175 hp displaced diesel forklifts. The medium case forecast was chosen as halfway in between the “In Line with Current Adoption” and "Aggressive Adoption" cases for total incremental populations and <120 hp and 120 to 175 hp populations.

Based on research into electric and conventional fueled forklifts from Nissan, CAT and Kalmar, 6,000 to 8,000 lb forklifts were chose as representative of <120 hp and 19,800 lb forklifts were chose as representative of 120 to175 hp. The 6,000 to 8,000 lb lifts had an average battery pack size of 43.6 kWh (Nissan and Crown Spec sheets) and the 19,800 lb lifts had an average battery pack size of 124 kWh (Kalmar spec sheets). In addition, Class 3 forklifts had an average battery pack size of 12.5 kWh. ICF used previous CalETC assumptions of 3,150 hours of operation (525 6 hr shifts) per year which were based on

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[82] http://www.indtrk.org/wp-content/uploads/2013/04/US-Factory-Shipments-Through-2012.pdf

a 50/25/25 breakdown of single, double and triple shift forklift operation. It is assumed that each shift is 6 hours and that each battery uses 80% of its charge per shift. This resulted in 18,312 kWh per year for the 6,000 to 8,000 lb lift and 52,808 kWh per year for the 19,800 lb lifts. Displaced petroleum was calculated by taking the electricity consumed and converting it to gasoline and diesel using CARB fuel consumption factors in pounds per brake horsepower-hour (lb/bhp-hr) and the energy density of gasoline and diesel.

GHG emission reductions were calculated using the values in Table 32 and electricity consumed and gasoline and diesel displaced. Propane powers a substantial portion of the smaller forklifts and over 50% of all Class 4 and 5 forklifts, which includes all internal combustion forklifts.[83] GHG emissions for propane are assumed to be similar to gasoline since most propane consumed in California is petroleum based and requires the same crude production and refining processes. Criteria pollutant emission factors for gasoline and LPG lifts are based on the EPRI report 1007455 (consistent with the previous CalETC report) and diesel emission factors from OFFROAD 2011. The criteria pollutant emission factors are shown in Table 38 below. Electric consumed was converted to bhp and multiplied by the factors noted below to determine criteria pollutants reduced.

Table 38. Forklift Criteria Pollutant Emission Factors

	NOx (g/bhp-hr)	ROG (g/bhp-hr)	PM (g/bhp-hr)
Gasoline/LPG	0.6	0.3	0.015
Diesel – 2010	2.45	0.1	0.14
Diesel – 2020	0.27	0.05	0.01
Diesel – 2030	0.27	0.05	0.01

Truck Stop Electrification (TSE). Currently in California there are an estimated 262 electrified parking spaced as identified by the DOE Alternative Fuels Database and shorepower documentation under the DOE Shorepower Project that was funded by ARRA. Based on an SCE inventory, there are 9,282 truck parking spaces in California. The “In Line with Current Adoption” case assumes that there are still only 262 electrified parking spaces in 2020 and 2030 and also assumes that the capacity factor for each space increases from the current value of 0.28 to 0.5 in 2020 and 0.6 in 2030. The "Aggressive Adoption" case assumes a port-like mandate with 30% of spaces electrified in 2020 and 50% in 2030, and increases in the capacity factor to 0.67 in 2020 and 0.75 in 2030. The medium case is assumed to be halfway in between the “In Line with Current Adoption” and "Aggressive Adoption" cases.

The average load of 1.39 kW while plugging in (from the previous CalETC study) was combined with the value of 0.21 gallons of diesel per hour from the CARB Anti-Idling Regulation Initial Statement of Reasons (ISOR) and the number of spaces and capacity factors to determine electricity consumed and

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[83] http://www.afdc.energy.gov/uploads/publication/2013_Propane_Market_Outlook_1_.pdf

fuel displaced. Based on the CARB HDV Idling Regulation ISOR combined with new LEV III regulations for PM, the following emissions factors in Table 39 were used. The factors in the ISOR for NOx+NMHC were assumed to be 95% NOx and 5% NMHC based on data from the Bay Area Air Quality Management District (BAAQMD).[84]

Table 39. TSE Criteria Pollutant Emission Factors

	NOx (g/hr)	ROG (g/hr)	PM (g/ hr)
2013	14.3	0.76	0.87
2020	14.3	0.76	0.048
2030	14.3	0.76	0.048

Transport Refrigeration Units (TRUs). The TRU forecasts are based on the CARB TRU ISOR.[85] The ISOR has projected 2013 populations of eTRUs and based on conversations with CARB staff only 1% are semis (25 to 50 hp) and the remaining are bobtails (11 to 25 hp). The ISOR also contains California-based and out-of-state TRUs. Forecasts of TEU (truck equivalent unit) from the San Pedro Bay Container Forecast[86] were used to project 2020 and 2030 TRUs. The “In Line with Current Adoption” case maintains a consistent 11% market share of eTRUs and a 99/1 ratio of bobtails to semis. The “In Between” case assumes a port-like mandate for California-based TRUs with 30% and 80% electric in 2020 and 2030. The forecast projects that 75% and 100% of bobtails will be all electric in 2020 and 2030 respectively, <11 hp TRUs will be 25% and 80% electric, and semis will be 18% and 75% electric in 2020 and 2030. The "Aggressive Adoption" case includes the same projections for California-based TRUs and adds the out-of-state TRUs which are all semis. The same percent penetrations of 18% and 75% in 2020 and 2030 as the California-based were used.

Electricity consumption calculations included average electricity loads from the previous CalETC study of 8, 6 and 2.3 kW for the 25 to 50, 11 to 25 and <11 hp categories. The annual hours of operation are based on the CARB TRU ISOR and only 30% of the hours are at the facility and have the potential for e-standby. The fuel consumption values of 0.21, 0.62 and 0.85 gal/hr for <11 hp, 11 to 25 hp and 25 to 50 hp are based on the previous CalETC study. Criteria pollutant emission factors are based on the CARB TRU database with the only adjustments made for PM emission factors to comply with LEV III and are either 0.01g/bhp-hr or 85% emission reductions, whichever is higher. The criteria pollutant emission factors are shown in Table 40.

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[84] http://www.baaqmd.gov/~/media/Files/Engineering/policy_and_procedures/Engines/EmissionFactorsforDieselEngines.ashx

[85] http://www.arb.ca.gov/regact/2011/tru2011/truisor.pdf

[86] “San Pedro Bay Container Forecast Update,” The Tioga Group, Inc – HIS Global Insight, July 2009. http://www.portoflosangeles.org/pdf/SPB_Container_Forecast_Update_073109.pdf

Table 40. TRU Criteria Pollutant Emission Factors

	NOx (g/bhp-hr)			PM (g/bhp-hr)			ROG (g/bhp-hr)		
	2010	2020	2030	2010	2020	2030	2010	2020	2030
25-50 hp	4.8	2.9	2.9	0.16	0.01	0.01	0.1	0.1	0.1
11-25 hp	4.8	4.37	4.37	0.19	0.029	0.029	0.1	0.1	0.1
<11 hp	4.37	4.37	4.37	0.19	0.029	0.029	0.1	0.1	0.1

Shore Power. The overall “In Line with Current Adoption”, “In Between” and "Aggressive Adoption" forecasts contain individual forecasts for each type of ship that could use alternative marine power: container, reefer, cruise ships and tanker ships. Tanker ships are included in the analysis even though the only fleets affected by the regulation include those composed of container vessels, passenger vessels, or refrigerated cargo vessels. Electrification of tanker ships is only included in the "Aggressive Adoption" case. The container, reefer and cruise ship visits forecasted are consistent with CEC forecasts in the *California Energy Demand 2014-2024 Revised Forecast*[87].

The container ship forecasts are based on Wharfinger data[88] for container visits at the ports of Los Angeles/Long Beach, Oakland, and San Diego, using the San Pedro Bay Container Forecast Update to project future container ship visits out to 2020 and 2030.[89] Two current regulations and requirements are in place for shore power. The At-Berth Regulation requires fleets to meet 50% shorepower visit requirement starting 2014, 70% by 2017, and 80% by 2020. Any berths that received Prop 1b funding must exceed the At-Berth Regulation requirements and have 50% of total visits electrified in 2013, 60% by 2014, 80% by 2017 and 90% by 2020. The “In Line with Current Adoption” case assumes minimum compliance with 50%, 80% and 80% of fleet visits (approximately 74% of total visits from 2004 CARB data electrified in 2013, 2020, and 2030. The “In Between" case assumes 50%, 80% and 80% of total visits are electrified in 2013, 2020 and 2030 and the "Aggressive Adoption" case assumes 50%, 90% and 90% of total visits in 2013, 2020, and 2030 which matches the Proposition 1B funding requirements for all berths and visits..

The reefer ship visit forecasts are for Port Hueneme. Reefer ships are refrigerated cargo ships typically used to transport perishable commodities. For all three cases it is assumed that 50%, 80% and 80% of all visits will be electrified since three of the five berths at Port Hueneme have received Proposition 1B funding and have the additional requirements stated above.

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[87] “California Energy Demand 2014-2024 Revised Forecast: Volume 1,” CEC, September 2013. CEC-200-2013-004-SD-V1-REV

[88] Wharfinger data utilized for this study is data collected by keepers and owners of each of the wharfs identified and supplied to CARB as part of the shore power regulation. CARB supplied the data to ICF via email communication.

[89] http://www.portoflosangeles.org/pdf/SPB_Container_Forecast_Update_073109.pdf

For cruise ships at the ports of Los Angeles (LA), Long Beach (LB), San Diego (SD) and San Francisco (SF), CEC estimates for total visits and electrification in 2013 were utilized and an estimated 5% annual increase was applied until 2030 for total cruise ship visits. In the “In Line with Current Adoption” case, it is assumed that number of electrified visits in 2013 stays the same in 2020 and 2030 for the ports of LA, LB and SD. In the "Aggressive Adoption" case, it is assumed that the number of electrified visits is increased by an annual rate of 5% from 2013 to 2020 and 2030. The “In Between" cases is halfway between the “In Line with Current Adoption” and "Aggressive Adoption" cases. For the Port of SF, it is assumed for all cases that 0, 80, and 80 electrified visits occur in 2013, 2020 and 2030 respectively based on projections made by the port staff.

For tanker ships, total visits reported in the CARB Evaluation of Cold-Ironing Vessels at California Ports[90] were escalated to 2020 and 2030 based on petroleum fuel consumption from the CEC Fuels Forecast. Electrification of tanker visits is assumed to be zero in the “In Line with Current Adoption” and “In Between” cases. In the "Aggressive Adoption" case, it is assumed that tanker ships comply with the regulation and 80% of all visits will be electrified in 2020 and 2030.

Data from the Port of Long Beach 2011 emissions inventory[91] was used to determine electrical load and berthing time for each type of ship visit. The weighted average total berth time, hoteling time and load shown in Table 41 below were used to calculate the total electricity consumption in 2013, 2020 and 2030.

Table 41. Shore Power Berth Time, Hoteling Time and Electric Load

Vessel	Total Berth Time (hrs)	Hoteling Time (hrs)	Electric Load (MW)
Container Ships	47	45	1.168
Reefer	60	58	0.630
Cruise/Passenger	14.8	12.8	5.445
Tanker	42.6	40.6	0.679

Diesel fuel consumption reductions are calculated by converting electricity consumed to diesel based on the assumption of displacing 35% efficient diesel auxiliary engines. GHG emission reductions are based on factors in Table 32. Criteria pollutant emissions are calculated based on factors from the CARB Evaluation of Cold-Ironing Vessels at California Ports[92] shown in Table 42 below.

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[90] “CARB Evaluation of Cold-Ironing Vessels at California Ports (Draft Report): Appendix C,” http://www.arb.ca.gov/ports/marinevess/documents/coldironing0306/execsum.pdf

[91] http://www.polb.com/civica/filebank/blobdload.asp?BlobID=10194

[92] “CARB Evaluation of Cold-Ironing Vessels at California Ports (Draft Report): Appendix C,” http://www.arb.ca.gov/ports/marinevess/documents/coldironing0306/execsum.pdf

Table 42. Cold-Ironing Criteria Pollutant Emission Factors

Pollutant	Diesel Engine Emission Factor (g/kW-hr)
NOx	13.6
PM	0.25
HC (VOC)	0.4

Port Cargo Handling Equipment. Forecasts for port cargo handling equipment (CHE) were made based on three different technologies that could be electrified: yard tractors, forklifts and RTG cranes. The baseline population for these technologies for 2010 is from the 2011 cargo handling equipment information in Appendix B[93]. Forecasts for total populations in 2020 and 2030 for each of the three technologies were made using the San Pedro Bay Container Forecast Update similar to TRUs. The "In Line with Current Adoption" case assumes a 10% electric technology market penetration in 2020 and 2030 for yard tractors and forklifts and 5% in 2020 and 10% in 2030 for RTG cranes. The lower 2020 electric penetration for RTG cranes is due to increased issues around RTG expansion and planning required for their acceptance. The "Aggressive Adoption" case uses a port like mandate with 40% market penetration in 2020 and 80% in 2030. The "In Between" case is in the middle of the "In Line with Current Adoption" and "Aggressive Adoption" cases.

Fuel consumption of both conventional and electric yard hostlers (192 kWh/shift) and RTG cranes (417 kWh/shift) is based on a 2012 TIAX study[94]. The fuel consumption for forklifts is based on the forklift analysis and assumes an 8,000 lb capacity for each lift. GHG emission reductions are based on factors in Table 32. Criteria pollutant emission factors are based on the CARB cargo handling equipment inventory model (2011) and the TIAX report for average horsepower of the conventional technologies. Criteria pollutant emission factors for CHE can be found in Table 43 below.

Table 43. Port CHE Criteria Pollutant Emission Factors

	NOx (g/bhp-hr)			PM (g/bhp-hr)			ROG (g/bhp-hr)		
	2010	2020	2030	2010	2020	2030	2010	2020	2030
Yard Tractors	2.45	0.27	0.27	0.11	0.01	0.01	0.1	0.05	0.05
Forklifts	2.45	0.27	0.27	0.14	0.01	0.01	0.1	0.05	0.05
RTG Cranes	2.45	0.27	0.27	0.11	0.01	0.01	0.12	0.05	0.05

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[93] http://www.arb.ca.gov/regact/2011/cargo11/cargoappb.pdf

[94] "Roadmap to Electrify Goods Movement Subsystems for the Ports of Los Angeles and Long Beach," Consultant Report by TIAX LLC for the Ports of LA and LB, February, 2012.

Airport Ground Support Equipment (GSE). Forecasts for total pieces of GSE in California are based on the ACRP report[95] of national GSE using the Federal Aviation Administration (FAA) national and California enplanements[96] for 2010 to scale for California GSE. The FAA enplanement data shows California had approximately 11% of total national enplanements in 2010. The FAA forecasts for national and total enplanements were used to scale the 2010 GSE population to 2020 and 2030 and the same California proportion of the national average (11%) was used to determine total California GSE. The 2010 electrified population was estimated by using the Los Angeles World Airports Sustainability Plan[97] which indicates that 100% of Ontario Airport GSE and 24% of LAX is electrified, and information from Southwest that all of its GSE at San Jose International Airport (SJC) is electrified (approximately 50% of gates and enplanements at SJC). Based on the FAA enplanement data for these three airports, approximately 15.8% of the GSE in California was electrified in 2010. The “In Line with Current Adoption” case assumes that only LAX increased its GSE population from 2010 to include 100% of push tractors, container loaders, belt loaders and baggage tractors which make up 56% of individual gate GSE. This results in a total California GSE penetration of 23.7% in 2020 and 2030. The "Aggressive Adoption" case assumes a port-like mandate with 40% of GSE being electrified in 2020 and 60% in 2030. This is consistent with EPRI’s estimate that approximately 30% of airport GSE could be electrified in 2015. The “In Between” case is directly in between the other two cases.

The electricity consumption was calculated by using the EPRI Technical Update[98] of GSE electrical load for narrow-body and wide-body gates combined with the CARB OFFROAD model for activity (hrs/yr). Based on a report by The MITRE Corporation[99], only 20.8% of planes are wide body. This data was used to assume that 20.8% of gates in California are wide-body gates. ICF assumed the same proportion of narrow-body and wide-body gates GSE were electrified. The consumption per gate was escalated to 2020 and 2030 based on the ratio of increased enplanements and the assumption that there would be no new gates to handle the increased enplanements but rather higher utilization of the existing gates.

Displaced petroleum was calculated by taking the electricity consumed and converting to gasoline and diesel using CARB fuel consumption factors in lb per brake horsepower-hr (lb/bhp-hr) and the energy density of gasoline and diesel. GHG emission reductions were based on emission factors from Table 32. The weighted average of CARB emission factors by GSE horsepower share from the OFFROAD model was used to calculate criteria pollutant emissions. Criteria pollutant emission factors can be found in Table 44 below.

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[95] ACRP Report 78: Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial (2012)

[96] http://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger/

[97] http://www.lawa.org/uploadedFiles/LAWA/pdf/Sustainability%20Plan%20%28Final%29.pdf

[98] EPRI Technical Update: Alternative Ground Support Equipment Electrification Analysis (2010)

[99] https://www.mitre.org/sites/default/files/pdf/bhadra_analysis.pdf

Table 44. Airport GSE Criteria Pollutant Emission Factors

	NOx (g/bhp-hr)	ROG (g/bhp-hr)	PM (g/ bhp-hr)
Gasoline, 2013-2030	1.79	0.072	0.297
Diesel - 2013	3.08	1.34	1.34
Diesel - 2020	0.17	0.01	0.01
Diesel - 2030	0.1	0.07	0.07

High Speed Rail. The forecasts for High Speed Rail were based on the 2012 Business Plan[100] with the "In Line with Current Adoption" case only taking into account the initial operating section (IOS) in 2020 and 2030, the "In Between" case including the IOS in 2020 and Bay to Basin in 2030 and the "Aggressive Adoption" case including the IOS in 2020 and the Phase 1 Blended in 2030. Figure 9 shows the high speed rail operating scenarios. The total train set miles and service were modeled using the train schedule in the business plan and the energy consumption factor of 54 kWh/train set mile for an 8 car train.[101] Passenger-miles were calculated using the estimated passengers, percent of interregional travel and the estimated amount of track (mi) in each year from the business plan.

[100] http://www.hsr.ca.gov/About/Business_Plans/2012_Business_Plan.html

[101] http://www.hsr.ca.gov/docs/programs/merced-fresno-eir/final_EIR_MerFres_TA3_06C_EnergyUse.pdf

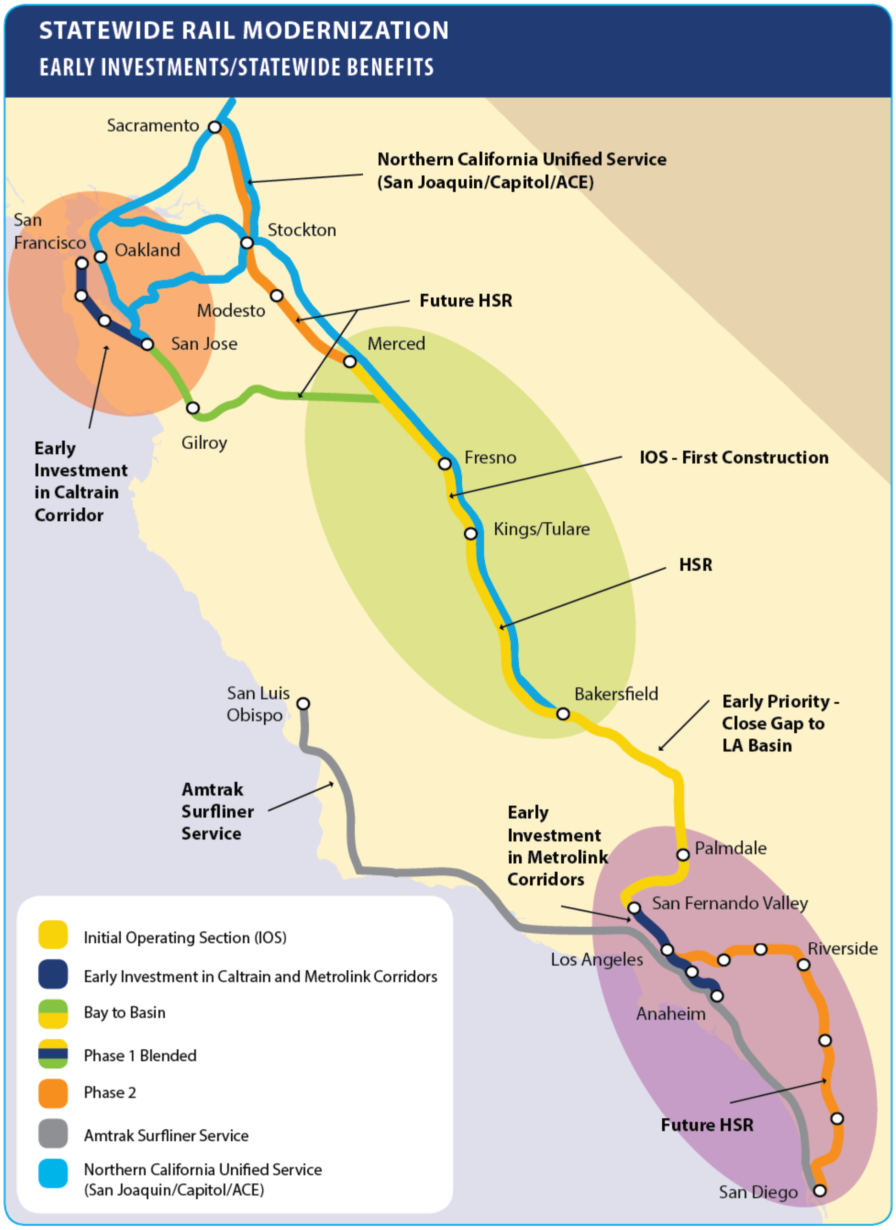

Figure 9. High-Speed Rail Operating Scenarios[102]

Petroleum (diesel) consumption displaced is calculated by assuming that high speed rail displaces transit buses and assuming that interregional buses would have 50% occupancy. The total number of passenger-miles is converted to fuel consumption by using the National Transit Database to determine the fuel consumption per passenger-mile at 50% occupancy of California buses. The factors in Table 32 were used to calculate GHG reductions. Criteria pollutant emission reductions were determined by using the factors in Table 45 below from the EMFAC model. The ratio of passenger-miles/bus-miles at 50%

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[102] http://www.hsr.ca.gov/docs/about/legislative_affairs/HSR_Reducing_CA_GHG_Emissions_2013.pdf

occupancy was used to calculate the total emissions. This methodology is simpler than that used by the High Speed Rail Authority, which includes displacing airline and passenger car miles.[103] The GHG emissions reductions from this analysis are lower than those from the High Speed Rail Authority due to the assumptions for electricity production. The High Speed Rail Authority assumes all renewable electricity, while this analysis assumes marginal electricity from 33% renewables and 67% natural gas. The GHG emission reduction calculations would be similar if the same electricity mix was used.

Table 45. Transit Bus Criteria Pollutant Emission Factors

	NOx (g/mi)	ROG (g/mi)	PM (g/mi)
Transit Bus	0.586	0.0304	0.0338

Light, Heavy and Commuter Rail. Light, Heavy and Commuter Rail analysis includes the rail systems in Table 46 below.

Table 46. Rail Systems Included in the Light, Heavy and Commuter Rail Analysis

Light Rail	Heavy Rail	Commuter Rail
LA Metro – Light Sacramento San Diego SF – Cable Car SF – Light Rail SF – Trolly Bus Santa Clara VTA	BART LA Metro Subway	Electrified Caltrain

Statistics from the National Transit Database were used to calculate the “In Line with Current Adoption”, “In Between” and "Aggressive Adoption" cases for passenger-miles and resulting electricity consumption. The “In Line with Current Adoption” case for Light and Heavy Rail uses the passenger-miles per track mile from 2011 for each system and takes into account planned increases in track length in 2020 and 2030 to calculate increases in passenger-miles in 2020 and 2030. The "Aggressive Adoption" case takes into account the trends in passenger-miles per track mile from 2007 to 2011 and continues these trends when positive (if negative the 2011 passenger-miles per track mile factor is used) with the planned increases in track length shown in Table 47 below.

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[103] http://www.hsr.ca.gov/docs/about/legislative_affairs/HSR_Reducing_CA_GHG_Emissions_2013.pdf

Table 47. Planned Increases in Track Length

Light/Heavy Rail Lines	Starting Track Length (miles)	Increased Track Length (miles) and Year
Los Angeles Light Rail	116.3	8.6 (2012); 6.6 (2015); 11 (2016); 8.5 (2018); 2 (2019); 1.9 (2020); 12 (2025)
Sacramento	73.4	1.1 (2012); 12.8 (2021)
San Diego	102.6	11 (2018)(
San Francisco Light Rail	103.5	1.7 (2019)
Santa Clara	79.6	10 (2018); 6 (2030)
Los Angeles Heavy Rail	34.1	
BART	267.6	3.2 (2014); 5.4 (2015); 16 (2018)

The “In Between” case is directly in between the “In Line with Current Adoption” and "Aggressive Adoption" cases. The “In Line with Current Adoption” case for commuter rail is zero, assuming that Caltrain would not be electrified. The “In Between” case scales the National Transit Database passenger-miles with the Caltrain 2014 Strategic Plan[104] estimate for passengers until 2018 (the last year in the plan) and uses the 0.8% annual growth from 2007 to 2011 to forecast the 2018 estimate of passenger-miles to 2020 and 2030. The "Aggressive Adoption" case uses a linear project of the estimated 2014 to 2018 passenger-miles to 2020 and 2030.

Electricity consumption for commuter rail is calculated using the estimated passenger-miles and the kWh/passenger-mile for the SEPTA (Southeastern Pennsylvania Transportation Authority) electrified commuter rail from the NTD. The electricity consumption for light and heavy rail is calculated using the 2011 kWh/passenger-mile from the NTD for each system and the forecasted passenger-miles. Diesel displaced by electrified commuter rail is based on the average diesel consumption per passenger-mile for 2009 to 2011 from NTD for the Caltrain and the projected passenger-miles. Displaced conventional fuel (either diesel or natural gas) is based on the average diesel or natural gas consumption per passenger-mile for the local transit bus fleet for each rail system and the projected passenger-miles.

The factors in Table 32 were used to calculate GHG reductions. Criteria pollutant emission reductions were determined by using the factors in Table 48 below from the EMFAC model for diesel urban bus. The state average ratio of passenger-miles to revenue-miles from the NTD was used convert passenger-miles to bus miles for the calculation of total criteria pollutants.

Table 48. Transit Bus Emission Factors

	NOx (g/mi)	ROG (g/mi)	PM (g/mi)
Transit Bus	0.586	0.0304	0.0338

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[104] http://www.caltrain.com/projectsplans/Plans/CaltrainStrategicPlan-2014.html

Dual Mode Catenary Trucks on I-710 / SR 60. The forecasts for electricity consumption and displacement of petroleum, GHG and criteria pollutant emissions is based on the annual average daily traffic (AADT) of heavy duty trucks from the California Department of Transportation (DOT) on I710 and SR-60[105] for 2009 to 2011. Forecasts of TEU from the San Pedro Bay Container Forecast are used to project AADT to 2020 and 2030. The "In Line with Current Adoption" case assumes that the catenary system is not built, with zero electrification. The "In Between" case only considers the potential electrification of the proportion of trucks making frequent or semi-frequent trips to the Ports of Los Angeles or Long Beach and only on the I-710. Based on Port of Long Beach data[106], this is approximately 80.7% of trips to the port and therefore is assumed to be the same percentage of AADT on the I710. The "In Between" case assumes 35% of frequent and semi-frequent truck trips are electrified in 2020 and 100% in 2030. The "Aggressive Adoption" case forecasts that all AADT have the potential to be electrified and 35% and 100% of all I-710 truck trips could be electrified in 2020 and 2030. The "Aggressive Adoption" case also forecasts that 65% of SR-60 trips will be electrified in 2030. The truck miles per AADT of 15.51 for I-710 and 32.58 for SR-60 were used to convert truck trips to truck miles.

Electricity consumption for the "In Between" case is based on the "In Line with Current Adoption" estimate of 2.7 kWh/truck-mile and the "Aggressive Adoption" case electricity consumption is based on the high estimate of 3.0 kWh/truck-mile.[107] Displaced diesel consumption is based on a fuel economy of 5.85 miles per gallon from EMFAC 2011 in 2020 and 2030 for heavy-duty class 8 trucks and forecasted truck-miles.

The factors in Table 32 were used to calculate GHG reductions. Criteria pollutant emission reductions were determined by using the factors for in-use and idling in Table 49 below from the EMFAC model for heavy-duty class 8 trucks. The weighted average of the Port of Long Beach daily trips per truck[108] was used to convert AADT to number of trucks for calculating the idling emissions.

Table 49. Heavy-Duty Class 8 Truck Criteria Pollutant Emission Factors

	NOx In-Use (g/mi)	NOx Idle (g/vehicle/day)	ROG In-Use (g/mi)	ROG Idle (g/vehicle/day)	PM In-Use (g/mi)	PM Idle (g/vehicle/day)
2020	1.002	30.49	0.136	5.87	0.0402	0.0787
2030	1.003	30.49	0.137	5.87	0.0400	0.0787

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[105] http://traffic-counts.dot.ca.gov/

[106] http://www.polb.com/civica/filebank/blobdload.asp?BlobID=3371

[107] Memo from Brian Burkhard (Transpo Group) to the Gateway COG and LAMTA, "Truck Catenary System Update to Transpo Group's July 11 Memo," August 28, 2012.

[108] http://www.polb.com/civica/filebank/blobdload.asp?BlobID=3371

Medium-Duty Vehicles. The forecast of medium-duty vehicles is based on an ICF developed penetration of three EMFAC vehicle classes – including light-heavy duty trucks (two classes) and medium duty vehicles (Classes 2 and 3). The forecasts are based on an S-curve like adoption out to 2030, linked to new vehicles sales. ICF extracted vehicle populations from EMFAC and estimated annual new vehicles sales. Vehicle retirement was accounted for based on survivability profiles extracted from EMFAC. ICF made a subjective determination of the split between PHEVs and BEVs in each of the “In Line with Current Adoption”-, "In Between"-, and "Aggressive Adoption"-cases, with the latter having the most aggressive deployment of fully electric vehicles. In most cases, it was assumed that approximately 90% of vehicles deployed would be PHEVs; however, in the "Aggressive Adoption" case this was decreased to around 50%. The “In Line with Current Adoption”, "In Between", and "Aggressive Adoption" cases looked to achieve 5%, 10% and 50% of sales in 2030 which would achieve 1.5%, 2.9% and 13.4% of the population.

Electricity consumption was estimated based on an EER value of 3.4, provided by CARB for medium-duty electric vehicles.

The factors in Table 32 were used to calculate GHG reductions. Criteria pollutant emission factors were weighted based on the VMT and population of each of the vehicle classes considered.

Table 50. Medium-Duty Vehicle Criteria Pollutant Emission Factors

	NOx In-Use (g/mi)	NOx Idle (g/vehicle/day)	ROG In-Use (g/mi)	ROG Idle (g/vehicle/day)	PM In-Use (g/mi)	PM Idle (g/vehicle/day)
2020	0.538	0.242	0.067	0.090	0.005	0.003
2030	0.268	0.243	0.030	0.086	0.004	0.003

Heavy-Duty Vehicles. The forecast of heavy-duty vehicles is based on an ICF developed penetration of 23 EMFAC vehicle classes – including medium-heavy duty trucks (seven vehicle classes), heavy-heavy duty trucks (11 vehicle classes) and buses (five vehicle classes). The forecasts are based on an S-curve like adoption out to 2030, linked to new vehicles sales. ICF extracted vehicle populations from EMFAC and estimated annual new vehicles sales. Vehicle retirement was accounted for based on survivability profiles extracted from EMFAC. ICF made a subjective determination of the split between PHEVs and BEVs in each of the “In Line with Current Adoption”-, "In Between"-, and "Aggressive Adoption"-cases, with the latter having the most aggressive deployment of fully electric vehicles. In most cases, it was assumed that approximately 90% of vehicles deployed would be PHEVs; however, in the "Aggressive Adoption" case this was decreased to around 50%.

The “In Line with Current Adoption” case includes port trucks and buses increasing to a 5% sales rate by 2030. The "In Between" case includes all medium-heavy and heavy-heavy duty market segments with 10% sales in port trucks and buses and 5% sales for the remaining market segments in 2030. The

"Aggressive Adoption" case includes 50% sales for buses, 25% sales for port trucks and 15% sales for the remaining segments in 2030.

Electricity consumption was estimated based on an EER value of 2.7, provided by CARB for heavy-duty electric vehicles.

The factors in Table 32 were used to calculate GHG reductions. Criteria pollutant emission factors were weighted based on the VMT and population of each of the vehicle classes considered.

Table 51. Heavy-Duty Vehicle Criteria Pollutant Emission Factors

	NOx In-Use (g/mi)	NOx Idle (g/vehicle/day)	ROG In-Use (g/mi)	ROG Idle (g/vehicle/day)	PM In-Use (g/mi)	PM Idle (g/vehicle/day)
2020	3.397	42.536	0.211	6.869	0.075	0.127
2030	1.927	43.024	0.176	7.929	0.066	0.118

Appendix B: Costing Analysis Methodology and Assumptions

This appendix lists the major assumptions and data sources for the costing analysis in addition to detailed tables showing the analysis. Analysis for each technology was done on an annualized basis to determine costs and benefits. This includes using a 5% discount rate and the corresponding vehicle life or infrastructure life to determine annualized capital costs. In each section below is a set of tables identifying the main data sources and assumptions, the annualized private cost and benefit analysis, and annual societal benefit and monetization of those benefits using the values in Table 16. The annual capital costs (costs), operating cost savings (private benefits) and monetized societal benefits (societal benefits) are then fed into the tables in Section 3 to develop the benefit-cost ratios.

PEVs. Table 52 below shows the main data sources and assumptions for the PEV cost analysis. The analysis and results in the following tables are per PEV. Table 53 and Table 55 use the values in Table 52 to develop the annualized cost and private benefits of passenger cars and light truck, respectively. Table 54 and Table 56 show the annual societal benefits per PEV and the monetization of these benefits. The cost analysis and societal benefits are for a new PEV purchased in 2013, 2020 or 2030 and are compared to a new ICE in 2013, 2020 or 2030, respectively. See Appendix A for the details on the calculation of societal benefits. The assumptions below do not apply to Section 2 and are for costing analysis only.

Table 52. PEV Data Sources and Assumptions

Variable	Value	Source
Incremental Vehicle Costs	Various Values for PC and LT that can be found in Table 53 and Table 55	ICF with consultation from CalETC
EVSE Cost	Various Values for LEV 1 and LEV 2 charges that can be found in Table 53 and Table 55	ICF International (2013), Bay Area Plug-in Electric Vehicle Readiness Plan
Ratio of LEV1 of LEV for PHEVs and BEVs	PHEV10 – 100% LEV 1 PHEV20 – 100% LEV 1 PHEV40 – 90% LEV 1; 10% LEV 2 BEV – 30% LEV 1 and 70% LEV 2	ICF and CalETC assumption
Federal Rebate[109]	100% Value in 2013 50% Value in 2020 0% in 2030	ICF Assumption
State Rebate	\$2,500/\$1,500 BEV/PHEV in 2013 \$1,000/\$500 BEV/PHEV in 2020 \$0/\$0 BEV/PHEV in 2030	ICF Assumption
Vehicle/EVSE Lifetime	10 years (no battery replacement)[110] / 20 years	ICF Assumption
Discount Factor	5%	ICF Assumption
Annual VMT/eVMT	See Table 35	ICF/CalETC Assumptions and EV Project Data
Fuel Economy	New Vehicle MPG for ICE, HEV and EV – See Table 36	AEO2013
CA Average Electricity Prices – TOU and Domestic	Population weighted average of PGE, SCE, SDGE and SMUD service territories for 2013, 2020 and 2030 found in Table 53 and Table 55	Extracted from the E3 model for used in the Phase 2 report based on rates supplied by each utility
Gasoline Prices	2013 - \$3.89 2020 - \$4.34 2030 - \$5.10	CEC IEPR 2013
Maintenance Costs	Lifetime Oil Change: ICE - \$2,365.82; PHEV - \$1,474.02; BEV - \$0 Total Routine Maintenance: ICE - \$4,591.66; PHEV - \$3.677.06; BEV - \$3,094.66	ORNL[111] and Tesla[112]

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[109] Federal Rebate values used: \$2,500 for PHEV10; \$4,000 for PHEV20; \$7,500 for PHEV40 and BEV

[110] Based on required battery warranty of 10yr/100,000 mi for BEV and 10yr/150,000 mi

[111] ORNL (2010), Plug-In Hybrid Electric Vehicle Value Proposition Study. Available online at: http://www.afdc.energy.gov/pdfs/phev_study_final_report.pdf

[112] Tesla Motors, 2007, "The 21st Century Electric Car", http://www.fcinfo.jp/whitepaper/687.pdf

Table 53. PEV Passenger Car Annualized Cost Analysis

Passenger Car	Conventional			PHEV10			PHEV20			PHEV40			BEV		
() Denotes Cost Savings	2013	2020	2030	2013	2020	2030	2013	2020	2030	2013	2020	2030	2013	2020	2030
Vehicle															
Incremental Price ($)	-	-	-	$5,717	$2,524	$399	$11,434	$5,047	$798	$15,206	$6,448	$1,597	$16,380	$5,151	$197
Federal Rebate ($/car)	-	-	-	$2,500	$1,250	$-	$4,000	$2,000	$-	$7,500	$3,750	$-	$7,500	$1,875	$-
State Rebate ($/car)	-	-	-	$1,500	$500	$-	$1,500	$500	$-	$1,500	$500	$-	$2,500	$1,500	$-
Total Capital ($)	-	-	-	$1,717	$774	$399	$5,934	$2,547	$798	$6,206	$2,198	$1,597	$6,380	$1,776	$197
Annual Costs ($/yr)	-	-	-	$222	$100	$52	$768	$330	$103	$804	$285	$207	$826	$230	$26
Infrastructure															
LEV1 Percent	-	-	-	100%	100%	100%	100%	100%	100%	70%	70%	70%	10%	10%	10%
LEV2 Percent	-	-	-	0%	0%	0%	0%	0%	0%	30%	30%	30%	90%	90%	90%
LEV 1 ($/charger)	-	-	-	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200
LEV 2 ($/charger)	-	-	-	$1,757	$1,326	$1,326	$1,757	$1,326	$1,326	$1,757	$1,326	$1,326	$1,757	$1,326	$1,326
Total Capital ($)	-	-	-	$200	$200	$150	$200	$200	$150	$667	$538	$451	$1,601	$1,213	$1,053
Annual Costs ($/yr)	-	-	-	$16	$16	$12	$16	$16	$12	$54	$43	$36	$128	$97	$84
Operating Costs															
Annual Gas VMT (mi/year)	14,965	14,965	14,965	11,315	11,315	11,315	7,665	7,665	7,665	3,796	3,796	3,796	0	0	0
Annual eVMT (mi/yr)	-	-	-	3,650	3,650	3,650	7,300	7,300	7,300	11,169	11,169	11,169	10,768	10,768	10,768
Total Gasoline Consumption (GGE/yr)	520	432	350	263	222	183	178	151	124	88	75	61	0	0	0
Total Electricity Usage (kWh/yr)	-	-	-	1,006	1,007	908	2,012	2,015	1,817	3,079	3,083	2,780	2,968	2,972	2,680
TOU Grid Price ($/kWh)	-	-	-	$0.11	$0.18	$0.26	$0.11	$0.18	$0.26	$0.11	$0.18	$0.26	$0.11	$0.18	$0.26
Domestic Grid Price ($/kWh)	-	-	-	$0.18	$0.28	$0.40	$0.18	$0.28	$0.40	$0.18	$0.28	$0.40	$0.18	$0.28	$0.40
Gasoline Price ($/GGE)	$3.89	$4.34	$5.10	$3.89	$4.34	$5.10	$3.89	$4.34	$5.10	$3.89	$4.34	$5.10	$3.89	$4.34	$5.10
TOU Electricity Cost ($/yr)	-	-	-	$115	$180	$234	$231	$361	$469	$353	$552	$717	$341	$532	$691
Domestic Electricity Cost ($/yr)	-	-	-	$181	$280	$361	$362	$559	$722	$554	$855	$1,105	$534	$825	$1,065
Gasoline Cost	$2,024	$1,873	$1,783	$1,024	$964	$931	$693	$653	$631	$343	$323	$312	$-	$-	$-
Fuel Cost Avoided	$2,024	$1,873	$1,783	$2,024	$1,873	$1,783	$2,024	$1,873	$1,783	$2,024	$1,873	$1,783	$1,456	$1,348	$1,283
Incremental Fuel Cost TOU Rate	$-	$-	$-	$(885)	$(728)	$(617)	$(1,100)	$(859)	$(683)	$(1,327)	$(998)	$(753)	$(1,116)	$(816)	$(591)
Incremental Fuel Cost Dom. Rate	$-	$-	$-	$(819)	$(629)	$(491)	$(968)	$(661)	$(430)	$(1,126)	$(694)	$(365)	$(922)	$(523)	$(217)
Incremental Maint. Cost ($/lifetime)	-	-	-	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(3,863)	$(3,863)	$(3,863)
Incremental Maint. Cost ($/yr)	-	-	-	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(386)	$(386)	$(386)
Total Cost															
Annual Incremental Capital Costs	-	-	-	$238	$116	$64	$785	$346	$115	$857	$328	$243	$955	$327	$110
Annual Incremental Fuel TOU Rate Cost	-	-	-	$(885)	$(728)	$(617)	$(1,100)	$(859)	$(683)	$(1,327)	$(998)	$(753)	$(1,116)	$(816)	$(591)
Annual Incremental Fuel Dom. Rate Cost	-	-	-	$(819)	$(629)	$(491)	$(968)	$(661)	$(430)	$(1,126)	$(694)	$(365)	$(922)	$(523)	$(217)
Annual Incremental Maintenance Cost	-	-	-	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(386)	$(386)	$(386)
Total Annual Costs TOU Rate	-	-	-	$(827)	$(793)	$(734)	$(496)	$(694)	$(749)	$(651)	$(851)	$(691)	$(547)	$(875)	$(868)
Total Annual Costs Domestic Rate	-	-	-	$(761)	$(694)	$(608)	$(364)	$(495)	$(495)	$(450)	$(547)	$(303)	$(354)	$(582)	$(494)

Table 54. PEV Passenger Car Annualized Societal and Monetized Societal Benefits

Passenger Cars	PHEV10			PHEV20			PHEV40			BEV		
	2013	2020	2030	2013	2020	2030	2013	2020	2030	2013	2020	2030
Annual Societal Benefits per Vehicle												
Petroleum Displacement (GGE/yr)	257	209	167	342	281	226	432	357	288	374	311	252
GHG Emission Benefits (MT/yr)	2.56	2.09	1.63	3.16	2.60	2.03	3.78	3.14	2.45	3.16	2.65	2.06
NOX (tons/yr)	2.27E-04	1.37E-04	4.67E-05	4.32E-04	2.56E-04	7.95E-05	6.49E-04	3.82E-04	1.14E-04	6.20E-04	3.64E-04	1.07E-04
PM (tons/yr)	3.61E-05	1.69E-05	6.64E-07	7.13E-05	3.31E-05	7.81E-07	1.09E-04	5.03E-05	9.04E-07	1.05E-04	4.84E-05	7.37E-07
VOC (tons/yr)	3.74E-04	2.58E-04	1.47E-04	6.51E-04	4.39E-04	2.33E-04	9.45E-04	6.31E-04	3.24E-04	8.88E-04	5.89E-04	2.97E-04
Monetized Societal Benefits per Vehicle												
Petroleum Displacement	$113.46	$90.82	$70.22	$150.91	$121.92	$94.98	$190.61	$154.87	$121.22	$165.17	$134.70	$105.75
GHG Emission	$28.19	$25.06	$26.14	$34.71	$31.21	$32.48	$41.61	$37.72	$39.20	$34.81	$31.75	$32.95
NOx	$1.06	$0.70	$0.28	$2.02	$1.30	$0.48	$3.03	$1.94	$0.70	$2.90	$1.85	$0.65
PM	$52.35	$27.92	$1.31	$103.44	$54.70	$1.54	$157.59	$83.08	$1.79	$151.62	$79.81	$1.46
VOC	$0.42	$0.31	$0.21	$0.73	$0.54	$0.33	$1.06	$0.77	$0.46	$0.99	$0.72	$0.42

Table 55. PEV Light Truck Annualized Cost Analysis

Light Truck	Conventional			PHEV10			PHEV20			PHEV40			BEV		
() Denotes Cost Savings	2013	2020	2030	2013	2020	2030	2013	2020	2030	2013	2020	2030	2013	2020	2030
Vehicle															
Incremental Price ($)	-	-	-	$7,509	$3,442	$1,027	$15,017	$6,884	$2,055	$20,142	$8,873	$3,280	$24,035	$8,251	$1,995
Federal Rebate ($/car)	-	-	-	$2,500	$1,250	$-	$4,000	$2,000	$-	$7,500	$3,750	$-	$7,500	$1,875	$-
State Rebate ($/car)	-	-	-	$1,500	$500	$-	$1,500	$500	$-	$1,500	$500	$-	$2,500	$1,500	$-
Total Capital ($)	-	-	-	$3,509	$1,692	$1,027	$9,517	$4,384	$2,055	$11,142	$4,623	$3,280	$14,035	$4,876	$1,995
Annual Costs ($/yr)	-	-	-	$454	$219	$133	$1,233	$568	$266	$1,443	$599	$425	$1,818	$632	$258
Infrastructure															
LEV1 Percent	-	-	-	100%	100%	100%	100%	100%	100%	70%	70%	70%	10%	10%	10%
LEV2 Percent	-	-	-	0%	0%	0%	0%	0%	0%	30%	30%	30%	90%	90%	90%
LEV 1 ($/charger)	-	-	-	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200
LEV 2 ($/charger)	-	-	-	$1,757	$1,326	$1,326	$1,757	$1,326	$1,326	$1,757	$1,326	$1,326	$1,757	$1,326	$1,326
Total Capital ($)	-	-	-	$200	$200	$150	$200	$200	$150	$667	$538	$451	$1,601	$1,213	$1,053
Annual Costs ($/yr)	-	-	-	$16	$16	$12	$16	$16	$12	$54	$43	$36	$128	$97	$84
Operating Costs															
Annual Gas VMT (mi/year)	14,965	14,965	14,965	11,315	11,315	11,315	7,665	7,665	7,665	3,796	3,796	3,796	0	0	0
Annual eVMT (mi/yr)	-	-	-	3,650	3,650	3,650	7,300	7,300	7,300	11,169	11,169	11,169	10,768	10,768	10,768
Total Gasoline Consumption (GGE/yr)	687	593	471	336	309	232	228	209	157	113	104	78	0	0	0
Total Electricity Usage (kWh/yr)	-	-	-	1,326	1,242	1,039	2,652	2,483	2,077	4,058	3,800	3,178	3,912	3,663	3,064
TOU Grid Price ($/kWh)	-	-	-	$0.11	$0.18	$0.26	$0.11	$0.18	$0.26	$0.11	$0.18	$0.26	$0.11	$0.18	$0.26
Domestic Grid Price ($/kWh)	-	-	-	$0.18	$0.28	$0.40	$0.18	$0.28	$0.40	$0.18	$0.28	$0.40	$0.18	$0.28	$0.40
Gasoline Price ($/GGE)	$3.89	$4.34	$5.10	$3.89	$4.34	$5.10	$3.89	$4.34	$5.10	$3.89	$4.34	$5.10	$3.89	$4.34	$5.10
TOU Electricity Cost ($/yr)	-	-	-	$152	$222	$268	$304	$444	$536	$466	$680	$820	$449	$656	$791
Domestic Electricity Cost ($/yr)	-	-	-	$239	$345	$413	$477	$689	$826	$730	$1,054	$1,263	$704	$1,016	$1,218
Gasoline Cost	$2,672	$2,575	$2,400	$1,309	$1,339	$1,181	$887	$907	$800	$439	$449	$396	$-	$-	$-
Fuel Cost Avoided	$2,672	$2,575	$2,400	$2,672	$2,575	$2,400	$2,672	$2,575	$2,400	$2,672	$2,575	$2,400	$1,922	$1,853	$1,727
Incremental Fuel Cost TOU Rate	$-	$-	$-	$(1,211)	$(1,013)	$(951)	$(1,481)	$(1,223)	$(1,064)	$(1,767)	$(1,445)	$(1,184)	$(1,473)	$(1,197)	$(936)
Incremental Fuel Cost Dom. Rate	$-	$-	$-	$(1,124)	$(891)	$(806)	$(1,308)	$(979)	$(774)	$(1,502)	$(1,071)	$(740)	$(1,218)	$(836)	$(509)
Incremental Maint. Cost ($/lifetime)	-	-	-	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(1,806)	$(3,863)	$(3,863)	$(3,863)
Incremental Maint. Cost ($/yr)	-	-	-	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(386)	$(386)	$(386)
Total Cost															
Annual Incremental Capital Costs	-	-	-	$470	$235	$145	$1,249	$584	$278	$1,496	$642	$461	$1,946	$729	$343
Annual Incremental Fuel TOU Rate Cost	-	-	-	$(1,211)	$(1,013)	$(951)	$(1,481)	$(1,223)	$(1,064)	$(1,767)	$(1,445)	$(1,184)	$(1,473)	$(1,197)	$(936)
Annual Incremental Fuel Dom. Rate Cost	-	-	-	$(1,124)	$(891)	$(806)	$(1,308)	$(979)	$(774)	$(1,502)	$(1,071)	$(740)	$(1,218)	$(836)	$(509)
Annual Incremental Maintenance Cost	-	-	-	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(181)	$(386)	$(386)	$(386)
Total Annual Costs TOU Rate	-	-	-	$(921)	$(959)	$(987)	$(413)	$(820)	$(967)	$(451)	$(984)	$(904)	$86	$(854)	$(980)
Total Annual Costs Domestic Rate	-	-	-	$(834)	$(836)	$(842)	$(240)	$(575)	$(677)	$(186)	$(610)	$(460)	$342	$(494)	$(552)

Table 56. PEV Light Truck Annualized Societal and Monetized Societal Benefits

Light Trucks	PHEV10			PHEV20			PHEV40			BEV		
	2013	2020	2030	2013	2020	2030	2013	2020	2030	2013	2020	2030
Annual Societal Benefits per Vehicle												
Petroleum Displacement (GGE/yr)	350	285	239	459	384	314	574	490	393	494	427	339
GHG Emission Benefits (MT/yr)	3.51	2.88	2.42	4.25	3.64	2.96	5.04	4.44	3.53	4.18	3.77	2.94
NOX (tons/yr)	2.24E-04	1.37E-04	5.08E-05	4.18E-04	2.51E-04	8.07E-05	6.23E-04	3.72E-04	1.12E-04	5.93E-04	3.52E-04	1.03E-04
PM (tons/yr)	3.48E-05	1.62E-05	4.27E-07	6.85E-05	3.15E-05	2.04E-08	1.04E-04	4.77E-05	-4.10E-07	1.00E-04	4.57E-05	-5.99E-07
VOC (tons/yr)	4.23E-04	2.98E-04	1.86E-04	7.11E-04	4.93E-04	2.80E-04	1.02E-03	6.99E-04	3.79E-04	9.46E-04	6.49E-04	3.43E-04
Monetized Societal Benefits per Vehicle												
Petroleum Displacement	$154.58	$123.50	$100.50	$202.46	$166.68	$131.91	$253.21	$212.45	$165.21	$218.03	$185.18	$142.38
GHG Emission	$38.60	$34.54	$38.68	$46.76	$43.66	$47.29	$55.41	$53.32	$56.41	$45.97	$45.19	$47.03
NOx	$1.05	$0.70	$0.31	$1.95	$1.28	$0.49	$2.91	$1.89	$0.68	$2.77	$1.79	$0.63
PM	$50.53	$26.76	$0.84	$99.28	$51.98	$0.04	$150.96	$78.71	$(0.81)	$145.11	$75.50	$(1.19)
VOC	$0.47	$0.36	$0.26	$0.79	$0.60	$0.40	$1.14	$0.85	$0.54	$1.06	$0.79	$0.49

Forklifts. Table 57 below shows the main data sources and assumptions for the forklift cost analysis. All analyses and results in the following tables are per forklift. The 8,000 lb forklift is assumed to operate on gasoline and the 19,800 lb forklift to operate on diesel. Table 59 uses the values in Table 57 to develop the annualized cost and private benefits. Table 60 shows the annual societal benefits per forklift and the monetization of these benefits. The cost analysis and societal benefits are for a new forklift purchased in 2013 and are compared to a new ICE forklift 2013. See Appendix A for the details on the calculation of societal benefits for forklifts.

Table 57. Forklift Data Sources and Assumptions

Variable	Value	Source
Vehicle, Battery and Charger Costs	Values in Table 59	Direct quotes from dealers – Hawthorne and SCMH
Operating Life	Conventional Fuel Lift – 7 yrs / 21,000 hrs 8,000lb Electric – 8 yrs / 24,000 hrs 19,800ln Electric – 8 yrs / 24,000 hrs	Conventional: OFFROAD model; Electric: ratio of Electric/Conventional from Hyster[113]
Charger Life	14 yrs	Previous CalETC Study
Fraction of Regular and Fast Charge	Regular Charge: 72.5% Fast Charge: 27.5%	Previous CalETC Study
Annual Usage	3,150 hrs/yr (525 6-hr shifts/yr)	Previous CalETC Study
Battery Sizes	8,000 lb – 43.6 kWh 19,800 lb – 124 kWh	Survey of existing electric forklifts including Kalmar, Nissan, and CAT
Electricity Usage	80% battery depletion per 6-hr shift	ICF Assumption
Electricity Grid Cost	Regular Charge - \$0.18/kWh Fast Charge - \$0.32/kWh	Previous CalETC Report with update for current rate schedules: See Table 58
Discount Factor	5%	ICF Assumption
Gasoline and Diesel Prices	2013 Gasoline - \$3.89/gal (used as surrogate for propane) 2013 Diesel - \$3.91/gal	CEC IEPR 2013
Gasoline and Diesel Fuel Consumption	Gasoline – 0.70/gal Diesel – 1.10/gal	OFFROAD Model
Maintenance Costs	Electricity – 22 hrs/yr Conventional – 40 hrs/yr \$26/hr for Labor	Previous CalETC Study

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[113] "Timely Replacement of Lift Trucks," Hyster Company, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=9&cad=rja&ved=0CIIBEBYwCA&url=http%3A%2F%2Fwww.hyster.com%2FWorkArea%2FDownloadAsset.aspx%3Fid%3D8589935299&ei=qDbsUqW-BdO1kQecuoDQAg&usg=AFQjCNGiyt9PkuQeuuMU03LatU2bIQqAIA&sig2=7nT4Qh_ufsaK4VgPZqfk8A&bvm=bv.60444564,d.eW0

Table 58. Forklift Electricity Rate Assumptions

	SCE	PG&E	LADWP/Public	SDGE
Tariff Schedule	TOU-8	E-19 Mandatory	A-3	AL-TOU
Share of Electricity	35%	35%	20%	10%
Summer Share	33%	50%	33%	42%
Winter Share	67%	50%	67%	58%
Charging Power Demand	11kW: Regular 34.88kW: Fast	11kW: Regular 34.88kW: Fast	11kW: Regular 34.88kW: Fast	11kW: Regular 34.88kW: Fast
Percent Subject to Time Demand Charges	25%	25%	25%	25%
Percent Subject to Facility Demand Charges	100%	100%	100%	100%

Table 59. Forklift Annualized Cost Analysis

	Conventional 8,000 lb	Electric 8,000 lb	Conventional 19,800 lb	Electric 19,800 lb
() Denotes Cost Savings	Gasoline/LPG	Electric	Diesel	Electric
Forklift				
Forklift High Cost ($/truck)	$23,500	$38,000	$165,000	$170,000
Forklift Low Cost ($/truck)	$31,500	$34,000	$165,000	$170,000
Battery High Cost ($/battery)		$13,000		$14,280
Battery Low Cost ($/battery)		$9,850		$12,750
Forklift Operating Life	7	8.9	7	8.4
Battery Operating Life		8.9		8.4
Batteries per forklift		1.0		2
Total Capital - High	$23,500	$51,000	$165,000	$198,560
Total Capital - Low	$31,500	$43,850	$165,000	$195,500
Annual Costs -High	$4,061	$7,234	$28,515	$29,526
Annual Costs -Low	$5,444	$6,219	$28,515	$29,071
Charger				
Regular Charger Cost - High		$4,650		$5,000
Regular Charger Cost - Low		$3,500		$3,500
Fast Charger Cost - High		$15,000		$15,000
Fast Charger Cost - Low		$10,000		$10,000
Regular Charger (%)		72.5%		72.5%
Fast Charger (%)		27.5%		27.5%
Charger Life		14		14
Total Capital - High		$7,496		$11,375
Total Capital - Low		$3,913		$7,825
Annual Costs - High		$757		$1,149
Annual Costs - Low		$395		$791
Operating Costs				
Annual Usage (hr/year)	3,150	3,150	3,150	3,150
Total Electricity Usage (kWh/yr)		18,312		52,080
Regular Grid Cost ($/kWh)		$0.18		$0.12
Fast Grid Cost ($/kWh)		$0.32		$0.17
Electricity Cost ($)		$4,046		$7,082.67
Gasoline/Diesel Fuel Cost ($)	$9,193		$13,593	
Annual Maint. Cost ($)	$2,452	$1,546	$2,452	$1,546
Total Cost				
Annual Incremental Capital Costs - High		$4.587		$3,355
Annual Incremental Capital Costs - Low		$1,736		$2,523
Annual Incremental Operating Cost ($)		$(6,053)		$(7,416)
Total Annual Costs - High		$(1.466)		$(4,061)
Total Annual Costs - Low		$(4,317)		$(4893)

Table 60. Forklift Annualized Societal and Monetized Societal Benefits

	8,000 lb Electric	19,800 lb Electric
Annual Societal Benefits		
Petroleum Displacement (GGE/yr)	2,205	4,043
GHG Emission Benefits (MT/yr)	18.33	29.93
NOX (tons/yr)	0.016	0.021
PM (tons/yr)	3.18E-04	0.001
VOC (tons/yr)	0.009	0.004
Monetized Societal Benefits		
Petroleum Displacement	$972.83	$1,783.66
GHG Emission	$201.59	$329.22
NOx	$73.38	$97.18
PM	$461.55	$1,116.31
VOC	$10.27	$4.30

Truck Stop Electrification. Table 61 below shows the main data sources and assumptions for the TSE cost analysis. All analyses and results in the following tables are per truck stop (20 spaces).Table 63 uses the values in Table 61 to develop the annualized cost and private benefits. Table 64 shows the annual societal benefits per truck stop and the monetization of these benefits. See Appendix A for the details on the calculation of societal benefits for TSE.

Table 61. TSE Data Sources and Assumptions

Variable	Value	Source
Vehicle Side Cost	328 - 600	Carrier Transicold and DiamondPower APU
Operating Life	7 yrs	Previous CalETC Study
Spaces Per Truck Stop	20	Previous CalETC Study
Capacity Factor	0.6	Previous CalETC Study (SCE/ IdleAir)
Idle Hours to Plug-In per Day	8	ICF Assumption
Market Share	Plug-In APU – 75% IdleAir – 25%	Previous CalETC Study
Facility Infrastructure Costs ($/space)	Plug-in APU: $2,600 - $6,000 IdleAir - $5,000 - $10,000	Plug-in APU – Previous CalETC study (Shorepower); IdleAir – Ethan Garber of IdleAir
Facility Operating Life	20 yrs	Previous CalETC Study
Power Requirement	1.39 kW	Previous CalETC Study
Electricity Grid Cost	Plug-In APU - $0.16/kWh IdleAir - $0.15/kWh	Previous CalETC Report with update for current rate schedules: See Table 62
Discount Factor	5%	ICF Assumption
Diesel Prices	2013 Diesel - $3.91/gal	CEC IEPR 2013
Diesel Fuel Consumption	Diesel – 0.21/gal	Anti-Idling ISOR
Labor Costs	IdleAir - $105,000/yr	Previous CalETC Study (NYSERDA)

Table 62. TSE Electricity Rate Assumptions

	SCE	PG&E	LADWP/Public	SDGE
Tariff Schedule	GS-2	A-6	A-2 (B)	AL-TOU
Share of Electricity	35%	35%	20%	10%
Summer Share	50%	75%	50%	42%
Winter Share	50%	25%	50%	58%
Power Demand (kW)	Plug-In APU – 27.7 IdleAir – 83.2			
Percent Subject to Time Demand Charges	0%	0%	0%	0%
Percent Subject to Facility Demand Charges	100%	100%	100%	100%

Table 63. TSE Annualized Cost Analysis

	Plug-In APU/ Shorepower	IdleAir
Vehicle		
Incremental High Cost ($/truck)	$600	$-
Incremental Low Cost ($/truck)	$328	$-
Spaces per Truck Stop	20	60
Capacity Factor	0.6	0.6
Idle Hours to Plug-In (hr/day/truck)	8	8
Stop Based Trucks	36	108
TSE Technology Life (yrs)	7.0	7
Total Capital per Truck Stop - High	$21,600	$-
Total Capital per Truck Stop - Low	$11,808	$-
Annual Costs per Truck Stop - High	$1,244	$-
Annual Costs per Truck Stop -Low	$680	$-
Facility		
Infrastructure Cost - High ($/space)	$6,000	$10,000
Infrastructure Cost - Low ($/space)	$2,600	$5,000
Facility Project Life (yrs)	20	20
Total Capital - High	$120,000	$600,000
Total Capital - Low	$52,000	$300,000
Annual Costs - High	$9,629	$48,146
Annual Costs - Low	$4,173	$24,073
Operating Costs		
Annual Usage (hr/year/space)	5,256	5,256
Total Electricity Usage (kWh/yr/space)	7,290	7,290
Regular Grid Cost ($/kWh)	$0.16	$0.15
Electricity Cost ($/stop)	$23,762	$66,857
APU Diesel Fuel Consumption	0.21	0.21
Diesel Fuel Cost ($/gallon)	$3.91	$3.91
Diesel Cost Savings ($/stop/yr)	$85,492	$256,476
Annual Labor Cost ($)	$-	$105,000
Total Cost		
Annual Incremental Capital Costs - High	$10,873	$48,146
Annual Incremental Capital Costs - Low	$4,853	$24,073
Annual Incremental Operating Cost ($)	$(61,730)	$(84,619)
Total Annual Costs per Stop - High	$(50,856)	$(36,474)
Total Annual Costs per Stop- Low	$(56,877)	$(60,546)

Table 64. TSE Annualized Societal and Monetized Societal Benefits

	Plug-In APU/ Shorepower	IdleAir
Annual Societal Benefits (Per Truck Stop)		
Petroleum Displacement (GGE/yr)	25,427	76,282
GHG Emission Benefits (MT/yr)	233	700
NOX (tons/yr)	1.658	4.975
PM (tons/yr)	0.014	0.043
VOC (tons/yr)	0.084	0.251
Monetized Societal Benefits (Per Truck Stop)		
Petroleum Displacement	$11,218	$33,655
GHG Emission	$2,566	$7,698
NOx	$7,754	$23,262
PM	$20,917	$62,751
VOC	$94	$281

Transport Refrigeration Units. Table 65 below shows the main data sources and assumptions for the TRU cost analysis. All analyses and results in the following tables are per facility (19 spaces). All TRUs are assumed to operate on diesel if not plugged in. Table 67 uses the values in Table 65 to develop the annualized cost and private benefits. Table 68 shows the annual societal benefits per facility and the monetization of these benefits. The cost analysis and societal benefits are for new e-standby TRUs purchased in 2013 and are compared to new non e-standby TRUs purchased in 2013 that comply with LEV III. See Appendix A for the details on the calculation of societal benefits for TRUs.

Table 65. TRU Data Sources and Assumptions

Variable	Value	Source
Vehicle Side Cost	Semi - $3,700 - $5,000 Bobtail - $550 - $650	Dealers for Thermoking and Carrier Transicold
Operating Life	16 yrs	Previous CalETC Study
Spaces Per Facility	19	ARB 2005 ISOR
Capacity Factor	0.6	Previous CalETC Study
Annual Operating Hours in California	Semi In-State: 1,325 hrs/yr Semi Out of State: 210 hrs/yr Bobtail: 1,360 hrs/yr Bobtail <11hp: 1,360 hrs/yr	ARB 2011 TRU ISOR
Fraction of Time at the Facility for e-standby	30%	ARB2011 TRU ISOR and Conversations with CARB Staff
Facility Infrastructure Costs ($/space)	Semi - $4,300 Bobtail - $1,500	Previous CalETC Study (EPRI)
Facility Operating Life	20 yrs	Previous CalETC Study
Power Requirement	Semi - 8 kW Bobtail – 6 kW Bobtail <11hp – 2 kW	Previous CalETC Study
Electricity Grid Cost	Semi - $0.25/kWh Bobtail - $0.27/kWh Bobtail <11hp - $0.24/kWh	Previous CalETC Report with update for current rate schedules: See Table 66
Discount Factor	5%	ICF Assumption
Diesel Prices	2013 - $3.91/gal	CEC IEPR 2013
Diesel Fuel Consumption	Semi - 0.85 gal/hr Bobtail – 062 gal/hr Bobtail <11hp – 0.29 gal/hr	OFFROAD model and EPRI

Table 66. TRU Electricity Rate Assumptions

	SCE	PG&E	LADWP/Public	SDGE
Tariff Schedule	TOU G-3	E-19 Mandatory	A-3	AL-TOU
Share of Electricity	35%	35%	30%	0%
Summer Share	33%	50%	33%	42%
Winter Share	67%	50%	67%	58%
Power Demand (kW)	Semi – 152 kW Bobtail – 152 kW Bobtail <11 HP – 43.7 kW			
Percent Subject to Time Demand Charges	20%	20%	20%	20%
Percent Subject to Facility Demand Charges	20%	20%	20%	20%

Table 67. TRU Annualized Cost Analysis

	Semi In-State	Semi Out of State	Bobtail	Bobtail <11 HP
Horsepower Category	25-50	25-50	11-25	<11
Truck				
Incremental High Cost ($/truck)	$5,000	$5,000	$650	$650
Incremental Low Cost ($/truck)	$3,700	$3,700	$550	$550
Hook-ups per Facility	19.0	19	19	19
Capacity Factor	0.6	0.6	0.6	0.6
Annual Operating Hours in CA (hr/truck)	1,325	210	1,360	1,360
Fraction of Time at Facility to Plug-In	0.3	0.3	0.3	0.3
Facility Based Trucks	251	1585	245	245
TRU Technology Life (yrs)	16	16	16	16
Total Capital per Truck Stop - High	$1,256,151	$7,925,714	$159,097	$159,097.06
Total Capital per Truck Stop - Low	$929,552	$5,865,029	$134,621	$134,621
Annual Costs per Truck Stop - High	$115,905	$731,305	$14,680	$14,680
Annual Costs per Truck Stop -Low	$85,770	$541,166	$12,421	$12,421
Facility				
Infrastructure Cost - ($/hook-up)	$4,300	$4,300	$1,500	$1,500
Facility Project Life (yrs)	20	20	20	20
Total Capital	$81,700	$81,700	$28,500	$28,500
Annual Costs	$7,538	$7,538	$2,630	$2,630
Operating Costs				
Baseline Fuel Consumption (gal/hr)	0.85	0.85	0.62	0.29
Annual Usage (hr/year/hook-up)	5,256	5,256	5,256	5,256
Electricity Load (kW)	8	8	6	2
Total Electricity Usage (kWh/yr/hook-up)	42,048	42,048	31,536	11,826
Regular Grid Cost ($/kWh)	$0.25	$0.25	$0.27	$0.24
Electricity Cost ($/facility)	$196,427	$196,427	$164,240	$52,957
Diesel Cost Savings ($/facility/yr)	$331,898	$331,898	$242,090	$112,142
Total Cost				
Annual Incremental Capital Costs - High	$123,443	$738,843	$17,310	$17,310
Annual Incremental Capital Costs - Low	$93,308	$548,704	$15,051	$15,051
Annual Incremental Operating Cost ($)	$(135,471)	$(135,471)	$(77,851)	$(59,185)
Total Annual Costs - High	$(12,028)	$603,372	$(60,541)	$(41,876)
Total Annual Costs - Low	$(42,163)	$413,233	$(62,799)	$(44,134)

Table 68. TRU Annualized Societal and Monetized Societal Benefits

	Semi In-State	Semi Out of State	Bobtail	Bobtail <11 HP
Annual Societal Benefits (Per Facility)				
Petroleum Displacement (GGE/yr)	98,715	98,715	72,004	33,354
GHG Emission Benefits (MT/yr)	818	818	590	293
NOX (tons/yr)	7.402	7.402	8.375	3.211
PM (tons/yr)	0.022	0.022	0.052	0.020
VOC (tons/yr)	0.221	0.221	0.175	0.089
Monetized Societal Benefits (Per Facility)				
Petroleum Displacement	$43,552	$43,552	$31,767	$14,715
GHG Emission	$8,996	$8,996	$6,494	$3,227
NOx	$34,609	$34,609	$39,157	$15,014
PM	$31,979	$31,979	$75,490	$29,041
VOC	$247	$247	$195	$100