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Filer:	Tami Haas
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California Transportation Electrification Assessment

Phase 3-Part A: Commercial and Non-Road Grid Impacts – Final Report

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Prepared by

ICF International
620 Folsom St, Suite 200
San Francisco, CA 94107
415.677.7100

Energy+Environmental Economics
101 Montgomery Street, Suite 1600
San Francisco, CA 94104
415.391.5100

Disclaimer. This Transportation Electrification Assessment 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
C&I	Commercial and Industrial
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
E-TRU	Electric Transport Refrigeration Unit
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
GVW	Gross Vehicle Weight
GWh	Gigawatt-hour
HD	Heavy-Duty
HHD	Heavy-Heavy Duty
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

LHD	Light-Heavy Duty
MD	Medium-Duty
MDU	Multi-Dwelling Unit
MHD	Medium-Heavy Duty
MT	Metric Ton
NMOG	Non-Methane Organic Gases
NOx	Oxides of Nitrogen
O&M	Operational and Maintenance
PEV	Plug-In Electric Vehicles
PG&E	Pacific Gas and Electric
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
RIM	Ratepayer Impact Measure
ROG	Reactive Organic Compounds
RTG	Rubber Tire Gantry
SCE	Southern California Edison
SCT	Societal Cost Test
SDG&E	San Diego Gas and Electric
SMUD	Sacramento Municipal Utility District
SPM	Standard Practice Manual
TE	Transportation Electrification
TEA	Transportation Electrification Assessment
TOU	Time of Use
TRC	Total Resource Cost Test
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
ZEMT	Zero Emission Miles Traveled
ZEV	Zero Emission Vehicle

Executive Summary

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. California has set a bold target of reducing GHG emissions to 80% below 1990 levels by 2050.[1] Achieving the 2050 goal will require significant innovation and a fundamental transformation of the transportation and goods movement system that accounts for about 50 percent of total emissions in the state including emissions due to the fuels to serve transportation.[2] EPA ambient air quality compliance deadlines in 2023 and 2032 will require even more acceleration of ZEV adoption. Studies indicate that achieving California's 2050 greenhouse gas (GHG) reduction goals and 2032 air-quality standards require replacing 70 to 90% of internal combustion engine vehicles with zero emission vehicles including the medium- and heavy-duty trucks.[3] The Governor's Draft 2015 ZEV Action Plan[4] includes expansion to freight, rail, and other medium- and heavy-duty technologies in the commercial and non-road sectors to put California on the path to meeting these goals and standards

Despite the environmental benefits of transportation electrification, the technologies in the commercial and non-road sectors 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 cases such as electric trucks and buses, high costs are due to low production volumes of an emerging technology. 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) or lack of awareness.

Transportation Electrification Assessment

Phase 1 Report: Environmental and Societal Benefits

The Phase 1 Transportation Electrification Assessment (TEA) Report[5] updated previous CalETC estimates of the market sizing, forecasts and societal benefits for 20 different TE technology segments out to

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[1] Governor Executive Order S-3-05, June 6, 2005. http://gov.ca.gov/news.php?id=1861

[2] http://www.arb.ca.gov/board/books/2015/102215/15-8-6pres.pdf

[3] Based on transportation reducing its fair share to achieve 75-80% NOX emission reductions and 80% GHG emission reductions: SCAQMD Technology Advancement Office Clean Fuels Program 2013 Annual Report and 2014 Plan Update, March 2014. available online at: http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2014/2014-mar7-029.pdf; http://www.arb.ca.gov/board/books/2015/102215/15-8-6pres.pdf

[4] https://www.gov.ca.gov/docs/DRAFT_2015_ZEV_Action_Plan_042415.pdf

[5] TEA Phase 1 Report. available at http://www.caletc.com/wp-content/uploads/2014/08/CalETC_TEA_Phase_1-FINAL.pdf

2030. In addition, the report focused on performing life-cycle costing analyses of four TE segments: plug-in electric vehicles (PEVs), forklifts, truck stop electrification (TSE), and electric standby transport refrigeration units (e-TRUs) and identified the market gaps, barriers and potential solutions for light-duty PEV adoption to achieve the maximum grid and societal benefits. The societal benefits considered in the Phase 1 report included greenhouse gas (GHG) emission reductions, criteria pollutant (specifically NOx, PM and VOCs) emission reductions and petroleum displacement.

Phase 2 Report: PEV Grid Impacts

The TEA Phase 2 Report[6] provided an in-depth analysis of electric utility costs that will be incurred to support PEV charging, with an emphasis on utility distribution systems. The inputs and results from the Phase 1 report were used to describe the impacts of PEV charging under a variety of scenarios. The analysis was performed collectively for Pacific Gas and Electric (PG&E), Southern California Edison (SCE), San Diego Gas and Electric (SDG&E) and Sacramento Municipal Utility District (SMUD), all of which provided detailed distribution system data for the study.

The TEA Phase 2 Report used California Air Resources Board (CARB) and California Public Utility Commission (CPUC) adopted methods to show that PEVs are cost-effective, providing benefits for electric utilities, their customers and the state as whole. The CPUC has developed a framework to determine when the utility and societal costs of energy production “avoided” by load reductions from energy efficiency, demand response and distributed generation (collectively distributed energy resources or DER) are greater than the costs of programs promoting them. The Phase 2 Report used the CPUC avoided cost framework to show that the benefits of PEVs are greater than the incremental PEV costs and the additional infrastructure needed to support them.

The Phase 2 Report first determined whether California as a state is economically better off with PEVs. The analysis compared the monetized costs and benefits that represent actual cash transfers into or out of the state to determine whether California achieves net economic benefits with additional PEV adoption (The CPUC Total Resources Cost Test or TRC). The benefits included the federal tax credit for PEVs, gasoline savings and reduced cap-and-trade GHG allowance costs. The evaluation was expanded to include environmental and societal benefits that are not monetized in actual cash transactions, but still provide direct and quantifiable benefits to California. This Societal Cost Test (SCT) included benefits for health and reduced reliance on petroleum from the Phase 1 report – benefits that are included in the CARB cost-effectiveness method and described as benefits in the interest of utility ratepayers in PUC 740.3 and 740.8. In addition, the cap-and-trade GHG allowance costs were replaced with a higher estimate of the societal value of reducing GHG emissions.

Phase 3 Report: Commercial and Non-Road Grid Impacts

Phase 3 builds on the analysis of the previous phases and includes the detailed modeling and quantification of the grid benefits from the following off road and commercial market segments: forklifts, truck stop electrification (TSE), electric transport refrigeration units (e-TRU), transit buses and

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[6] TEA Phase 2 Report available at http://www.caletc.com/wp-content/uploads/2014/10/CalETC_TEA_Phase_2_Final_10-23-14.pdf

medium- and heavy-duty trucks (MD/HD). The analysis is for the California markets and may vary by region depending on market variables such as vehicle mix. Similar to the Phase 2 report, results are presented here using the CPUC Standard Practice Manual (SPM) cost-tests with E3's DER Avoided Cost Framework utilizing the TRC and SCT. ICF and E3 found that additional research and modeling is required to understand the newly developing medium heavy-duty (MHD) and heavy heavy-duty (HHD) electric truck markets. This Part A of Phase 3 report only includes medium-duty (MD) and light-heavy-duty (LHD) trucks and buses while Part B will include all MD/HD truck segments (MD, LHD, MHD, HHD) and buses. (See section 2.1.3 for descriptions of these truck segments)

Phase 3 Results

Figure ES-1 below shows the combined results from the TRC and SCT for all of the technologies analyzed. The TRC looks at monetized resource expenditures and savings for the region as a whole, and the SCT includes additional environmental and societal benefits that are not directly monetized. The largest cost components of the TRC and SCT are the incremental vehicle costs and the energy costs; the majority of the benefit comes from fossil fuel savings[7]. Costs on the utility side are based on the obligation to serve and do not include program costs and beyond the meter investments .The increase in net benefits for the SCT compared to the TRC are primarily due to the addition of energy security benefits. All market segments analyzed in this report showed significant per vehicle or facility benefits. Section 4 includes TRC and SCT results for each of the individual technologies: MD/LHD, buses, forklifts, TSE and e-TRU.

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[7] The Phase 2 report explains that improvements are needed to the TRC and SCT tests, and that in the past these tests have not been applied to transportation electrification programs by utilities

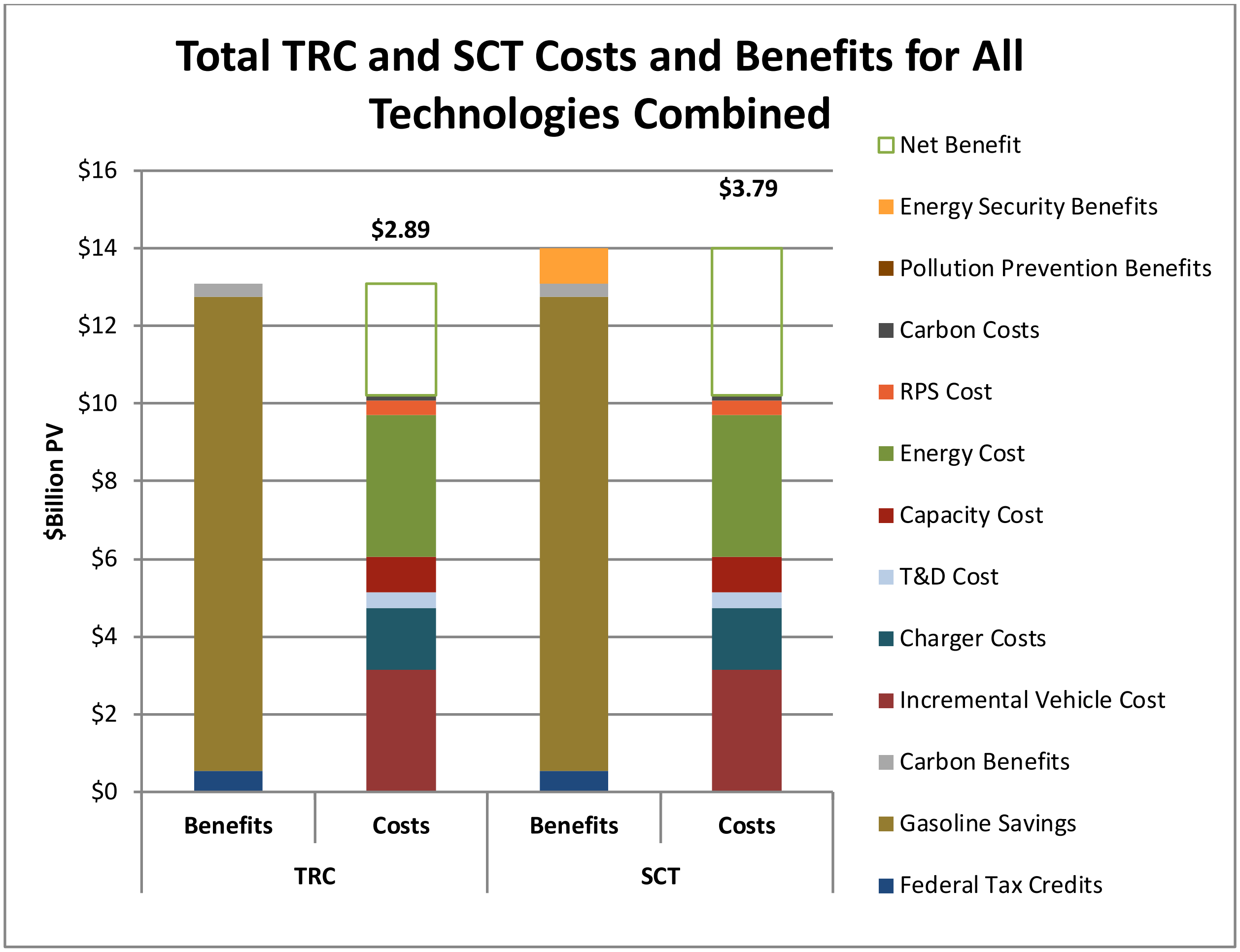

Figure ES-1. Total TRC and SCT Costs and Benefits for All Technologies Combined to 2030

The Ratepayer Impact Measure Cost test (RIM), which was performed in Phase 2 for PEVs, was not performed during Phase 3. These sectors encompass a diverse group of technologies with more complicated rate structures compared to PEVs. The households adopting LDVs in Phase 2 were on residential rates, which are relatively similar to one another within and across utilities and do not include demand charges. Contrastingly, the Phase 3 technologies will be adopted by ratepayers at commercial and industrial (C&I) establishments. C&I electric rates vary widely based on the size of the company's demand, the voltage it takes, and other factors. Furthermore, demand charge impacts of commercial and off-road sector charging can vary significantly from customer to customer based on their individual situations and whether PEV charging is separately or co-metered.

Market Gaps and Barriers and Potential Solutions

Commercial and non-road sector technologies such as electric forklifts, TSEs and e-TRU have achieved relative cost maturity and are cost effective to the consumer as shown in the Phase 1 report. Even though there are lifecycle cost benefits to these technologies, there are still obstacles to deployment including incremental cost and technology availability. MD/HD on-road technologies on the other hand are still extremely expensive compared to the conventional alternative and have limited lifecycle cost-benefits, especially at the current low diesel prices and there are currently very few companies and vehicle models to choose from. ICF and E3 identified the following major obstacles and barriers for off-road, commercial and transit sector market penetration: consumer costs, market outreach and education, cost of providing appropriate charging infrastructure, customer bill impacts including demand charges and rate structures, and vehicle options. Table ES-1 summarizes the major obstacles to deployment and potential utility solutions.

Table ES-1. Market Gaps and Barriers and Potential Utility Solutions

Market Gaps and Barriers		Potential Solutions
Consumer Costs	• Upfront vehicle/technology costs • Upfront charging infrastructure (EVSE) and installation costs • Vehicle operating costs; need for competitive charging rates for technologies	• Increased publicity and continued availability of existing incentives • Creative use of utility LCFS credits or utility developed programs to reduce total cost of ownership • Improved charging rate structures to increase the reduced fuel cost benefits for drivers
Market Outreach and Education	• General lack of TE and ZE truck awareness and knowledge • Total cost of vehicle ownership is poorly understood • Little to no efforts to improve TE education	• Utilities should act as a trusted advisor with the creation of a TE program manager role to educate consumers about unique issues to and opportunities for TE technologies • Utilities should engage with other TE ecosystem partners to improve education efforts
Cost of Providing Appropriate Charging Infrastructure	• Owners must take responsibility for ensuring enough chargers • Current charger costs, including installation and make-ready are cost prohibitive • Each situation is unique based on vehicle type (PHEV, short range BEV, long range BEV), charging and service upgrade requirements	• Utilization of the TE program manager from the utility to assist in load management coaching • Utilities make investments in charging infrastructure for TE similar to PUC proposals for light-duty PEVs
Customer Bill Impacts	• Daily load profile and utility rate schedule could end up negating or severely reducing fuel savings • Commercial TE applications have specific requirements and duty cycles that are not flexible upon rates or demand • Demand charges pose costs that are potentially large and uncertain	• Utilities should assist customers to lower their electricity bills appropriately
Vehicle Options	• Limited vehicle offerings in marketplace	• Utilities support larger scale deployments of a wide range of technologies to allow for concrete examples of cost savings and economic benefits

ICF and E3 also discussed potential utility opportunities for solutions to address these obstacles including education and outreach, incentives for the vehicles themselves, tariff redesign, and load management coaching. Similar to the results from Phase 2 for PEVs, utility involvement is necessary to increase the adoption of commercial and off-road sector technologies past the point of minimal regulatory compliance.

Conclusions and Recommendations

In this TEA Phase 3 Report, ICF and E3 quantified the costs and benefits of off-road and commercial TE for utilities and the state of California. We used cost-effectiveness methods from the CARB and the CPUC to show that off-road and commercial TE provide net economic and societal benefits for California as a whole.

Our conclusions from the analysis performed for this study are:

- The present value net TRC and SCT benefits in $2014 are $2.9 billion and $3.8 billion respectively. These net benefits for the off-road and commercial sectors are somewhat smaller but similar in scale to the net benefits estimated for the LDV sector in the TEA Phase 2 Report.
- Our results show the potential for the off-road and commercial sector to provide a similar level of benefits from electrification as the LDV sector. However, the off-road and commercial sector includes a much wider range of vehicle technologies, end-uses and customers. More detailed analysis for specific sectors is needed to evaluate the range of possible TRC, SCT and ratepayer costs and benefits.
- LHD trucks, forklifts and buses all show positive per vehicle TRC and SCT benefits. TSEs and TRUs both have very high per-unit benefits relative to their cost, but also require truck drivers/owners to adopt new equipment.
- The market for PEVs in the light heavy-duty (LHD) sector is larger and more established than in the medium and heavy heavy-duty sectors (MHD and HHD). Due to limited experience and model availability, we defer a cost-benefit analysis for MHD and HHD to the forthcoming Phase 3 Part B study that can include more scenario and sensitivity analysis than was possible here.
- Demand charges and TOU rates could limit the potential cost savings for many customers in the MHD and HHD sectors that must operate during peak load hours with limited flexibility to shift driving patterns. Utilities will need to explore rate design strategies that fairly allocate costs while also promoting PEV adoption for commercial and industrial customers. Customers will need tools, education and sometimes experienced professional technical assistance to manage charging in a manner that accommodates unique business operations without negating potential fuel cost savings.
- Utilities could act as a trusted advisor with the creation of a TE program manager role to educate consumers about unique issues to TE technologies and assist in load management coaching to limit demand changes and maximize fuel cost savings.
- In the near-term, accelerated investment in enabling technology and infrastructure is needed to support PEV adoption and market transformation. Such investment may not pass current cost-effectiveness tests, but will still provide net utility customer and societal benefits in the long term.
- Utilities could partner with vehicle manufacturers to educate ratepayers about the types of electric vehicles available and how they could impact adopters’ electricity bills. Outreach efforts could also clarify some of the costs identified in Table ES-1 and described in more detail in Section 5.

- Utility support for “larger scale deployments over single truck demonstrations would allow for concrete examples of cost savings and economic benefits when actually switching to electrified technologies.”

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 medium- and heavy-duty (MD/HD) trucks.

The California Transportation Electrification Assessment (TEA) consists of three Phases. Phase 1 included 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. The main takeaways from the Phase 1 report were: (1) TE has the potential to provide significant benefits to society and utility customers; (2) 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[8]; and (3) 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.

Phase 2 was the detailed modeling and quantification of the grid benefits from light-duty PEVs. Phase 2 focused on the economic and cost effectiveness tests from a utility and overall ratepayer perspective including estimating downward pressure on average system rates due to increases in net revenue for the utilities from PEVs. Phase 2 showed that PEVs pass both the CPUC TRC and RIM. In addition the SCT, which takes the results of the TRC plus benefits for health and reduced reliance on petroleum, shows increased benefits due to the environmental benefits from electrification, compared to the TRC.

Phase 3 builds on the analysis of Phase 2 and includes the detailed modeling and quantification of the grid benefits from the following off road and commercial market segments: forklifts, truck stop electrification, electric transport refrigeration units, and medium- and heavy-duty trucks. Market segment mixes and costs can vary by region. Similar to the Phase 2 report, results are presented here using CPUC SPM cost-tests with E3's Distributed Energy Resources (DER) Avoided Cost Framework. The DER Avoided Cost Framework was developed to calculate the utility and societal costs "avoided" by load

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[8] 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

reductions from energy efficiency and demand response, but is equally applicable to load increases from energy storage or PEVs. The CPUC cost-effectiveness framework compares the incremental costs of distributed resources against the costs the utility would otherwise incur to deliver energy to the customer. Each of five SPM cost-tests represents different perspectives of individual stakeholder groups within California and for the region as a whole. The analysis was performed collectively for PG&E, SCE, SDG&E and SMUD, all of which provided detailed distribution system data for the study.

Section 2 details the adoption rates, load profiles, energy consumption, and costs for each of the TE technologies. The adoption rates and energy consumption are from Phase 1. The load profiles for all technologies and costs for medium- and heavy-duty trucks were developed during Phase 3. Compared to light-duty PEVs, there is less data and information about load profiles, usage patterns, and spatial distribution for these technologies resulting in more assumptions required to fill the gaps in available data.

The Phase 3 report is divided into the following sections:

- Section 1 – Introduction
- Section 2 – Technology Descriptions, Adoption Rates, and Load Profiles
- Section 3 – Grid Impact Analysis
- Section 4 – Cost Effectiveness Analysis
- Section 5 – Market Gaps, Barriers, and Potential Solutions

2 Technology Descriptions, Adoption Rates and Load Profiles

Phase 1 includes scenarios for adoption and energy consumption for forklifts, TSE, TRUs, and MD/HD trucks and costing for forklifts, TSE and TRUs. The section below summarizes the necessary information from Phase 1 in addition to MD/HD costing and load profiles for all technologies.

Technology Descriptions

2.1.1 Forklifts

The analysis for forklifts has been divided into two categories by weight: 8,000 lb forklifts that displace gasoline and propane lifts <120 horsepower (hp) and 19,800 lb[9] larger forklifts that displace larger 120-175 hp diesel lifts. This is due to differences in incremental capital costs and fuel consumption between the two classes of vehicles. There are little to no electric forklift technologies that can displace conventional forklifts >175 hp.

Table 2-1. Forklift Costs and Operating Life[10]

Type of Electric Forklift	Incremental Cost	Operating Life (yrs)	Charger Cost	Operating Life (yrs)
<120hp	$12,350 - $27,500	8.9	Slow (11kW): $3,500-$4,650 Fast (35kW): $10,000-$15,000	14
120-175hp	$30,500 - $33,500	8.4	Slow (11kW): $3,500-$4,650 Fast (35kW): $10,000-$15,000	14

Previous CalETC assumptions of 3,150 hours of operation (525 6-hr shifts) per year were used which are based on a 50/25/25 breakdown of single, double and triple shift forklift operation respectively. ICF spoke with forklift operators to understand their usual operations and how single and multi-shift forklifts charge between conventional charge, rapid charge and conventional charge with battery swap. Table 2-2 includes the assumed breakdown by shift and type of charging based on conversations ICF and E3 had with forklift operators.

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[9] http://www.kalmarusa.com/equipment/forklift-trucks/electric-forklift-trucks-5-9-ton/ecg50-90/ Kalmar electric forklift ECG50-90 up to 20,000lbs

[10] Additional details can be found in the Phase 1 Report.

Table 2-2. Forkshift Charging and Work Shifts

Type of Forklift Charging	Work Shifts			Total
	1	2	3	
Conventional Charge	14.5%	N/A	N/A	14.5%
Rapid Charge		10.0%	17.5%	27.5%
Conventional Charge with Battery Swap	35.5%	15.0%	7.5%	58.0%
Total	50.0%	25.0%	25.0%	100%

2.1.2 Truck Technologies (TSE and TRUs)

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. 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 11-25 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. Bobtail <11 hp incremental costs are not included because this market segment is mainly made up of ocean-going reefer technology that is already electrified.

Table 2-3. TSE and TRUs Costs and Operating Life[11]

Truck Technology	Vehicle Side Cost	Operating Life (yrs)	Facility Cost ($/space)	Operating Life (yrs)	Host Site Configuration
TSE	$328-$600	8.9	Plug-In APU (75%): $2,600 - $6,000 IdleAir (25%): $5,000 - $10,000	20	20 spaces per truck stop

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[11] Additional details can be found in Phase 1.

e-TRU	25-50hp - $3,700-$5,000 11-25hp - $550 - $650	16	25-50hp - $4,300 11-25hp - $1,500	20	19 spaces per facility

2.1.3 MD and HD Trucks

The MD/HD truck penetrations and energy consumption from Phase 1 are divided into four categories[12] designed by their gross vehicle weight rating (GVWR):

- Medium-duty and light heavy-duty (MD/LHD) – Classes 2 and 3 (8,500 – 14,000 lbs)
- Medium-heavy duty (MHD) – Classes 4-7 (14,001 – 33,000 lbs)
- Heavy-heavy duty (HHD) – Classes 8a/8b (>33,000 lbs)
- Buses

A costing analysis was performed to determine the estimated incremental cost of a representative plug-in hybrid and full battery electric (PHEV and BEV) version of each of the four categories. The battery sizing was based on EMFAC data and incremental costing is based on data and forecasts contained in a CE DELFT report[13]. For incremental costing, the battery pack and glider costs were separately forecasted to take into account duplicate engines and transmissions in PHEVs and varying trajectories of cost reductions. Table 2-4 reviews the incremental costing for select years between 2015 and 2030. A specific incremental cost estimate was developed for each year. Federal tax credits are available for vehicles up to 14,000 lbs GVW which includes the MD/LHD vehicles.

Table 2-4. MD/HD Truck Incremental Costing

Vehicle	Battery Size (kWh)	Operating Life	2015	2020	2025	2030
MDV/LHD PHEV	19	10	$14,122	$10,673	$8,338	$7,158
MDV/LHD BEV	46	10	$22,012	$13,899	$8,364	$5,625
MHD PHEV	36	8	$27,245	$20,638	$16,177	$13,905
MHD BEV	125	8	$60,524	$39,502	$24,975	$18,044
HHD PHEV	61	8	$39,533	$29,681	$22,795	$19,616
HHD BEV	304	8	$134,851	$86,232	$52,153	$36,550
Bus PHEV	162	12	$90,033	$65,505	$48,035	$40,411
Bus BEV	324	12	$144,851	$93,325	$57,151	$40,668

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[12] http://www.afdc.energy.gov/data/tab/all/data_set/10380 for vehicle class listings

[13] http://www.cedelft.eu/publicatie/zero_emission_trucks/1399

Based on charging costing from the Phase 2 and conversations with fast/rapid charger developers, incremental cost projections were developed based upon what is actually being seen now and a cost reduction curve similar to that used in Phase 2. Table 2-5 shows the incremental charger costs for vehicle category and speed. The total incremental charger costs include the additional customer installation costs.

Table 2-5. MD/HD Truck Charger Incremental Costing[14]

Charger (kW)	Vehicles/ Charger	Operating Life	Additional Customer Installation Costs	2015	2020	2025	2030
MDV/LHDV Slow (6.6)	1	20	-	$5,250	$3,829	$3,442	$3,222
MHD Slow (19)	1	20	-	$25,000	$18,235	$16,389	$15,343
HHD Slow (40)	1	20	$10,000	$35,000	$25,530	$22,945	$21,480
Bus Slow (80)	1	20	$50,000	$50,000	$36,471	$32,779	$30,686
Fast Charger (240)	5	20	$300,000	$1,500,000	$1,094,124	$983,360	$920,572

With slow and fast chargers available for all technologies and vehicle types, it is necessary to determine which vehicle types will utilize each charging technology. Table 2-6 shows the breakdown estimated for Phase 3 based on conversations with technology developers and daily VMT data in the EMFAC model for each vehicle category.

Table 2-6. Breakdown of Charging Speed by Vehicle Type and Technology

Vehicle	Slow Charger (kW)	Fast Charger (kW)	% Slow Charge	% Fast Charge	% kWh of Vehicle Class
MDV/LHD PHEV	6.6	240	100%	0%	85.5%
MDV/LHD BEV	6.6	240	100%	0%	14.5%
MHD PHEV	19	240	100%	0%	81%
MHD BEV	19	240	80%	20%	19%
HHD PHEV	40	240	80%	20%	12%
HHD BEV	40	240	13%	87%	88%
Bus PHEV	80	240	80%	20%	5%
Bus BEV	80	240	25%	75%	95%

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[14] Table 2-5 does not show all the possible charging level options for the many types of PHEVs and BEVs

2.1.4 Charger Installation Costs

In addition to the charging equipment costs described above, we also included estimates of installation costs for Level 2 and DC fast chargers at commercial sites. Cost estimates are developed from EV Project data in San Diego.[15] Cost estimates are provided for installing five commercial L2 chargers and two DC fast chargers at each site respectively. The report includes estimates for trenching, conduit, engineering & design, breakers, fuses, panels, signs and permitting. The installation cost (not including the chargers themselves) for five commercial L2 chargers is $19,075 and for two DC fast chargers is $11,095 These estimates are used as representative installation costs for commercial and workplace sites that are added to the costs of the chargers themselves. Utility experience has shown that actual costs vary substantially from site to site and can be much higher.

2.2 Adoption Scenarios

Contained within the Phase 1 report are detailed explanations of the assumptions made in forecasting the adoption rates of each technology for three different scenarios: “In Line with Current Adoption”, “Aggressive Adoption,” and “In Between.” Figure 2-1 and Figure 2-2 show the adoption rates of each technology for the “In Between” for select years. Specific populations were not determined for the in-between years for forklifts, TSE and TRUs and populations were interpolated. While only values are shown for specific years between 2015 and 2030 for MD/HD trucks, actual values were developed for each individual year. Note that in Figure 2-2, the MDV/LHD adoption rate is decreased by an order of magnitude to allow for all values to fit in one figure.

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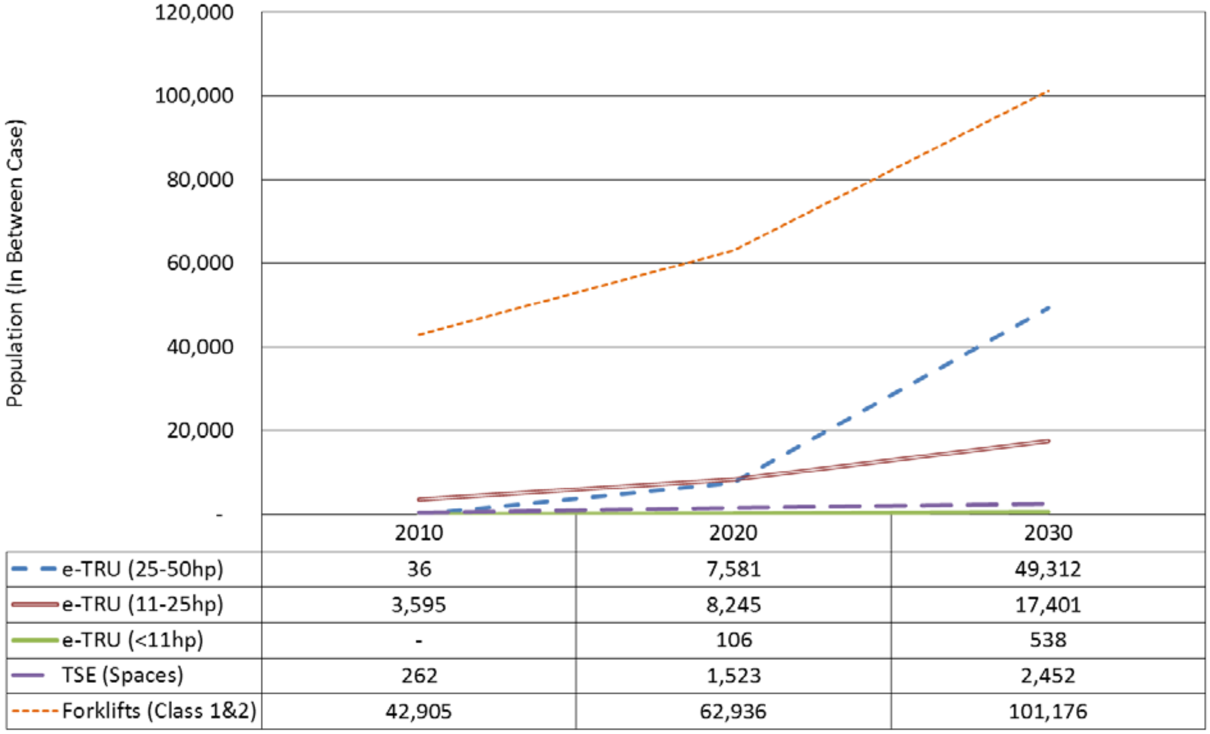
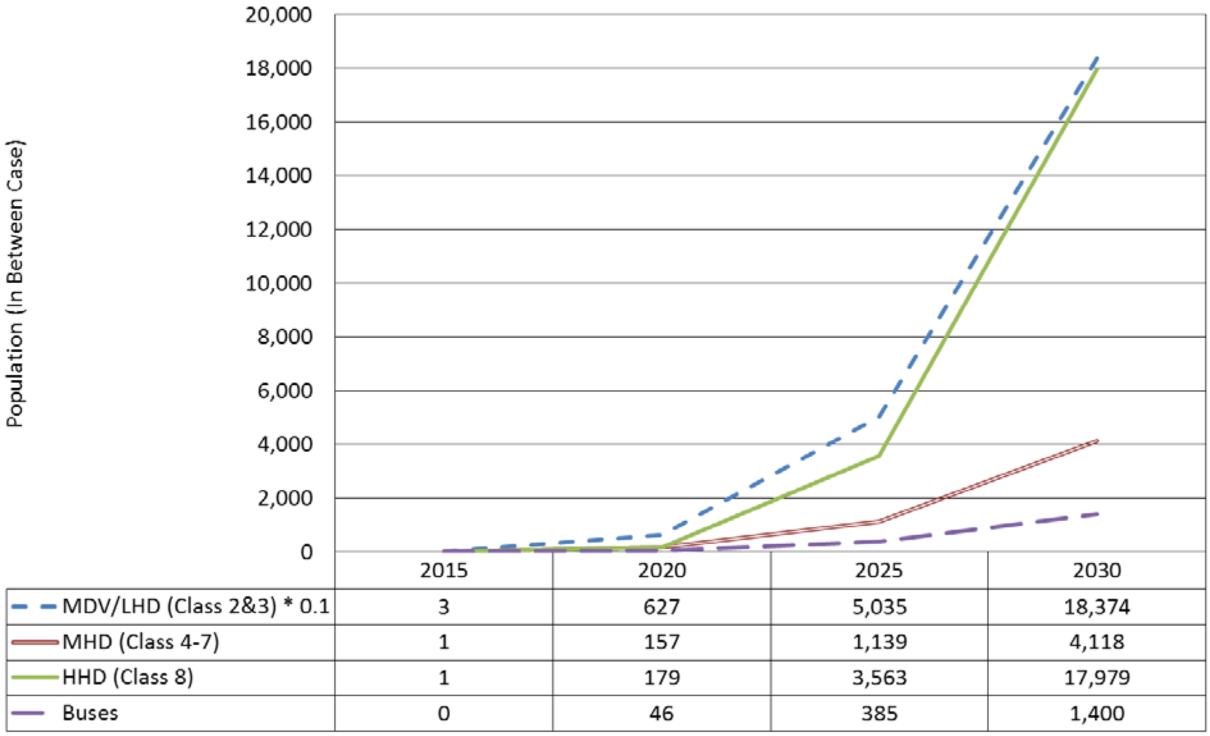
[15] Deployment Guidelines for the Greater San Diego Area”. May 2010. Available at: http://avt.inl.gov/pdf/EVProj/EVChrgInfraDeployGuidelinesSanDiegoVer3.2.pdf



	2010	2020	2030
e-TRU (25-50hp)	36	7,581	49,312
e-TRU (11-25hp)	3,595	8,245	17,401
e-TRU (<11hp)	-	106	538
TSE (Spaces)	262	1,523	2,452
Forklifts (Class 1&2)	42,905	62,936	101,176

Figure 2-1. Adoption Rates for Forklifts, TSE and e-TRUs



	2015	2020	2025	2030
MDV/LHD (Class 2&3) * 0.1	3	627	5,035	18,374
MHD (Class 4-7)	1	157	1,139	4,118
HHD (Class 8)	1	179	3,563	17,979
Buses	0	46	385	1,400

Figure 2-2. Adoption Rates for MD/HD Trucks

2.3 Energy Consumption

Annual energy consumption for each technology was determined during the Phase 1 report when technology adoption and total electricity consumption potential was forecasted. Table 2-7and Table 2-8 detail the individual energy consumption by technology, vehicle class and vehicle type. For MD/HD, representative vehicles were developed for each vehicle class based on weighted average of total vehicles in that class.

Table 2-7. Forklift, TSE and e-TRU Electricity Consumption

Technology	Annual kWh
Forklifts - <120 hp	18,312
Forklifts – 120-175 hp	52,080
TSE (per space)	7,305
e-TRU – 25-50 hp	10,600
e-TRU – 11-25 hp	8,160
e-TRU - <11 hp	2,720

Table 2-8. MD/HD Electricity Consumption by Vehicle Class and Type.

Vehicle Class	PHEV Annual kWh	BEV Annual kWh
MDV/LHD	6,080	14,720
MHD	11,520	40,000
HHD	19,520	107,840 - 160,000
Buses	51,840	103,680

2.4 Load Profiles

The following section discusses how the normalized load profiles were developed for each of the technologies and charging types.

2.4.1 Forklifts

Four separate load profiles were developed for each of the charging types: rapid charge – 2 shifts, rapid charge – 3 shifts, conventional charge – 1 shift, and conventional charge plus battery swap. Rapid charging is utilized at forklift locations where each lift is operated for 2-3 shifts per day. The quantity of daily shifts that the lift is in operation will determine when a greater portion of the load occurs. For the forklift load profiles, charging occurs when the forklift is plugged in with no consideration made of the time at which the charging is occurring. For two shift operations, the assumption was made that two six hour shifts occur between the 16 hour window of 6am to 10pm and that at the end of the second shift the battery is depleted. Overnight, each battery is plugged in and charges at the full speed of the charger. During the day, charging occurs on an as needed basis at breaks to make up the second daily battery charge. Since the exact time during the day that charging occurs varies, the same normalized load profile was given all day. Since not all operations start at 6am and end at 10pm, the load profiles include a sensitivity of plus or minus one hour from the starting and ending times.

It is assumed forklifts operating on one shift conventional charging operate during a shift from 8am to 5pm and that no charging occurs during the shift. Charging begins when the forklift is plugged in after the shifts ends and continues until the battery is fully charged. The load profile includes a sensitivity of plus or minus one hour from the starting and ending times. For three shift rapid charging and conventional charging with battery swap, the same constant load profile is given. For three shift rapid charge, the exact time for charging can vary and for conventional charging with battery swap, charging is occurring at the same rate all day long. Figure 2-3 shows the normalized forklift load profiles.

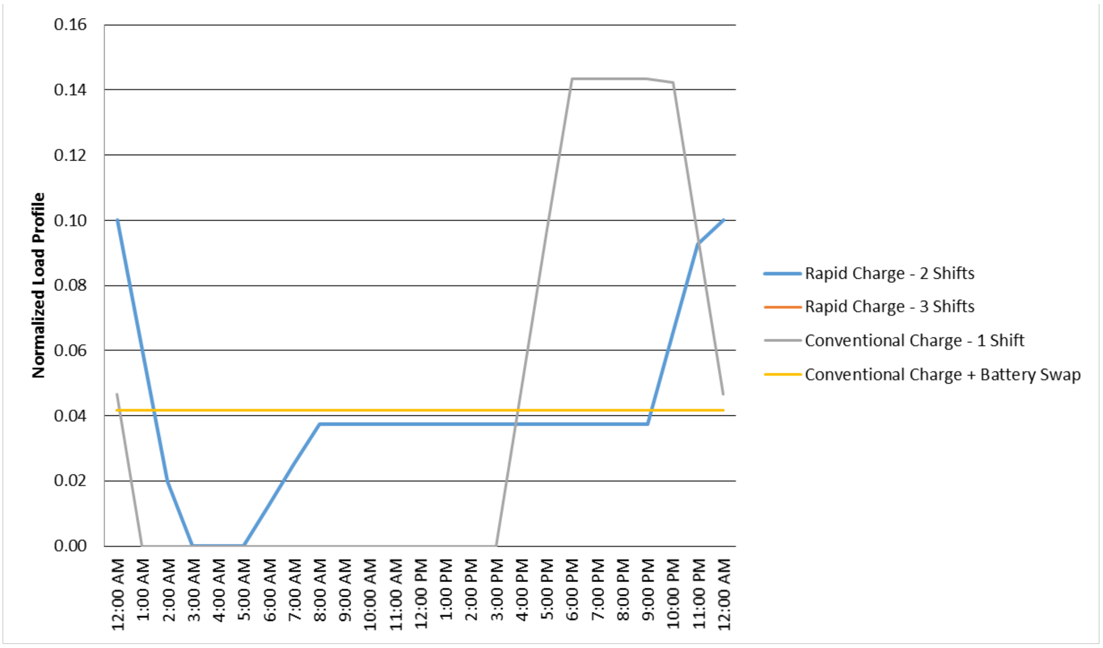


Figure 2-3. Forklift Normalized Load Profiles

2.4.2 Truck Technologies (TSE and e-TRUs)

A singular load profile was created for each for TSE and e-TRUs. For TSE, charging data was supplied by Shorepower collected under their NREL project[16]. The data includes the time the charging event started and its duration. From this data, the California representative normalized load profile was developed based on the charging events occurring at the West Coast truck stops. The e-TRU load profile is based on conversations with operators of conventional and electric TRUs to represent their operations and how they could be used. It is assumed the TRU is located at their home facility overnight from 6pm to 6am and departs at 6am for distribution, deliveries and pick-ups. It is assumed that one out of every three hours the TRU is located at a delivery location where there is the potential that an e-TRU could be plugged-in. Since the timing of deliveries/pick-ups varies, the normalized load profile is constant throughout the day. Since not all operations start at 6 am and end at 6 pm, the load profile include a sensitivity of plus or minus one hour from the starting and ending times. Figure 2-4 shows the normalized load profiles for TSE and e-TRUs.

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[16] This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under Award Number DE-EE0002613. Disclaimer: "This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

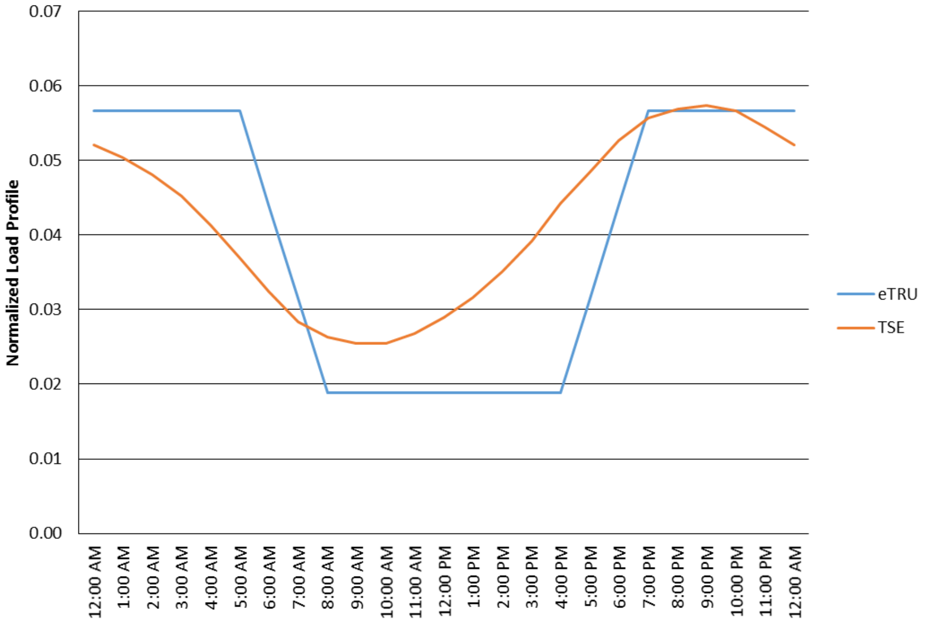

Figure 2-4. Truck Technology (TSE and e-TRU) Normalized Load Profiles

2.4.3 MD and HD Trucks

For MD/HD trucks, separate load profiles were developed for each of the technologies (PHEV or BEV) and vehicle class including both slow and fast charging for MHD, HHD and Buses.

For MD/LHD PHEVs and BEVs, MHD PHEVs and MHD BEV slow charge, it is assumed that charging does not occur during the day and starts at the end of day (5 pm) when the vehicle returns to the facility. For MHD BEV fast charging, it is assumed that a charging event occurs during the middle of the day (12pm) and when the vehicle returns to the facility at the end of the day (5pm) and each charging event is equal in electricity delivered. Since not all operations start and end at the same time, the load profile includes a sensitivity of plus or minus one hour for the start of each charging event. The assumptions for these load profiles were developed from reviewing reports from CalSTART[17] and data from Smith Electric[18]. Figure 2-5 shows the normalized load profiles for MD/LHD and MHD charging types and vehicle technologies.

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[17] http://www.calstart.org/Libraries/CalHEAT_2013_Documents_Presentations/Battery_Electric_Parcel_Delivery_Truck_Testing_and_Demonstration.sflb.ashx

[18] http://energy.gov/sites/prod/files/2014/07/f17/arravt072_vss_mackie_2014_o.pdf

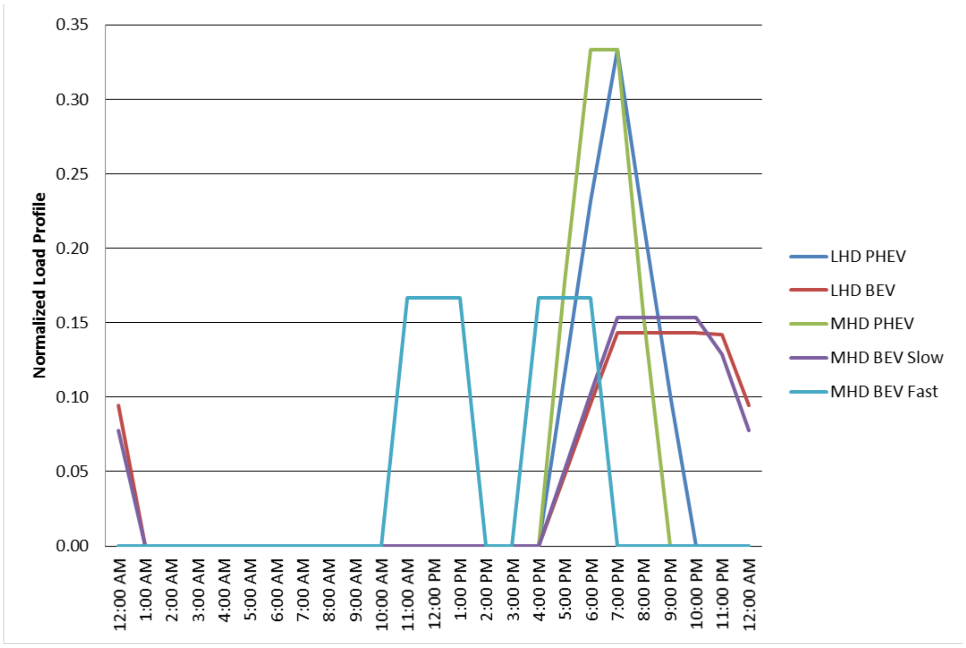

Figure 2-5. MD/LHD and MHD Normalized Load Profiles

Three different load profiles were developed for HHD trucks: HHD PHEV (slow charging), HHD BEV slow charging and HHD BEV fast charging. The load profile for HHD PHEV assumes that charging only occurs when the truck returns to the facility and is plugged-in. HHD BEVs were divided into two categories, based upon EMFAC categories, based upon daily VMT: 140 miles and 210 miles. It is assumed that those trucks that travel 140 miles per day utilize slow charging and those that travel 210 miles utilize fast charging. For slow charging, it is assumed that the truck charges once during the day at 10am for an hour to allow for the truck to operate all day and have a fully depleted battery at the end of the day. For fast charging, it is assumed that the trucks will charge twice during the day at 10am and 1pm for about 24 minutes each (~98 kWh each) to allow for the truck to operate its full daily VMT and have a fully depleted battery at the end of the day. Since not all operations start and end at the same time, the load profile includes a sensitivity of plus or minus one hour for the start of each charging event. Figure 2-6 shows the normalized load profiles for HHD trucks.

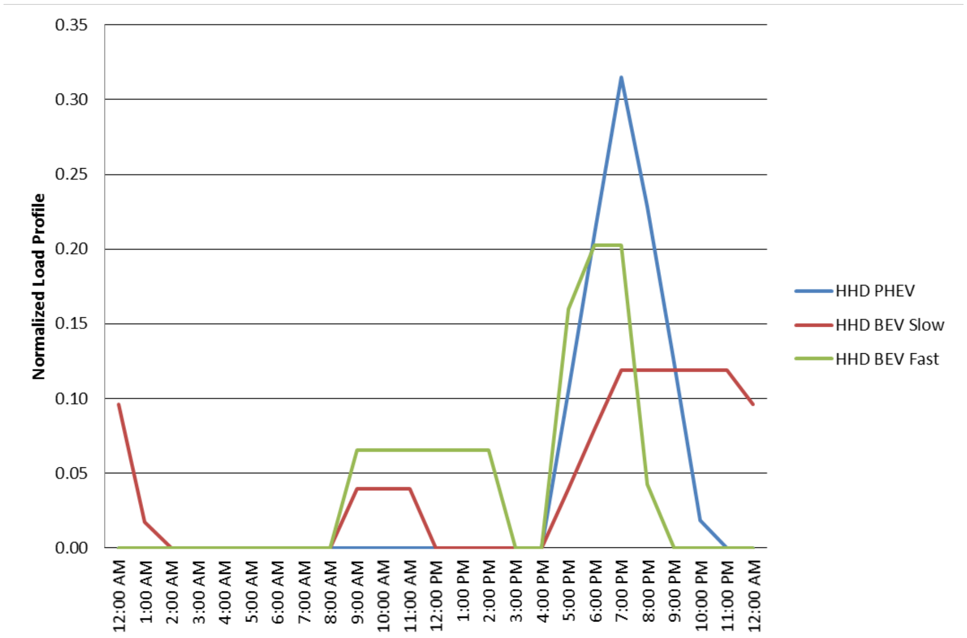

Figure 2-6. HHD Truck Normalized Load Profiles

Similar to HHD trucks, three load profiles were developed for buses. The assumptions for buses came from discussions with bus manufacturers and a CalSTART report[19]. The load profile for Bus PHEVs assumes charging occurs at the end of day when the bus is plugged-in with a slow charger. The Bus BEV slow-charging profile assumes that the bus slow charges for one hour during the day (10am) and then plugs in again at the end of the day (6pm). The Bus BEV fast charging profile includes two charges of 40kWh during the day (10am and 1pm), with the balance of the charging occurring at the end of the day (6pm). Since not all operations start and end at the same time, the load profile includes a sensitivity of plus or minus one hour for the start of each charging event. Figure 2-7 shows the normalized load profiles for buses.

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[19] http://www.calstart.org/Libraries/Publications/Peak_Demand_Charges_and_Electric_Transit_Buses_White_Paper.sflb.ashx

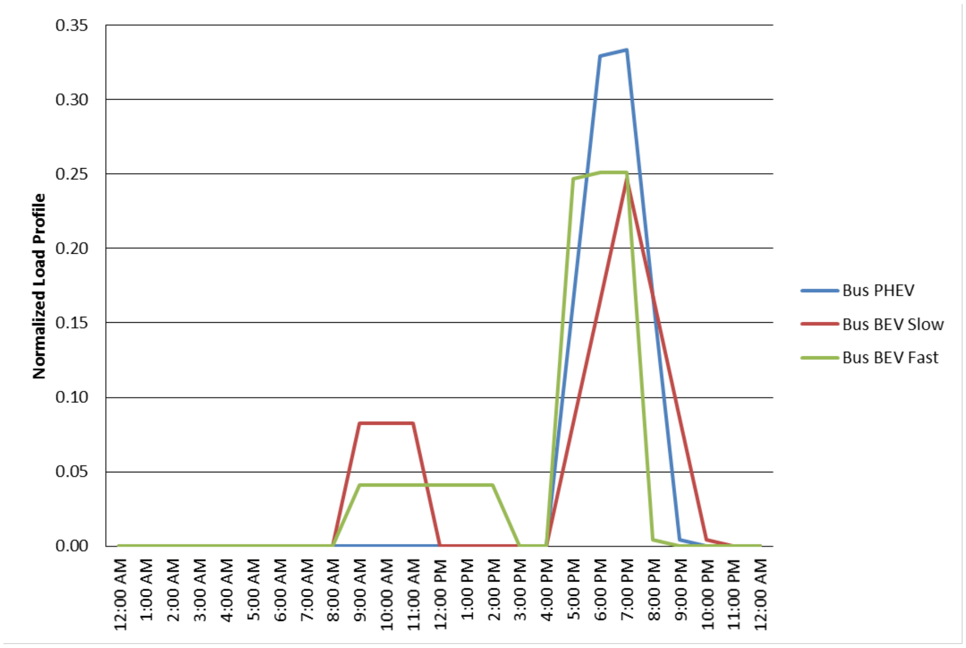

Figure 2-7. Bus Normalized Load Profiles

3 Grid Impact Analysis

We calculated the distribution grid impacts and upgrade costs for the MDV/HDV sector using the same approach we used in Phase 2 for LDVs. We calculated the PEV-related peak load growth that would occur at each location on the distribution system and calculated the PEV related distribution upgrade costs.

3.1 Spatial Adoption Patterns

A key difference from the Phase 2 approach is the method used to spatially distribute the technologies studied. Phase 2 forecasted the spatial distribution of light-duty BEVs and PHEVs based on the historical adoption patterns of hybrid electric vehicles (HEVs). We assumed that LDV PEV adoption would follow the pattern of clustering seen for HEV adoption based on demographic information.

For the MDV/HDV sector there is no similar record of prior HEV adoption. Phase 3 technologies are typically owned by businesses and governments rather than residential consumers, and are mostly used for transporting goods rather than passengers (with the exception of buses). Some of the technologies, like TSEs and e-TRUs are not even vehicles.

The model uses a random distribution approach. The annual number of incremental units for each technology is taken from adoption forecasts and randomly distributed across all feeders each year. For Phase 3, the unit of analysis is the customer, since vehicles such as forklifts are assumed to operate as a fleet rather than as individual vehicles. Since the distribution process is stochastic, each run of the model produces a different distribution pattern.

3.2 Distribution Data and Upgrade Costs

Distribution system data was provided by PG&E, SCE, SDG&E, and SMUD for the Phase 2 study. The data provided by the utilities is illustrated in Table 3-1. Each utility provided detailed information on the circuits and feeders in their service territory, including capacity rating, utilization, peak loads, percentage of load by sector, and forecasted load growth. The utilities also provided latitude and longitude location information for each data point.

In all, the investor-owned utilities (IOUs) provided data for 7,894 feeders and circuits located in their respective service territories. SMUD provided data for 73,786 circuits. In order to reduce model runtime, the SMUD circuit/feeder data was reduced to a representative sample of 1,500 circuits. A small fraction of the circuits and feeders were discarded due to having incomplete data. The samples for each utility were then grossed up to represent the full service territory of each utility.

Table 3-1. Distribution Data Provided by Each Utility

Utility	Circuits & Feeders in Sample
PG&E	2,980
SCE	3,693
SDG&E	1,051
SMUD	1,474

3.2.1 Distribution System Upgrade Costs

Each utility provided a utilization that would trigger a circuit, feeder or substation upgrade. For each type of upgrade, the utilities also provided average upgrade sizes and costs representative of their respective systems (Table 3-1 and Table 3-2). As load at each location exceeds rated capacity, upgrades are added in that year. The cost of distribution system upgrades is added to the utility rate base and included in the cost-effectiveness analysis. The model looks forward several years to determine whether a single (larger) new substation or substation upgrade or several (smaller) feeder upgrades are more cost-effective. The utilities also estimated the percentage of existing substation locations at which upgrades could feasibly be performed (e.g., have sufficient high-side capacity and land area to add a new low-side bus). The lower cost substation expansion upgrades were limited according to the utility input so that the model would implement higher-cost new substations in some cases.

Table 3-2. Circuit/Feeder Upgrade Costs

	PG&E	SCE	SDG&E	SMUD
Size (MVA)	10	10	10	0.57
Underground Cost ($)	$2,045,000	$2,045,000	$2,045,000	$7,691
Overhead Cost ($)	$1,810,000	$1,810,000	$1,810,000	$7,691
Utilization Upgrade Trigger	90%	90%	90%	115%

3.2.2 Commercial PEV-Related Distribution Upgrades

With the combination of adoption scenarios, load shapes and geographic distribution, we calculated the commercial PEV related peak load growth that would occur at each location on the distribution system for each scenario.[20] With the utility distribution system data, we calculated utilization at each point with

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[20] The load shapes are based on current vehicle usage patterns with existing customers and technology. In aggregate, MDV and HDV loads peak at 7 pm, which is later than the peak load hour for the majority of feeders included in the analysis. Furthermore, due to limited availability of data on the locations where MDV and HDV technologies are being adopted, this study did not explore potential impacts of clustering. The potential for MDV

the total forecasted load growth, including incremental EV charging load. To examine the grid impacts specific to EV charging, we first modeled distribution upgrades required to meet the base case forecasted load growth provided by each utility. We then added the hourly EV-charging load for each adoption scenario to the base case load forecast and model the required distribution upgrades. We counted the incremental distribution upgrades in the EV charging case as being EV-related. The additional distribution upgrade cost with EV charging is due to both a greater number of required upgrades and some upgrades being required earlier than they are in the base case without EVs. The distribution upgrade costs are includes in the cost-effectiveness results presented in the next section.

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and HDV loads to be more clustered and coincident with feeder peak loads than assumed here could result in higher T&D upgrade costs and is an important area for future study.

4 Cost-Effectiveness Results

We used the cost tests developed in the California Standard Practice Manual to evaluate the cost-effectiveness of electrifying medium- and heavy-duty vehicles. These costs tests are the same tests the CPUC uses to evaluate energy efficiency measures. Appendix A at the end of this report describes the cost test methodologies. Each of the cost tests evaluates cost-effectiveness from a different stakeholder perspective. We focused on the TRC, which looks at monetized resource expenditures and savings for the region as a whole, and the SCT, which includes additional environmental and societal benefits that are not directly monetized.

Similar to the findings in Phase 2 for light-duty PEVs, we show that off-road and commercial EVs can be cost-effective using existing CPUC methodologies. However, these tests were not developed to address statewide carbon and air quality challenges. So, we again propose that new tests are needed to evaluate initiatives designed to meet long-term GHG reduction and air quality improvement targets. Even with the addition of health and environmental benefits, early investments intended to encourage market transformation often do not pass cost-effectiveness evaluation initially, but only after technological development and wide-spread adoption drive costs down. Furthermore, current tests do not explicitly address how environmental and GHG benefits in the transportation sector can or should be considered against increased emissions in the utility sector. New approaches will need to be developed to compare the relative costs of achieving GHG reductions across utility, transportation and other sectors of California’s economy which will require significant investment in new technologies and infrastructure.

This study includes the territories of the four utilities that contributed data and evaluates the regional perspective of the state of California as a whole. This is why federal tax credits for relevant vehicle classes (<14,000 lbs GVW) are included as a benefit but state tax credits are not. Federal tax credits add to the resource base in the state by bringing in money from outside the study area while state tax credits redistribute resources inside the state. This redistribution affects the results of other cost tests (e.g. PCT) but not the TRC.

Figure 4-1, below, shows the TRC and SCT cost test results for all technologies combined. The largest cost components are the incremental vehicle costs and the energy costs; the majority of the benefit comes from fossil fuel savings. The analysis includes all the costs associated with vehicles adopted between 2015 and 2030 and all the costs and benefits of operating those vehicles for their respective useful lives (including beyond 2030 until the last vehicles are retired). The present value net TRC benefits in $2014 are $2.9 billion. The net benefits for the SCT are $3.8 billion, primarily due to the addition of energy security benefits. The net benefits for the MDV/HDV sectors are somewhat smaller but similar in scale to the net benefits estimated for the LDV sector under the TOU rate and ZEV Most Likely adoption scenarios in the Phase 2 report - $4.3 and $5.4 billion respectively for TRC and SCT net benefits.

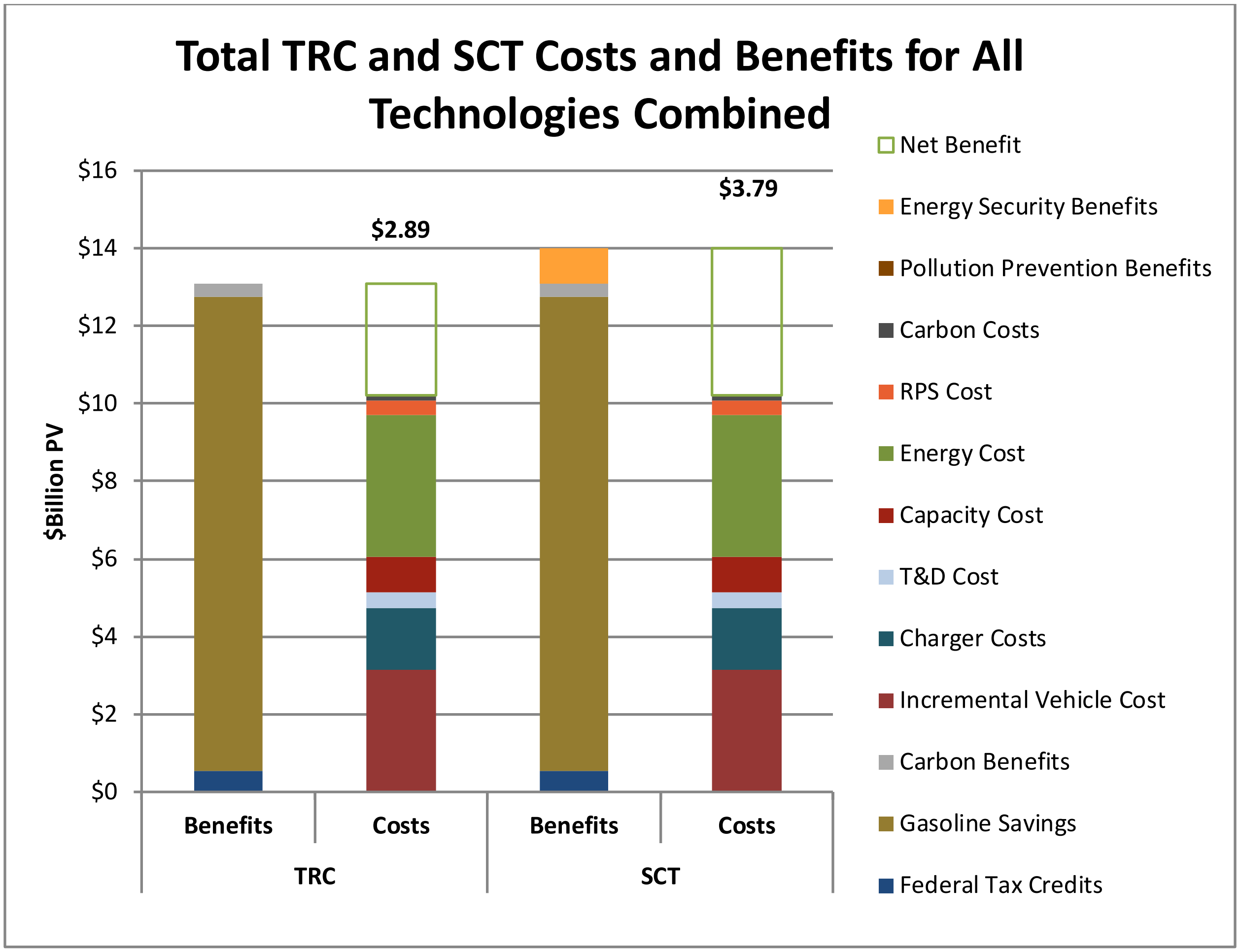

Figure 4-1. Total TRC and SCT Costs and Benefits for All Technologies Combined

In the following sections we present TRC and SCT results for each individual technology and discuss their most distinctive and influential characteristics.

4.1 Heavy Duty Truck Classes

The large trucks used in commercial and industrial operations fall into three categories: medium-duty/light heavy-duty (LHD), medium heavy-duty (MHD), and heavy heavy-duty (HHD). Electrified versions of all three classes are available, but the market for electric LHDs is larger and more established than it is for MHDs and HHDs. There are over ten electric delivery trucks and step van models in the LHD sector available in the market today, but options in the MHD and HHD sectors are almost completely limited to demonstration and prototype vehicles. Electrifying these vehicle classes presents a greater technical challenge because of their larger, more powerful engines and long-haul usage patterns with few stops and no fixed route. This usage configuration makes charging logistics particularly difficult.

There are very limited electric MHD and HHD vehicles on the market or in use and the rate of adoption has been slower than for LHDs. This leads to a smaller pool of data on which to draw for cost test analyses such as this one. Some technical specifications, such as engine efficiency, are available directly from vehicle manufacturers. However, others, such as annual mileage and daily load profiles, are only available from customers who have purchased the vehicles and put them into use. The smaller the pool of adopters to collect data from, the less likely it is that these adopters will be representative of the whole market as time passes and the number of adopters increases.

The cost-effectiveness results in general are extremely sensitive to equipment costs, zero emissions miles traveled (ZEMT) and charging level assumptions. We believe available data for the LHD sector is reasonably representative of available technologies, but cannot say the same for the much more limited experience of MHD and HHD vehicles. One way to compensate for the uncertainty associated with a small data sample is to model a broader range of scenarios and sensitivity analyses. By doing this, our analysis can anticipate the impact on cost test results if future adopters use electric MHDs and HHDs in ways that are significantly different from the early adopters in our sample. In order to provide the most rigorous results possible, we propose to conduct a follow-up analysis devoted exclusively to LHDs, MHDs, and HHDs. The follow-up report will investigate a larger range of scenarios and sensitivities than the scope of this report allows for.

4.1.1 Light Heavy-Duty (LHD) Trucks

Figure 4-2 shows the TRC results for light heavy-duty trucks (LHD). This class produces a positive net TRC benefit of $13,474 per vehicle and a larger net SCT benefit of $16,157 per vehicle.

While there is a potential range of charging for BEV and PHEV LHD models, in our study we assumed charging entirely on level 2 (L2) (rather than DC fast) chargers. The fossil fuel savings benefit is roughly three times the size of the delivered cost of electricity. While electric engines have inherent efficiency advantages over ICEs, this benefit is likely augmented by the driving environments where LHDs are used. LHDs are used for multiple shorter and/or urban routes. ICEs experience greater efficiency losses in stop-and-go urban traffic than electric engines do. Electric LHDs thus save even more fuel per unit of electricity consumed in the city than they would in less congested driving conditions.

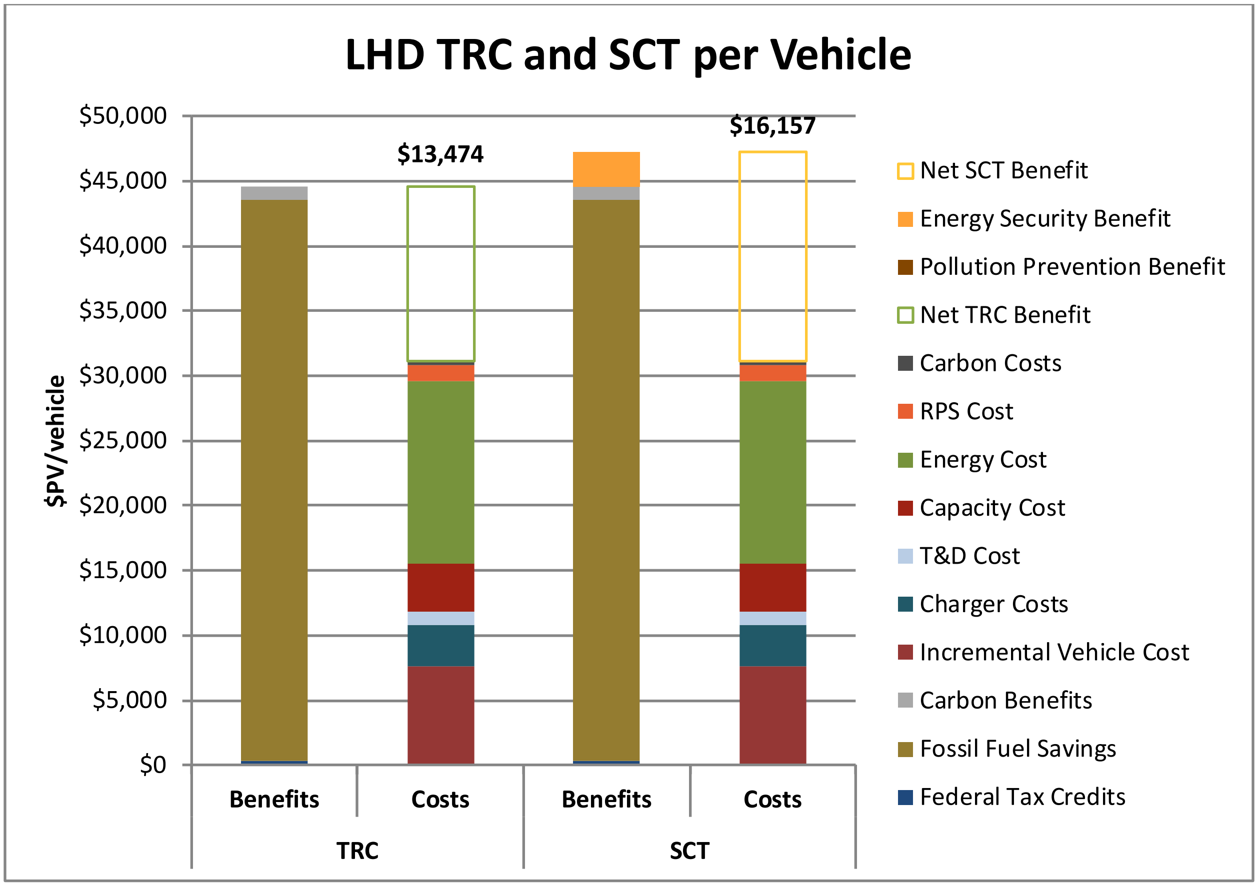

Figure 4-2. LHD TRC and SCT per Vehicle.

4.2 Buses

The Total Resource Cost test for electric buses is shown in Figure 4-3. The net TRC benefit per vehicle is $70,377, while the net SCT benefit per vehicle is $109,697.

The battery size and ZEMT are roughly 8x higher than for the LHD sector, resulting in a much higher absolute per vehicle benefit. The benefits as a proportion of costs are lower due in part to the higher infrastructure costs assumed for DC fast charging. As compared to the LHD sector which is charged at level 2, roughly 72% of the forecasted annual kWh demand for buses comes from fast charging. The investment in fast chargers is evident in the relatively high charger costs.

Actual grid impacts from electric buses will vary depending on which type of technology comes to dominate the market. Electric bus technologies are currently available in a variety of battery sizes and charging configurations. Models with smaller batteries will charge multiple times throughout the day and may create higher capacity costs due to the need for fast charging. Models with larger batteries that can charge through the night may have higher vehicle costs but cause less strain on the grid.

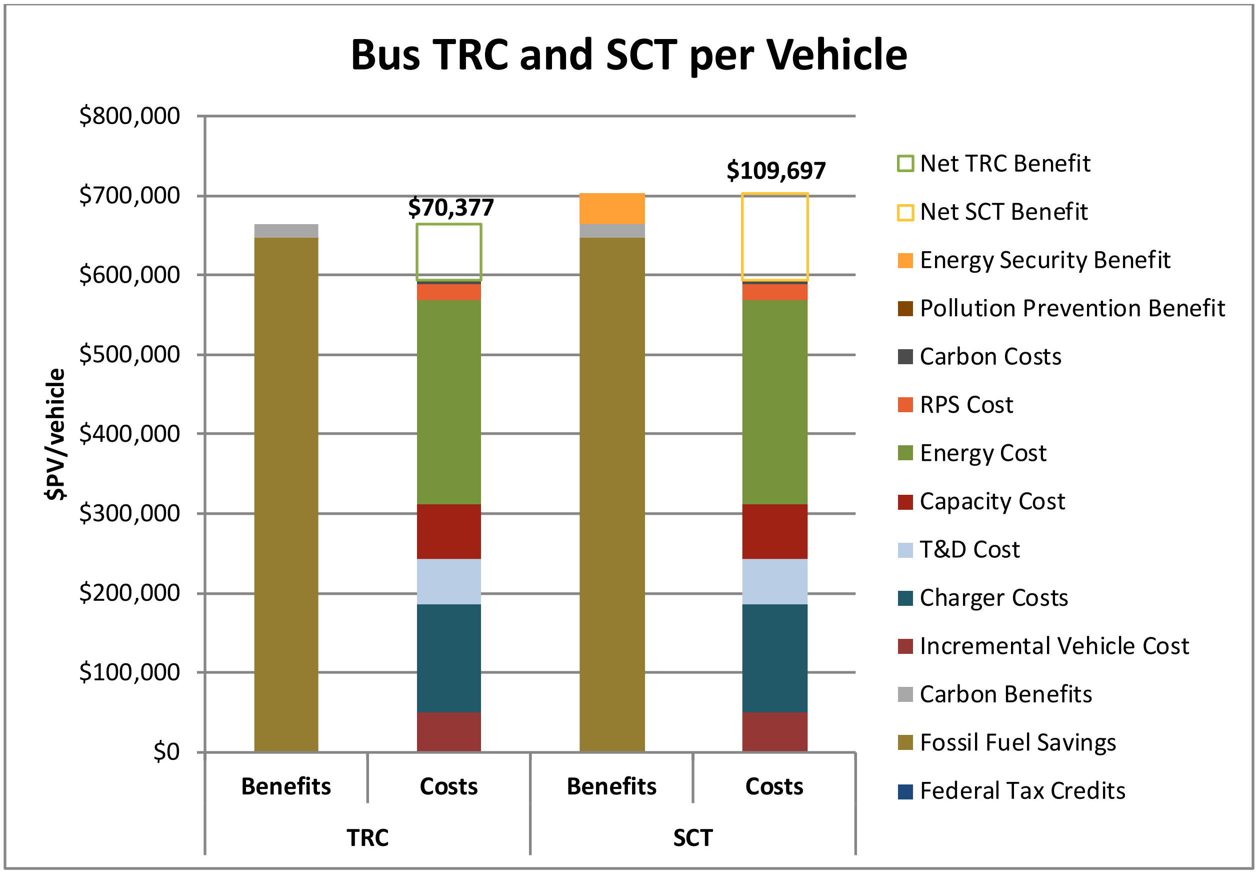

Figure 4-3. Bus TRC and SCT per Vehicle

4.3 Forklifts

Figure 4-4 shows the TRC costs and benefits for the forklift category. For forklifts there is a net TRC benefit of $18,551 per vehicle and a net SCT benefit of $22,859 per vehicle.

The forklift results show several unique characteristics. The most prominent is the high incremental vehicle cost. Forklifts have a per-vehicle incremental vehicle cost of $18,923. However, other than the incremental vehicle costs, the fixed costs for forklifts are relatively low. Only about a quarter (27.5%) of forklift charging is fast charging, so charger, capacity, and T&D costs are small in proportion to the energy costs. The conventional fuel savings are high compared to the electricity cost, due in part to the high fuel efficiency of electric forklifts compared to conventional forklifts. The combination of low charging costs and large fuel savings results in a positive net TRC benefit despite the high incremental vehicle cost.

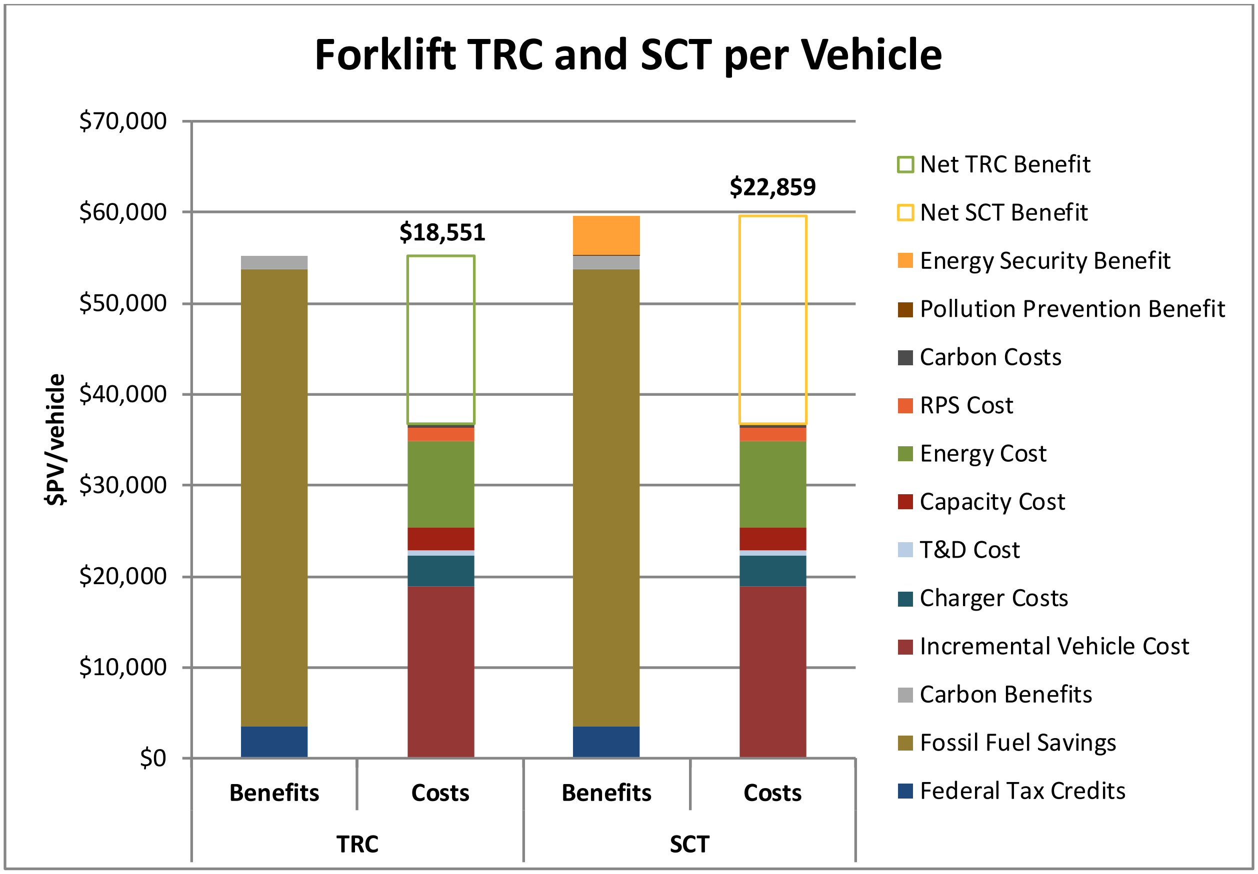

Figure 4-4. Forklift TRC and SCT per Vehicle

One of the most important variables in electric forklifts' impact on the grid will be the charging patterns selected by future adopters. Forklifts are used in many different industries, and mainstream adoption of electric forklifts will likely result in a variety of use and charging patterns. These patterns can vary both in the type of charging and in the timing of peak charging demand. While we have attempted to model a likely mix of charging types and schedules based on industry feedback, limited adoption of electric forklifts thus far means the sample size is small. Realized grid impacts from electric forklift adoption will depend on the structure and timing of the aggregate forklift charging load. Net benefits from electric forklifts will increase if the charging schedules favored by adopters minimize the need for distribution upgrades and additional generation capacity.

4.4 Truck Stop Electrification

Truck Stop Electrification (TSE) carries the highest "per-unit" net benefit of all the Phase 3 technologies. As Figure 4-5 below shows, each TSE facility provides a net TRC benefit of over $1.2 million dollars and a net SCT benefit of over $1.3 million.

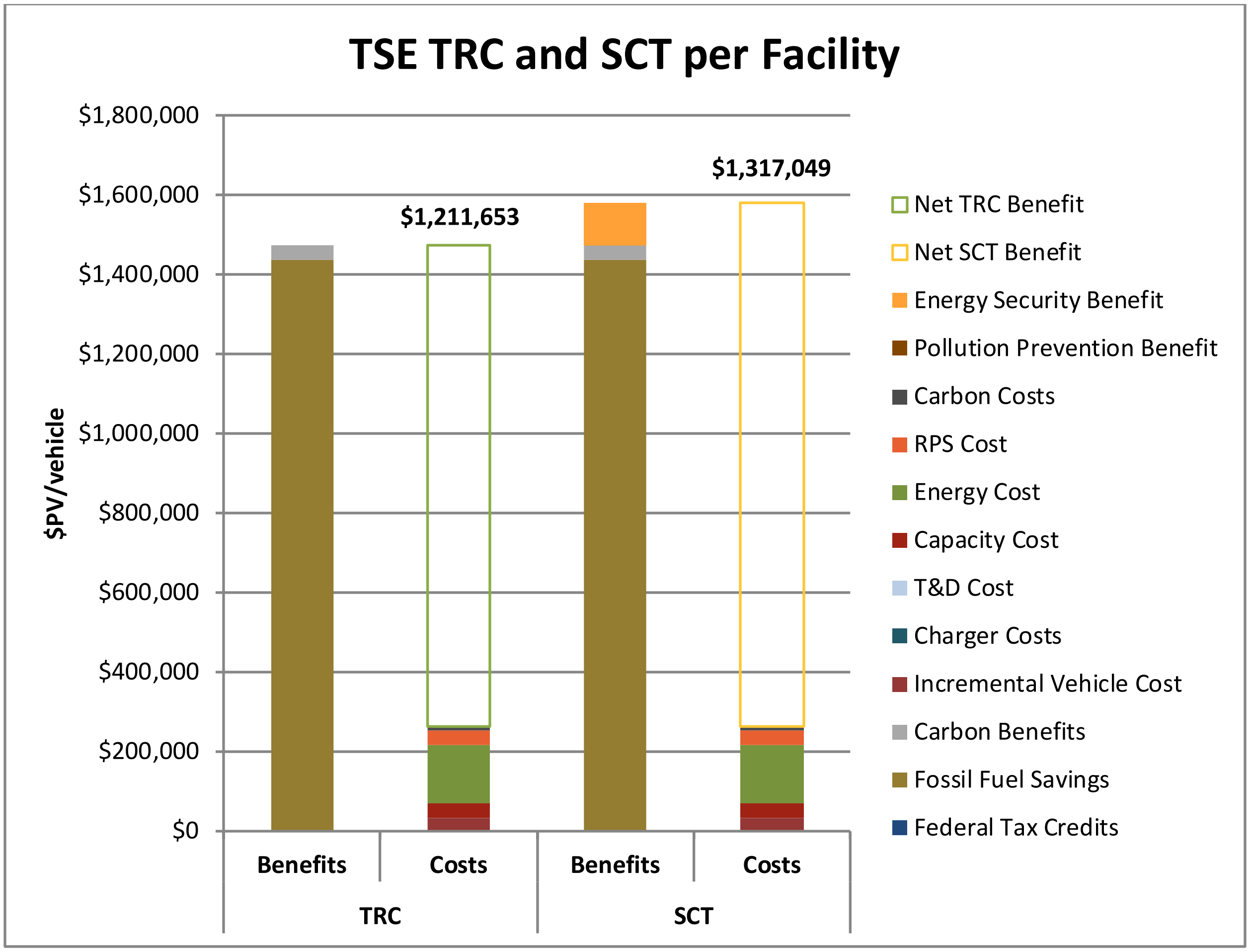

Figure 4-5. TSE TRC and SCT per Facility

A single TSE facility has multiple plugs and can therefore service multiple trucks at any given time. Additionally, while each individual truck spends only a portion of each day at a truck stop, a TSE plug is able to be used continuously throughout the day as trucks enter and leave the truck stop. Each TSE facility thus accrues the benefits from serving multiple vehicles each day.

The net benefit of a TSE unit is high in part because the traditional alternative is an especially inefficient means of providing the energy services in question. In the absence of TSE hook-ups, truckers usually idle their engines through the night in order to power auxiliary in-cabin functions like climate control. Running a diesel engine sized for a tractor trailer requires far more fuel than is necessary just to power the in-cabin functions. However, since no locomotion takes place when the truck is idling, all the fuel being burned must be attributed the in-cabin functions because no other energy service is being provided. This drives the energy efficiency of the process way down, and creates large fuel savings when truckers switch away from idling to an alternative such as TSE.

4.5 E-TRUs

E-TRUs are, like TSE, designed to reduce GHG emissions and air pollution from idling ICE engines in the goods transportation sector. Traditional TRUs run on diesel, and when the trailers are parked at truck stops the diesel engine must stay on in order to maintain the required temperature inside the unit. E-TRUs also run on diesel while driving (i.e. they do not have a battery), but they have the capacity to shut down the diesel engine and run on electricity while parked ("electric standby"). Truck stops that wish to service e-TRUs must install specialized plugs at their parking stations.

The TRC results for e-TRUs were positive at $16,787 per unit. The SCT net benefit is $18,026 per unit. Even though TRUs have separate designated generators that are sized appropriately for the TRU's needs, there are still efficiency gains from switching from a small diesel generator to centrally-generated electricity.

E-TRUs are unique among the Phase 3 technologies in that here the incremental vehicle costs include two pieces of technology. Like the other Phase 3 technologies, e-TRU adoption requires two types of equipment: an end-use device and a device that supplies it with power. For all the other Phase 3 technologies besides TSE, this translates to a vehicle and a charger. In the case of e-TRUs, this is the e-TRU itself, the plug, and associated equipment that provide it with electricity while parked. The plug-in station is not a charger since e-TRUs do not have batteries. The e-TRU results therefore show no charger costs, and the incremental vehicle costs include a fraction of the cost of a plug-in station. This fraction is based on the number of plugs per station (19).

Another aspect that makes e-TRUs unique is that their two essential pieces of equipment are owned by different parties. For trucks, buses, and forklifts, charging equipment is installed, owned, and operated by the owners of the vehicles. With e-TRUs, the e-TRUs themselves are owned by trucking companies or other businesses that need to transport goods, while the plug-in stations are owned separately by truck stops. This means that e-TRUs and their plug-in stations follow correlative but separate adoption curves, a factor that complicates efforts to predict future adoption rates.

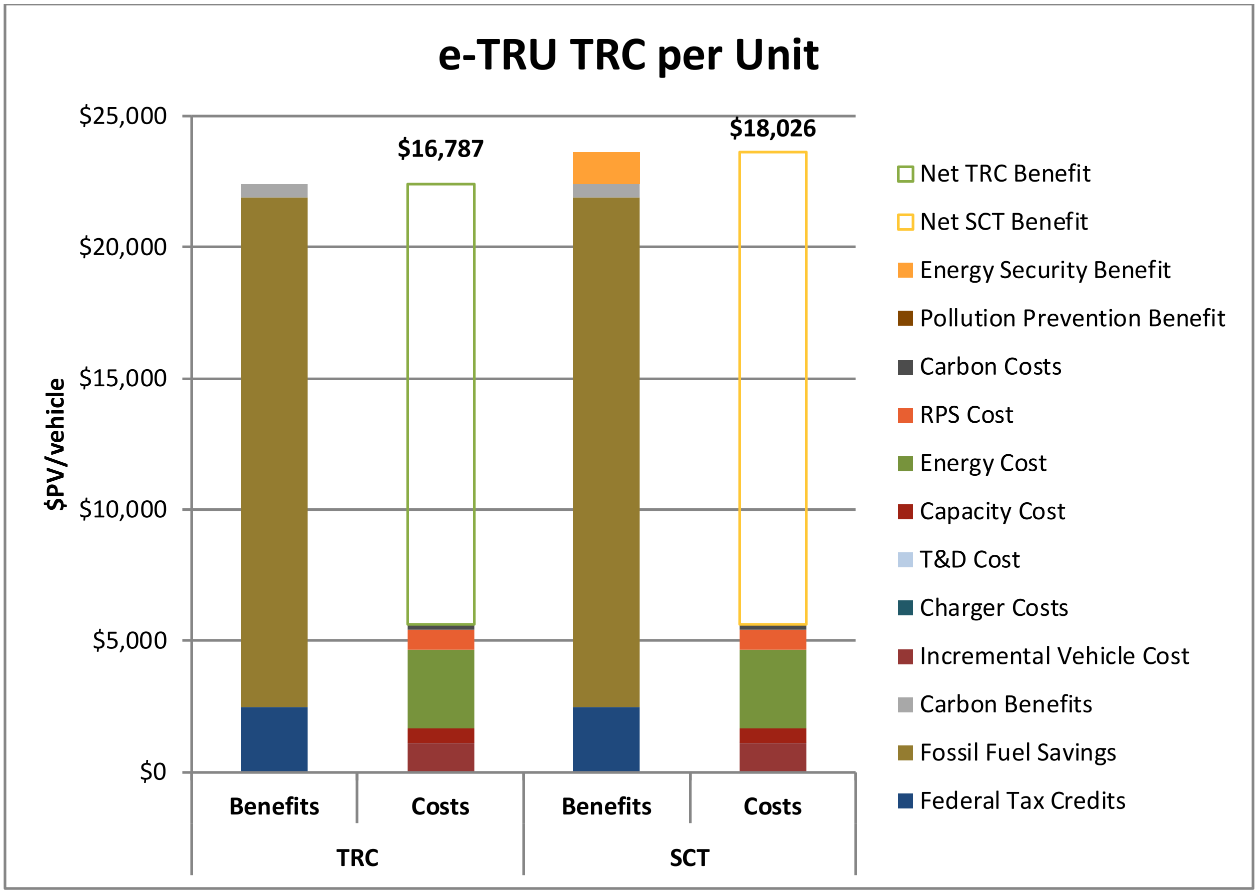

Figure 4-6. E-TRU TRC and SCT per Unit

4.6 Ratepayer Impact Discussion

The CalETC Phase 2 Grid Impacts Report provided Ratepayer Impact Measure (RIM) results showing the potential for increased electric load from LDVs to reduce rates for all ratepayers. Phase 3 encompasses a more diverse group of technologies with more complicated rate structures. The RIM test is not an appropriate metric when there is as much uncertainty and granular detail to the rate structures as there is for the Phase 3 technologies.

The households adopting LDVs in Phase 2 were on residential rates, which are relatively similar to one another within and across utilities and do not include demand charges. Conversely, the Phase 3 technologies will be adopted by ratepayers at commercial and industrial establishments. Commercial and industrial electric rates vary widely based on customer demand, serving voltage, time of day when the charging occurs, and other factors. Furthermore, commercial and industrial demand charge impacts of PEV charging can vary significantly from customer to customer based on the total demand in relation to other loads at the customer site, or whether the PEV charging is separately metered.

In addition to the many C&I rates in use, there is also uncertainty about which of these rates will be most prevalent among adopters of Phase 3 technologies. Vehicles such as forklifts and delivery trucks are used in many types of industries, and it remains to be seen which of these markets will be quickest to embrace electrification.

Rate impacts are one of many important factors to consider in developing PEV-related policies and programs. Given the wide variation in commercial and industrial customer types, sizes, load profiles and retail rates, a more detailed analysis than was possible for this multi-sector study is warranted. We propose that rate impacts be investigated for utility and sector specific proposals with additional scenario and sensitivity analysis as will be seen in Phase 3 Part B for MHD and HHD sectors.

5 Market Gaps, Barriers, and Potential Solutions

A confluence of regulatory policies, plans and rules are being developed by statewide and regional governments to meet the statewide greenhouse gas emission goals of 80% reduction by 2050 and federal National Ambient Air Quality Standards (NAAQS). Several regions, including the South Coast Air Quality Management District (SCAQMD), will require significant reductions in combustion emissions to meet the stringent 2023 and 2032 ozone standards. Specifically the SCAQMD is planning to achieve the reductions through reductions in NOx emissions - 67% reduction in NOx emissions to achieve the 2023 standard and 75% to achieve the 2032 standard.[21] Meeting these standards will require zero emission technologies in all segments of people and goods movement including on-road trucks and buses and off-road technologies.

Table 5-1. Brief Descriptions of Some of Policies, Plans and Regulations Advancing Transportation Electrification

Policy, Plan or Regulation	Brief Description
Governors 2015 Draft ZEV Action Plan[22]	Was expanded to include all forms of people and goods movement including freight, rail and medium- and heavy-duty trucks (including buses)
Sustainable Freight Plan[23]	Develop pathways to zero and near-zero emissions for the freight and goods movement sector
Executive Order B-32-15[24]	Directs multiple state government agencies and the Governor's Office "to develop an integrated action plan by July 2016 that establishes clear targets to improve freight efficiency, transition to zero-emission technologies, and increase competitiveness of California's freight system"
Advance Clean Transit Regulation[25]	Achieving a transition from heavy-duty mobile sources to zero and near-zero technologies to meet air quality, climate, and public health protection goals in all modes of public transit. The first proposed step is transitioning public transit bus fleets to zero emission technologies.[26]

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[21] SCAQMD Technology Advancement Office Clean Fuels Program 2013 Annual Report and 2014 Plan Update, March 2014. available online at: http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2014/2014-mar7-029.pdf

[22] https://www.gov.ca.gov/docs/DRAFT_2015_ZEV_Action_Plan_042415.pdf

[23] http://www.arb.ca.gov/gmp/sfti/sustainable-freight-pathways-to-zero-and-near-zero-emissions-discussion-document.pdf

[24] https://www.gov.ca.gov/news.php?id=19046

[25] http://www.arb.ca.gov/msprog/bus/bus.htm

[26] http://www.arb.ca.gov/msprog/bus/actdiscussiondocument.pdf

South Coast Air Quality Management Plan (2012)	Contains actionable regulatory control measures for reducing criteria pollutants. The 2012 AQMP focused control measures on transportation technologies and cleaner fuels including low NOx (potentially natural gas) and/or zero emission technologies (including electricity and hydrogen).

Multiple sources of funding have become available to advance the policies, plans and regulations in Table 5-1. Table 5-2 below identifies and describes some of the largest and most relevant sources of funding available for MD and HD, and off-road transportation electrification. Greenhouse Gas Reduction Funds (GGRF) from AB32 auction proceed are not included below since its proceeds are the funding source for many of the specific programs below.

Table 5-2. TE Funding Sources

Funding Source	Brief Description
California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)[27]	Offers vouchers for e-truck and bus purchases from 5,000 lb - >26,000 lb GVWR with funding ranging from $20,000 - $110,000 depending on vehicle size and location within a disadvantaged community
Low Carbon Transit Operations Program (LCTOP)	LCTOP funds are distributed by CalTrans to provide operating and capital assistance for transit agencies to reduce greenhouse gas emission and improve mobility.
California Energy Commission (CEC) Advanced and Renewable Fuel and Vehicle Technology Program (ARFVTP)[28]	The ARFVTP provides funding for electric charging infrastructure and for 2015-2016, medium- and heavy-duty advanced vehicle technology demonstration and scale-up through specific program opportunity notices (PONs)

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[27] https://www.californiahvip.org/about-the-project

[28] http://www.energy.ca.gov/2014publications/CEC-600-2014-009/CEC-600-2014-009-CMF.pdf

Proposition 1B: Goods Movement Emission Reduction Program (Prop 1B)	2015 Program guidelines[29] include specifications for heavy-duty trucks ($150,000-$200,000 for PHEV or BEV Class 8 trucks and $65,000 - $100,000 for Class 6 trucks), TSE (eligible costs include purchase and installation of electric infrastructure or equipment), MD/HD truck electric charging stations (lesser of 50% or $90,000), forklifts (3,000 – 8,000 lbs: lesser of 50% or $45,000 for 3 replacement forklifts; 8,000 – 12,000 lbs: lesser of 50% or $55,000 for 3 replacement forklifts), TRUs (lesser of 80% or $50,000 for replacing a diesel TRUs with an e-TRU; lesser of 50% or $30,000 to install 10 electric compatible with e-TRUs)
Zero Carbon Transportation	Funded by the Greenhouse Gas Reduction Fund (GGRF). Includes zero-emission truck, bus and freight equipment pilot commercial deployment projects and advanced technology demonstrations.[30]

While funding policies, plans, regulations and funding sources have and are being developed for transportation electrification in the commercial and off-road sectors, the follow are the major issues related to technology adoption in the commercial and off-road sectors:

- Consumer Cost
- Market Education and Outreach
- Charging Infrastructure
- Customer Bill Impacts
- Limitations on vehicle options

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., technology manufacturers) in developing solutions to increase market penetration.

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[29] http://www.arb.ca.gov/bonds/gmbond/docs/prop_1b_goods_movement_2015_program_guidelines_for_implementation.pdf

[30] http://www.arb.ca.gov/msprog/aqip/fundplan/final_meeting_notice_october15.pdf

5.1 Consumer Costs

5.1.1 Identification of Gaps and Barriers

Upfront Vehicle Costs

Electric forklifts and truck technologies such as TSEs and e-TRUs have achieved relative cost maturity and are extremely cost effective to the consumer as shown in the Phase 1 report. Even though there are lifecycle cost benefits to these technologies, the incremental cost over conventional technologies is still limiting their deployment. Product availability is also more limited for larger electric forklifts (e.g. over 8,000 pound lift capacity), and more capable electric forklift products are just emerging (e.g. 80 volt systems with AC motors). Misconceptions about electric forklifts also limit their adoption.

MD/HD trucks on the other hand are still extremely expensive compared to the conventional alternative and have limited lifecycle-cost benefits, especially at the current low diesel price. In addition, there are currently very few companies and vehicle models to choose from. Table 2-4 and Table 2-5 show incremental cost for vehicles and chargers and these are main limiting factors to increased vehicle deployment. While combining HVIP and Prop 1B funding shown in Table 5-2 could provide the incentives for initial purchases of electrified trucks, public funding is only a short term solution and the incremental vehicle costs need to drop over the next five years for long-term success of the technology.

Vehicle Operating Costs

TE operating costs tend to be lower than those of conventional vehicles but the actual reduction can be complicated and is based on the rate structure, time, and intensity of charging. The fuel price differential and reduced maintenance costs are the most significant driver for ownership savings. As such, it is critical that utilities provide competitive charging rates. The traditional billing paradigm for electricity consumption, however, is not optimized for TE charging. For instance, if a consumer has a non-shiftable load and added TE, that would penalize the consumer utilizing a TOU rate. 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 TE TOU rate (i.e., a rate specific to the TE charging load that does not require shifting the rest of the 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

TE adoption in California, outside of forklifts, remains in its infancy and 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 (see Table 5-2) should continue to be directed towards vehicle purchases. 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 TE 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 TE ecosystem to identify the incentives that could be successful in impacting vehicle adoption. For instance, the creation of a zero-emission only goods movement lane in heavily traveled truck corridors in that same vein as high occupancy vehicle (HOV) lanes for the light-duty vehicles.

Creative use of LCFS Credits

California's Low Carbon Fuel Standard (LCFS) was amended in September 2015 to provide utilities with an opportunity to earn credits for selling electricity as a transportation fuel not only for residential charging, but also for charging of electric forklifts, EVs in fleets, workplaces and public-access charging stations. Additionally, at transit locations, utilities can generate credits if requested by the transit agency. TSE and e-TRUs, however, are not eligible to generate LCFS credits. Utilities also have greater latitude on how to use the credits generated by charging at non-residential locations. At least one utility is already implementing a PUC approved pilot on generating credits for fleet vehicle charging. Additional PUC rulings may be needed for investor-owned utility LCFS programs that use LCFS proceeds generated from forklifts and fleet charging of medium and heavy duty vehicles. Publicly owned utilities do not need PUC approval if they voluntarily opt to implement forklift and fleet vehicle LCFS programs. As the market for TE evolves and the LCFS credit market matures, utilities can continue to explore opportunities to find innovative mechanisms to spur TE adoption using LCFS credits that are in line with CARB's LCFS Program requirements. The LCFS provides opportunities for utilities to explore creative ways to engage consumers. For example, in the case of forklifts, the utilities are the LCFS credit generators; these LCFS credits could be used for providing customer incentives such as on-bill credits, technology-cost rebates, EVSE rebates or reductions/offsets for customer paid utility upgrade costs[31].

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 TE 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[32] to evaluate whether there is a sufficient business case for light-duty automobile manufacturers to provide grid services from second life batteries and TE in service to the utility. Similar programs could be applied outside of the light-duty segment.

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[31] The investor-owned utilities may be limited to the December 2014 PUC Decision (D.14-12-083) which limits utility LCFS programs to either on-bill annual credits or one-time up-front rebates.

[32] 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 Market Outreach and Education

5.2.1 Identification of Gaps and Barriers

The introduction of new transportation electrification technologies requires careful coordination and continuous outreach to consumers to deliver high-level messaging at the local and regional levels to highlight 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 and operators including tax credits, grants, and the 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 Awareness and Knowledge

Similar to the light-duty PEV market, in the commercial and off-road sector, except for high-level messaging, there is a general lack of awareness of in the consumer market today. The following are mainly examples from the light-duty market segment but their message holds true to the commercial and off-road sector where knowledge of zero and near-zero technologies is extremely limited:

- Of the 1,846 vouchers distributed from the HVIP program, only 394 have gone to electric trucks or buses.[33]
- 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.

Utilities could partner with vehicle manufacturers to educate customers about the types of TE technologies available and how they could impact adopters' electricity bills. Outreach efforts could also clarify some of the costs, such as whether the cost of a distribution upgrade would fall on the customer

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[33] http://www.climateinvestmentmap.ca.gov/

who triggers it. A particularly useful resource could be a checklist that guides potential adopters through all the issues they need to consider when deciding whether to electrify their fleet.

Total Cost of Ownership

Consumers' unwillingness or hesitancy to pay for the additional upfront cost (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 an electric technology– 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 diesel, the price of electricity, the price of the vehicle, the cost of maintenance, resale value, and the availability of purchasing incentives. The price of electricity is also a variable, discussed in more detail above, which needs to be dealt with before a significant market campaign is developed. 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 longer than that.[34] 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.[35]

Calculating the total cost of ownership may prove complex to most customers, as there are limited data available regarding the resale value of electric technologies (due to the low volume of sales and limited historical data available). Finally, consumer concern about the life of the batteries, despite OEM vehicle warranties, will likely to limit the resale market until the batteries' lifespan and their residual value in their post-automotive life are clearer.

Improved Education

The familiar aspects of commercial operation – such as vehicle pricing, fuel pricing, vehicle range, availability of refueling infrastructure – changes with transportation electrification ownership. Consumers and property owners can often have a difficult time finding the practical and concrete information required to make an informed purchase. Ownership often requires a better understanding of vehicle availability, charging options, networking needs, installation costs, contractors capable of performing the installation, etc. There is limited 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 aggregators that have started to emerge and assume a leading role (e.g., goelectricdrive.com); however, as previously stated, awareness remains low, an indication that content and traffic to these sites could be improved.

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

[35] Indiana University, "Plug-in Electric Vehicles: A Practical Plan for Progress," *Indiana University*, 2011.

5.2.2 Potential Solutions

Utilities create a TE program manager role to act as a trusted advisor

Utilities have a critical role to play when communicating with consumers about the benefits of transportation electrification in commercial and non-road segments. As TE can be part of greater customer engagement about their energy consumption, utilities should expand their advisory role in this area by created a TE program manager, a combination of the recommendation in the TEA Phase 1 report and the recommendation in the CalSTART report.[36] This role would be able to educate consumers directly on the unique challenges and issues of commercial and non-road TE technologies. 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.[37]

The TE program manager could be part of the utility team than engages with local, regional and state planning agencies to help advance TE technologies throughout the state and help design programs that allow for utilities to leverage the public with their own planned investments.

Engage with TE ecosystem partners

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

5.3 Cost of Providing Appropriate Charging Infrastructure

5.3.1 Identification of Gaps and Barriers

Another potential obstacle to adoption of the TE technologies is the cost to adopters of providing charging infrastructure for their vehicles. The Phase 3 TE technologies (with the exception of TSEs and e-TRUs) are all commercial and/or industrial vehicles. Unlike LDVs, these vehicles will have little to no access to public-charging infrastructure. Owners must take responsibility for ensuring that enough chargers are available. This responsibility can inhibit adoption via both the costs themselves and uncertainty about how large those costs will be.

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[36] http://www.calstart.org/Libraries/Publications/Electric_Truck_Bus_Grid_Integration_Opportunities_Challenges_Recommendations.sflb.ashx

[37] 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).

Table 2-5 shows charger costs by vehicle type, which we assumed were borne entirely by the customer. These costs themselves may be intimidating to potential adopters, especially if their operating schedule and vehicle choice would require them to install fast chargers. Table 2-5 does not show all of the charging level options and does not address sequencing of charging to increase utilization. As mentioned in the previous subsection, customers need to analyze a series of cost-trade-offs: vehicle costs, charging station costs, and operating costs. PHEVs, short-range BEVs, and long-range BEVs, for example, present very different costs and challenges.

Additional make-ready costs may be incurred if a new electric service is needed, or if the distance between the service drop on the adopter's property and the area where the vehicles need to be charged is substantial. In this case, the customer must also pay to install the wiring between the service drop and the charging area. These costs can be small if the customer has space to park and charge the vehicles near the service drop, but depending on property configuration this may not be an option.

If the customer's property happens to be fed by a distribution transformer that is close to its full capacity, adding a substantial commercial or industrial EV load may trigger the need for a transformer upgrade. Utility policy regarding who pays the costs of such upgrades varies, and in some territories customers who trigger an upgrade may be required to pay part of the upgrade costs. This does not affect the TRC and SCT results because the upgrade cost is the same regardless of who pays, but having to pay for part of a distribution upgrade can be a substantial disincentive for potential EV adopters.

Even if the actual sum of these costs is still affordable to a potential adopter, the uncertainty and the research required to determine how large they will be may be enough to deter some potential adopters.

5.3.2 Potential Solutions

Utilization of the TE program manager to assist in load management coaching could help customers maximize their financial benefit from electrification by devising charging schedules that avoid the most expensive hours and reduce or eliminate infrastructure upgrades. This service may be especially useful for small to medium C&I customers for whom demand management has not previously been imperative. Such customers are less likely to have developed in-house load planning expertise and could benefit greatly from the utilities' expertise. This coaching could both save EV owners money and help the utility delay distribution upgrades.

Utilities could make investments in charging and propulsion infrastructure (e.g., charging stations, make-readies, TSE equipment) for commercial EVs and non-road equipment similar to their proposals for light-duty charging infrastructure pending before the CPUC. In fact, SB 350 (which grants utilities authority to install charging infrastructure) is broad in defining transportation electrification to include all forms of transportation and non-road mobile equipment.

5.4 Customer Electric Bill Impacts

5.4.1 Identification of Gaps and Barriers

Though most of the vehicles studied in Phase 3 produce net positive TRC and SCT results, this does not automatically guarantee financial benefit for any individual adopter of these technologies. In addition to paying for vehicle and charging infrastructure costs, customers will see an increase in their electric utility bill. Some EV adopters may see their utility bills increase enough to at least partially negate the savings on fuel and other ICE fleet costs. The extent to which this happens depends largely on two factors: their daily load profile and their utility rate schedule.

While LD ICEs operate very infrequently on a daily basis, mainly for commuting to and from work, and their load can be moved while achieving the same result; LD/MD/HD trucks, commercial applications, and buses have specific requirements and duty cycles that cannot be adjusted/modified daily based upon electricity rates or demand. Most commercial applications will require the vehicles to operate and charge on set schedules during business hours when there are peak electricity and demand charges. This limited flexibility may not allow commercial truck applications to mitigate demand charge impacts or take full advantage of lower cost off-peak rates. For ICE vehicles, commercial customers have not had to pay close attention to when and how vehicles are fueled. Without sufficient education and preparation, demand charges and TOU rates can contribute to unexpected bill increases for EV adopters who are not accustomed to closely monitoring their electricity use.

Cost allocation and rate design are complex tasks for which specific recommendations are beyond the scope of this report. Bill impacts, in particular those driven by demand charges, pose costs to customers that are potentially large and often uncertain, creating a potential barrier to customer adoption. Providing commercial customers with attractive rate options that fairly allocate costs while allowing them to minimize their electric bill will be even more important that it is for the LDV sector. In addition, providing customers education and tools to manage their electricity load and utility bill will also be important to make transportation electrification attractive.

One additional ratepayer benefit that will not show up directly on customer's bills are incentive programs that monetize the environmental benefits from consuming electricity instead of diesel. Utilities are the primary Low Carbon Fuel Standard (LCFS) credit generators for fleets and forklifts, although fleet operators can request to have this responsibility. For transit agencies, the transit operator is the primary LCFS credit generator but can request the utility to do this for them. LCFS credits are based on the amount of electricity consumed. For example, Table 2-8 shows MD/LDV BEVs electricity consumption of 15,000 kWh and buses BEVs of 104,000 kWh. When considering a $100 credit price and the 2020 compliance schedule[38], MD/LHD BEVs would generate approximately $1,110 in credit based revenue per truck and bus BEVs $10,500 per bus. It is likely that credit prices will reach upwards of $200 which would double the estimated benefits.

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[38] http://www.arb.ca.gov/regact/2015/lcfs2015/lcfsregtext.pdf

5.4.2 Potential Solutions

Improve charging rates

Utility rate structures are one of several key decision factors for potential TE 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 TE drivers are from a reduction in fuel expenditures. Utilities should continue to evaluate their rate structures in the context of the potential impact on TE consumers.

Another option is for utilities to consider developing rate schedules specifically for C&I electric fleets. In this case, utilities should strive to strike a balance between helping make C&I transportation electrification affordable and minimizing cross subsidization. Demand charges send an important price signal, and exempting electric fleets from them altogether runs the risk of incentivizing charging in hours coincident with non-EV peak load. However, intermediate measures such as metering EV fleets separately from a customer's non-EV load may be able to create a middle ground.

Lastly, a TE program manager could assist in load management coaching to help customers maximize their financial benefit from electrification by devising charging schedules that avoid the most expensive hours. This service may be especially useful for small to medium C&I customers for whom demand management has not previously been imperative. Such customers are less likely to have developed in-house load planning expertise and could benefit greatly from the utilities' expertise. This coaching could both save EV owners money and help the utility delay distribution upgrades.

5.5 Vehicle Options

5.5.1 Identification of Gaps and Barriers

Limited offerings

Currently there are very few options for commercial and off-road transportation electrification. Only a handful of companies are investing in development of MD and HD electric truck including[39] Altec (hybrid bucket truck), AMP (delivery walk-in truck), EVI (delivery walk-in and MHD truck), and Smith Electric (delivery walk-in truck). Based on the vehicles that qualify for HVIP funding, there is only one MHD electric truck available and zero HHD electric trucks. These vehicles have significantly less range between "fill-up" than the conventional vehicles and have limited to no options in battery size to all the costumer to customize the vehicle to their application. These types of limitations on options restrict potential purchasing opportunities. Consumers tend to purchase new vehicles that are similar to those that they are replacing and TE equivalents are limited across many market segments. HVIP and Prop 1B offer greater funding levels for larger GVWR vehicles with the intention of incentivizing larger electric trucks that have yet to materialize in the market.

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[39] https://www.californiahvip.org/docs/HVIP_Year4_EligibleVehicles.pdf

The electric buses, of which BYD, Proterra and New Flyer are the three main electric bus manufacturers, have limited selection between manufacturers but in terms of travel distance and payload, tend to have less limitations when compared to their conventional counterparts.

5.5.2 Potential Solutions

Larger Scale Deployments

Utility support for larger-scale deployments over single-truck demonstrations would allow for concrete examples of cost savings and economic benefits when actually switching to electrified technologies, not just “testing.” These demonstrations could include a wide range of technologies including short- and long-range BEVs and PHEVs for full market applicability.

6 Appendix A - Cost-Effectiveness Analysis

6.1 Cost-Effectiveness Framework

6.1.1 CARB Cost-Effectiveness Method

The TEA Phase 1 Report presents cost-benefit results using the CARB cost-benefit method for evaluating air quality improvement projects. The CARB cost-benefit method defines the cost-effectiveness of an air quality project based on "the amount of pollution it eliminates for each dollar spent."[40] The CARB cost-benefit method calculates a cost in $/unit of emission (e.g., ton, pound, gram) to determine which measures and programs are the most cost-effective. Costs include CARB funding for the incremental cost of the "clean" technology relative to its "standard" counterpart. For this report, it is important to emphasize that the CARB cost-benefit method does not include energy utility costs incurred to serve alternative fueled vehicles (AFVs).

6.1.2 CPUC Cost-Effectiveness Framework

CPUC Cost-effectiveness Tests

The origins of cost-effectiveness tests for distributed energy resources (DER), including energy efficiency, demand response and distributed generation, are found in the 1974 Warren-Alquist Act that established the California Energy Commission (CEC) and specified cost-effectiveness as a leading resource planning principle. Later, the 1983 California Standard Practice Manual of Cost-Benefit analysis of Conservation and Load Management Programs (SPM) developed five cost-effectiveness tests for evaluating energy efficiency programs. These approaches, with minor updates, continue to be used today and are the principal approaches used for evaluating DER programs across the United States.[41] The five cost tests are summarized in Table 6-1.

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[40] CARB. " Staff Proposal Regarding the Maximum Feasible and Cost-effective Reduction of Greenhouse Gas Emissions from Motor Vehicles." 2013 and CARB and CalTrans. "Methods to Find the Cost-Effectiveness of Funding Air Quality Projects" 2005

[41] The California SPM was first developed in February 1983. It was later revised and updated in 1987-88 and 2001 and a Correction Memo was issued in 2007. The 2001 California SPM and 2007 Correction Memo can be found at: http://www.cpuc.ca.gov/PUC/energy/electric/Energy+Efficiency/EM+and+V/

Table 6-1. The Five Principal Cost Tests Used for Distributed Energy Resources

Cost Test	Acronym	Key Question Answered	Summary Approach
Participant Cost Test	PCT	Will the participants benefit over the measure life?	Comparison of costs and benefits to the customer installing the measure
Utility/Program Administrator Cost Test[42]	UCT/PAC	Will utility bills increase or decrease?	Comparison of program administrator costs to supply side resource savings
Ratepayer Impact Measure	RIM	Will utility rates increase or decrease?	Comparison of changes in utility revenues to supply side resource savings, with administrator costs included
Total Resource Cost	TRC	Will the total costs of energy in the utility service territory decrease?	Comparison of program administrator and customer costs to utility resource savings
Societal Cost Test	SCT	Is the utility, state or nation better off as a whole?	Comparison of society's costs of energy efficiency to resource savings including non-energy benefits (NEBs)

The basic structure of each cost test involves a calculation of the total benefits and the total costs in dollar terms from a certain vantage point to determine whether or not the overall benefits exceed the costs. A test is positive if the benefit-to-cost ratio is greater than one, and negative if less than one. Results are reported either in net present value dollars (method by difference) or as a ratio (i.e., benefits/costs).

Each of the cost-effectiveness tests provides a different kind of information about the impacts of DER programs from different vantage points in the energy system. On its own, each test provides a single stakeholder perspective. Together, multiple tests provide a comprehensive approach. The TRC and SCT cost tests help to answer whether DERs are cost-effective for society overall. For the purpose of this analysis, society is defined as the residents of the state of California. The costs and benefits are totaled for society as a whole, irrespective of who pays the costs or who receives the benefits. Intra-regional transfers, such as utility incentives or customer bills, are not considered, as they represent an exchange from one party to another within the region considered.

The PCT, PAC, and RIM help to answer whether the portfolio and design of a proposed program is balanced from participant, utility, and non-participant perspectives, respectively. Looking at the cost tests together helps to characterize the attributes of a program or measure to enable decision-making, to determine whether some measures or programs are too costly, whether some costs or incentives are

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[42] The UCT/PAC was originally named the Utility Cost Test. As programs management has expanded to government agencies, not-for-profit groups and other parties, the term "Program Administrator Cost Test" has come into use, however the computations are the same. This document refers to the UCT/PAC as PAC for simplicity.

too high or too low, and what adjustments need to be made to improve distribution of costs and benefits among stakeholders.

Table 6-2. Summary of Cost Test Components for Load Reductions

Component	PCT	PAC	RIM	TRC	SCT
Deferred/avoided capital investment		+	+	+	+
Utility energy production/purchase savings		+	+	+	+
Quantifiable variable and environmental cost savings				+	+
Non-energy benefits					+
Equipment and install costs	-			-	-
Incentive payments/utility direct install costs	+	-	-		
Program administrative and overhead costs		-	-	-	-
Customer bill savings/reduced utility revenue	+		-		

+ = Benefit - = Cost

CPUC Avoided Costs

The benefits/ (costs) of reduced/ (increased) energy consumption are calculated using the CPUC and CEC-adopted avoided cost methodology used for evaluating DER. The avoided cost methodology developed by E3 has been updated and improved through several CPUC and CEC proceedings. The most recent update was performed by E3 for the 2013 Net Energy Metering Cost-effectiveness Evaluation, which was also subsequently used for the 2016 CEC Title 24 Time Dependent Valuation Update. The avoided costs include six components listed in Table 6-3.

Table 6-3. Components of Avoided Costs

Component	Description
Generation Energy	Estimate of hourly marginal wholesale value of energy adjusted for losses between the point of the wholesale transaction and the point of delivery
System Capacity	The marginal cost of procuring Resource Adequacy resources in the near term. In the longer term, the additional payments (above energy and ancillary service market revenues) that a generation owner would require to build new generation capacity to meet system peak loads
Ancillary Services	The marginal cost of providing system operations and reserves for electricity grid reliability
T&D Capacity	The costs of expanding transmission and distribution capacity to meet customer peak loads
CO2 Emissions	The market cost of carbon dioxide emissions (CO2) associated with the marginal generating resource
Avoided RPS	The cost reductions from being able to procure a lesser amount of renewable resources while meeting the Renewable Portfolio Standard (percentage of retail electricity usage).

The avoided costs are illustrated in Figure 6-1 and Figure 6-2. On an illustrative spring weekday, generation energy is the dominant cost (Figure 6-1). Generation capacity and T&D capacity costs are allocated predominately to a limited number of summer peak hours (Figure 6-2).

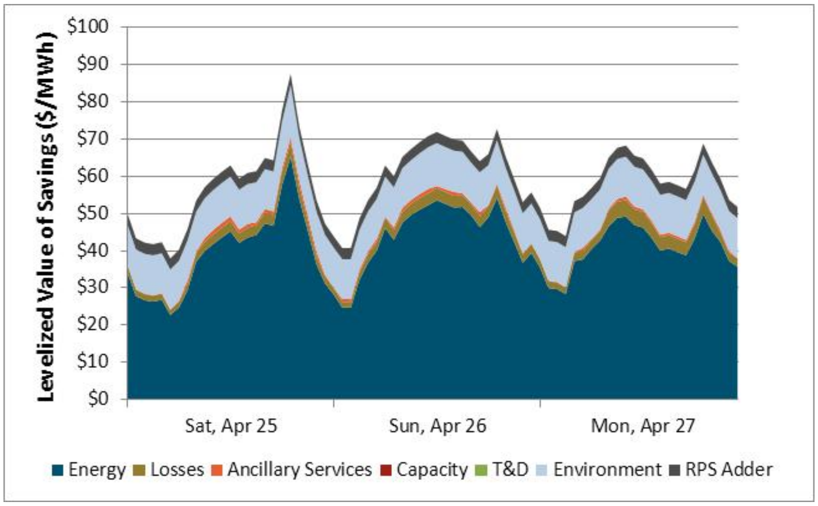

Figure 6-1. DER Avoided Costs – Spring Weekdays

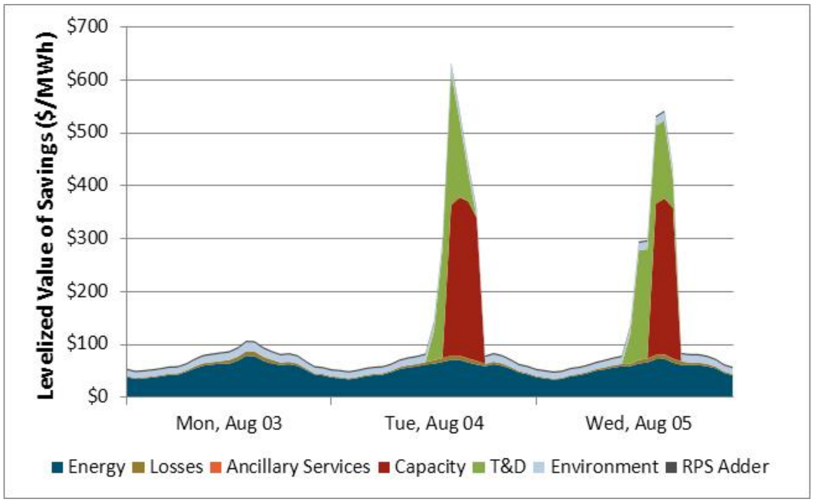

Figure 6-2. DER Avoided Costs – Summer Peak Days

6.1.3 PUC Code 740.8 Ratepayer Benefits

Section 740.3 of the California Public Utilities Commission code stipulates that in order for utilities to rate base investments for electric-powered and natural gas-fueled low-emission vehicles infrastructure, these investments must be "in the ratepayers' interest."[43] Section 740.8 further clarifies the phrase "ratepayers' interest" to include both direct benefits to the ratepayers and certain societal benefits. These societal benefits include increased energy efficiency, reduced health and environmental impacts from air pollution, reduced greenhouse gas emissions, and increased use of alternative fuels[44]. In order

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[43] "CAL. PUC. CODE §740.3: California Code – Section 740.3." *FindLaw.* Thomson Reuters, 2014. Web. Accessed 2 Sept 2014. http://codes.lp.findlaw.com/cacode/PUC/1/d1/1/4/2/s740.3

[44] "CAL. PUC. CODE §740.8: California Code – Section 740.8." *FindLaw.* Thomson Reuters, 2014. Web. Accessed 2 Sept 2014. http://codes.lp.findlaw.com/cacode/PUC/1/d1/1/4/2/s740.8

to maximize our model's relevance to the current policy context, our model includes these same benefits when performing the societal cost-benefit tests. The model incorporates them quantitatively as the monetary values of reducing criteria air pollutants ($/ton), reducing greenhouse gas emissions ($/MT), and displacing petroleum ($/GGE). Criteria air pollutants included in the model include nitrous oxides (NOx), particulate matter (PM), and volatile organic compounds (VOC). The values of reducing the three criteria air pollutants are combined into a health-benefit value for each PEV scenario. Table 6-4, below, shows the values from the Phase 1 Report used for displaced petroleum and criteria air pollutant benefits. For this report, we use the CPUC DER Avoided Cost values for GHG which are higher than those used in the Phase 1 Report (Table 6-5). The avoided cost values for GHG are intended to represent the monetized costs of GHG emissions under California's cap-and-trade allowance program.

For the economic regional benefits included in the TRC, we use the CPUC DER Avoided Cost values for GHG. For this study, we assume it is a natural extension in the spirit of the SPM to include the GHG benefits in the transportation sector as a benefit as a counterpart to the GHG cap and trade emission costs in the electric sector. We recognize, however, this interpretation has not been explicitly been adopted by the CPUC. For the SCT, in lieu of the monetized cap-and-trade allowance values, we use a higher societal value of avoided GHG emissions.[45]

Table 6-4. Factors for Monetizing Societal Benefits

Societal Benefit	Unit	2013	2020	2030
Displaced Petroleum[1],[2]	$/GGE	$0.44	$0.43	$0.42
NOx[5],[6]	$/ton	$4,675	$5,082	$6,098
PM [41,42]	$/ton	$1,450,038	$1,650,681	$1,977,357
VOC [41,42]	$/ton	$1,118	$1,20	$1,423

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[45] Presentation by Energy and Environmental Economics at CPUC Workshop on Societal Cost Test. http://www.cpuc.ca.gov/NR/rdonlyres/3A3835F9-070B-4068-8717-42177AB342AD/0/SCTWorkshop6132013.pdf

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

[2] 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

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

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

[6] 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.

Table 6-5. GHG Values

GHG Cost	Unit	2013	2020	2030
Phase 1 Report [3], [4]	$/Metric Ton	$11	$12	$16
CPUC Avoided Costs	$/Metric Ton	$17	$37	$73
Societal Value	$/Metric Ton	$49	$56	$70

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[3] 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

[4] 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.

Table 6-6. Detailed Cost Test Components for PEV Charging Load Increase

	Component	PCT	RIM	TRC	SCT (740.8)
PEV Customer costs and benefits					
	Incremental Vehicle Costs	-		-	-
	Gasoline Savings	+		+	+
	Utility Bills	-	+		
	Federal Tax Credits	+		+	+
	State Tax credits	+			
PEV Charger Cost					
	Utility Asset		-	-	-
	Customer Assets	-		-	-
Admin Costs					
	Utility Program Administration		-	-	-
Electricity Supply Costs					
	Energy Costs		-	-	-
	Losses Cost		-	-	-
	A/S Cost		-	-	-
	Capacity Cost		-	-	-
	T&D Cost		-	-	-
	RPS Cost		-	-	-
	Utility GHG Allowance Costs		-	-	-
Societal Benefits					
	Transportation GHG Allowance Costs			+	+
	"Societal" value for CO2				+
	Health benefits				+
	Decreased Petroleum Use				+