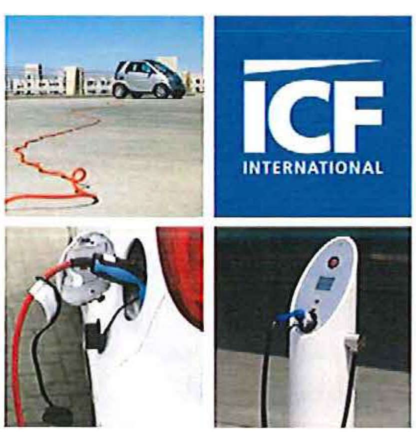
California Transportation Electrification Assessment

Phase 2: Grid Impacts

October 23, 2014



Energy+Environmental Economics

Schedule DRI-3

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Abbreviations and Acronyms

AEO	Annual Energy Outlook
ARB	California Air Resources Board
BEV	Battery Electric Vehicle
CARB	California Air Resources Board
CEC	California Energy Commission
CH4	Methane
CHE	Cargo Handling Equipment
CNG	Compressed Natural Gas
CO2	Carbon Dioxide
CO2E	Carbon Dioxide Equivalent
CPI	Consumer Price Index
CPUC	California Public Utilities Commission
DER	Distributed Energy Resources
DGE	Diesel Gallon Equivalent
EER	Energy Equivalency Ratio
EIA	United States Energy Information Administration
EPA	US Environmental Protection Agency
EVSE	Electric Vehicle Supply Equipment
FCV	Fuel Cell Vehicle
GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
GSE	Ground Support Equipment
GWh	Gigawatt-hour
HOA	Home Owners Association
HP	Horsepower
HSR	High Speed Rail
ICE	Internal Combustion Engine
IOU	Investor Owned Utility
ISOR	Initial Statement of Reasons
kW	Kilowatt
kWh	Kilowatt-hour

LCA	Lifecycle Analysis
LCFS	Low Carbon Fuel Standard
LEV	Low Emission Vehicle
MDU	Multi-Dwelling Unit
MT	Metric Ton
NMOG	Non-Methane Organic Gases
NOx	Oxides of Nitrogen
O&M	Operational and Maintenance
PEV	Plug-In Electric Vehicles
PHEV	Plug-In Hybrid Electric Vehicles
PHEV10	PHEV with 10 miles equivalent all electric range
PHEV20	PHEV with 20 miles equivalent all electric range
PHEV40	PHEV with 40 miles equivalent all electric range
PM	Particulate Matter
RIM	Ratepayer Impact Measure
ROG	Reactive Organic Compounds
RTG	Rubber Tire Gantry
SCT	Societal Cost Test
SPM	Standard Practice Manual
TE	Transportation Electrification
TEA	Transportation Electrification Assessment
TOU	Time of Use
TRU	Transport Refrigeration Unit
TRC	Total Resource Cost Test
TSE	Truck Stop Electrification
TTW	Tank-To-Wheel
ULETRU	Ultra Low Emission TRU
VOC	Volatile Organic Compounds
WTT	Well-To-Tank
WTW	Well-To-Wheels
ZEV	Zero Emission Vehicle

1. Executive Summary

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, holistic transformation of the transportation system, which accounts for about 38 percent of total emissions in the state. Governor Brown's Executive Order B-16-2012 establishes a goal of having 1.5 million zero emission vehicles (ZEVs) on California's roadways by 2025.[2] Looking further ahead to 2050, the California Air Resources Board (CARB) Climate Change Scoping Plan states that ZEVs will need to make up most of California's fleet[3] and Executive Order B-16-2012 establishes a 2050 target for reduction of greenhouse gas emissions from the transportation sector equaling 80 percent less than 1990 levels.[4] 2050 pathways studies find that 70% of vehicle miles traveled — including almost all light-duty vehicle miles — must be powered by electricity.[5] As ambitious as California's GHG goals are, EPA ambient air quality compliance deadlines in 2023 and 2032 will require even more acceleration of ZEV adoption. California utilities will be called upon to provide readily accessible, low-carbon electricity to fuel the state's transportation needs.[6]

1.1. Transportation Electrification Assessment

1.1.1. PHASE 1 REPORT: ENVIRONMENTAL AND SOCIETAL BENEFITS

The California Transportation Electrification Assessment (TEA) documents the crucial role that transportation electrification will have in meeting GHG and

[1] Governor Executive Order S-3-05, June 6, 2005. http://gov.ca.gov/news.php?id=1861
[2] See http://www.arb.ca.gov/msprog/zevprog/zevprog.htm
[3] California Air Resources Board (CARB). "First Update to the Climate Change Scoping Plan." May 2014. http://www.arb.ca.gov/cc/scopingplan/2013_update/first_update_climate_change_scoping_plan.pdf
[4] Exec. Order B-16-2012 available at http://gov.ca.gov/news.php?id=17472; Also see Exec. Order No. S-03-05 (June 1, 2005), available at http://gov.ca.gov/news.php?id=1861
[5] Williams, James H et al. "The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity." Science 335.6064 (2012): 53–9.
[6] CARB. (2012). Vision for Clean Air : A Framework for Air Quality and Climate Planning. http://www.arb.ca.gov/planning/vision/vision.htm. See also Greenblatt, Jeffery B. Estimating Policy-Driven Greenhouse Gas Emissions Trajectories in California: The California Greenhouse Gas Inventory Spreadsheet (GHGIS) Model. Lawrence Berkeley National Laboratory (LBNL), LBNL-6451e. November 2013. http://eetd.lbl.gov/sites/all/files/lbnl-6451e.pdf

ambient air quality goals. The Phase 1 Report (TEA Phase 1 Report)[7] describes the market size, environmental and societal benefits of 20 market segments of transportation electrification (TE), focusing on four segments in particular: plug-in electric vehicles (PEVs), forklifts, truck stop electrification and transport refrigeration units. PEVs are the largest of the segments studied: 2.3 million PEVs (CARB's "ZEV 'Most Likely' Scenario") could displace 5.8 million metric tons (MMT) of GHG in 2030, 50% of the total GHG reduction for all TE sectors in the TEA Phase 1 report's "in-between" adoption scenario.

1.1.2. PHASE 2 REPORT: PEV GRID IMPACTS

This TEA Phase 2 Report provides an in-depth analysis of electric utility costs that will be incurred to support PEV charging, with an emphasis on utility distribution systems. We use the inputs and results from this and the Phase 1 Report to describe the impacts of PEV charging under a variety of scenarios. We perform the analysis 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. We use 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.

1.2. PEVs Provide Regional and Societal Benefits

The California air and utility regulators have developed cost-effectiveness tests to allocate funding and resources to the most beneficial programs. The CARB approach determines which air quality initiatives are the most effective by comparing both the quantitative and societal value of the emission reduction against the cost of implementing less polluting technologies.[8] The TEA Phase 1 Report employs this approach to show that the societal benefits to California, including reduced emissions and reduced consumption of petroleum fuels are larger than the incremental costs of electric versus internal combustion engine (ICE) vehicles.

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

[8] CARB. " Staff Proposal Regarding the Maximum Feasible and Cost-effective Reduction of Greenhouse Gas Emissions from Motor Vehicles," November 2013. http://www.arb.ca.gov/cc/factsheets/cc_isor.pdf page viii , and CARB and CalTrans. "Methods to Find the Cost-Effectiveness of Funding Air Quality Projects" May 2005. http://www.arb.ca.gov/planning/tsaq/eval/eval.htm

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. For this report we use 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.

1.2.1. PEVS PASS CARB AND CPUC COST-EFFECTIVENESS TESTS

We first determine whether California as a state is *economically* better off with PEVs. We compare 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 include the federal tax credit for PEVs, gasoline savings and reduced cap-and-trade GHG allowance costs, which total about $20,000 per vehicle under our time-of-use (TOU) rate/load shape scenario (Figure 1).[9] The costs include incremental costs of the vehicle, charging infrastructure costs, distribution system upgrades and the avoided costs for delivered energy. Total costs are just under $15,000 per vehicle, for a net benefit of approximately $5,000 over the life of each PEV.

[9] Per the Standard Practice Manual, the TRC for California includes federal, but not state, tax credits and rebates as a benefit.

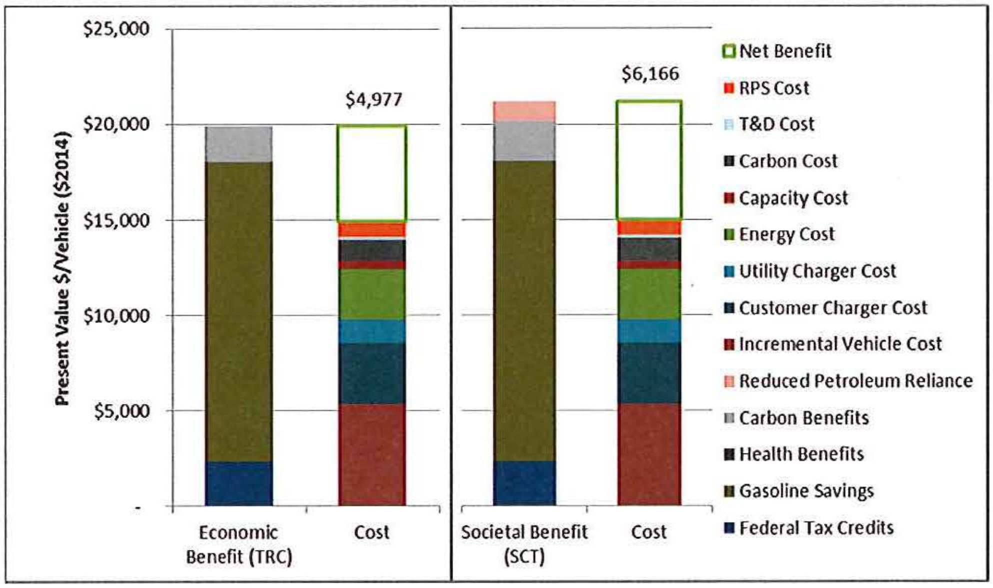

Figure 1. Regional Monetized and Societal Benefits

We expand the evaluation 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) includes 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 Public Utilities Code (PUC) 740.3 and 740.8. In addition, we replace the cap-and-trade GHG allowance costs with a higher estimate of the societal value of reducing GHG emissions. This increases the net benefit to about $6,600 per vehicle, $1,200 (22%) higher than the net benefit under the TRC. This is provided primarily as an illustrative and somewhat conservative result; alternative assumptions could produce net societal benefit values that are much higher.

1.2.2. ROLE OF THE FEDERAL TAX CREDIT

Currently, PEV's provide net economic benefits to California partially because the federal government provides a tax credit for PEVs. Accelerating PEV adoption in the state results in a direct benefit of increasing the amount of federal funds that are directed to California before the cap for the federal tax credit is reached. Increasing adoption also has the indirect benefits of accelerating technological learning and increasing economics of scale in PEV production, which in turn reduces vehicle costs. For a PEV purchased in 2023, the net benefits are lower without the tax credit, but still positive at about $2,700 per vehicle. In 2030, with continued reduction in PEV costs and increases in gasoline prices, net benefits increase to about $5,600 per vehicle, higher than they were in 2015 with the federal tax credit.

1.3. PEV Charging Decreases Rates for all Utility Customers

We use an additional CPUC cost test to show that PEVs also benefit all utility customers and not just the PEV owners themselves. The Ratepayer Impact Measure (RIM) shows that the utility bills PEV owners pay more than offset the costs incurred by the utility to deliver the electricity to charge the vehicles. From the utility customer perspective, revenues from PEV charging are a benefit and the resources expended to deliver electricity for charging are costs. Under each of four rates and charging load shape scenarios studied, additional revenue from PEV charging exceeds the marginal costs to deliver electricity to the customer, providing positive net revenues that put downward pressure on rates (Figure 2). The tiered and flat rate scenarios provide the highest revenues, but also have the highest supply costs, as there is no economic incentive to shift charging to lower cost off-peak periods. The mixed flat and TOU rate and all TOU scenarios do shift charging to off-peak hours, when both the rates and the cost of delivered electricity are lower. The TOU rate scenario results in the lowest net revenues, but also yields the lowest costs for both the utility and the PEV owner.

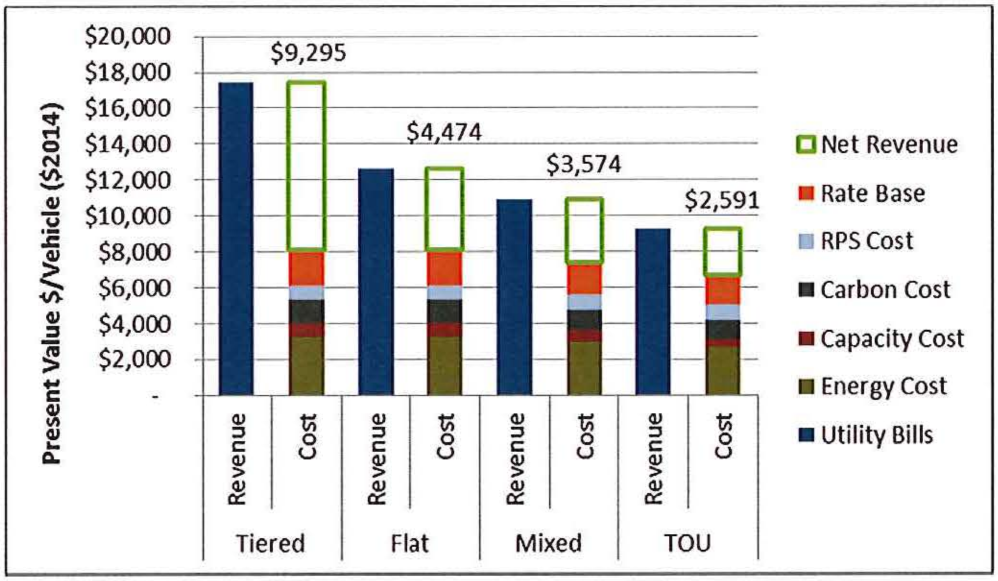

Figure 2. Utility Customer Benefits: Present Value of Revenue and Costs per Vehicle (Ratepayer Impact Measure Cost-test)

1.4. Distribution Costs are Modest in the Near-term

1.4.1. DISTRIBUTION COSTS FOR RESIDENTIAL CHARGING ARE MANAGEABLE IN THE NEAR TERM

One of the main concerns regarding PEV charging has been the impact on utility distribution grids from clustering of PEVs in specific neighborhoods. We use historical hybrid electric vehicle (HEV) registration data and census data to model clustering of PEVs. We then match the PEV clusters to individual circuit, feeder and substation locations for PG&E, SCE, SDG&E and SMUD. We then calculate the incremental load and distribution upgrade costs driven specifically by PEV charging at each location from 2014 through 2030.

For the scenarios studied, distribution upgrade costs for residential charging are manageable. Even under the most aggressive PEV adoption scenario with a flat rate load shape, present value distribution upgrade costs through 2030 are $1.4 billion, roughly $140 million per year across the four utilities or 1.5% of the 2012 distribution revenue requirement of $9 billion for the four utilities. Even with clustering, PEV adoption does not lead to dramatic increases in feeder or substation upgrade costs. Section 1.5 discusses how these distribution costs are significantly reduced with TOU rates that shift PEV charging to off-peak periods.

1.4.2. COSTS TO ACCELERATE PEV ADOPTION WITH MULTI-FAMILY, WORKPLACE AND PUBLIC CHARGING INFRASTRUCTURE MAY BE MORE SIGNIFICANT

Distribution and charging infrastructure costs for multi-family, public and workplace charging locations may be a more significant challenge. These include the so-called "make-ready" or "stub" costs to provide service from the customer meter to individual charging stations. Under the ZEV Most Likely adoption case, charging infrastructure costs total $3.8 billion through 2030, with costs to install Level 2 (240 volt) chargers assumed to be $1,700 and $8,000 at residential and commercial locations respectively. Actual costs will vary by site and depend to a significant extent on the number and cost of public and workplace charging installations as a proportion of the total PEV fleet. Furthermore, our scenarios assume most charging occurs at home - we did not analyze the cost required to dramatically increase access to charging and multi-family, public or workplace locations, which will be necessary to achieve the high penetration of PEVs contemplated under 2050 pathway scenarios. Understanding the costs and implications of multi-family, public and workplace charging for PEV adoption will be an important subject of further study.

1.5. Managed Charging Increases Grid Benefits

1.5.1. BENEFITS OF TOU RATES

Shifting charging to off-peak periods significantly increases the net benefit of PEVs for California – this notwithstanding the finding of modest distribution impacts discussed above. The $5,000 net TRC benefits under the TOU rate/load shape scenario (Figure 1) are $1,400 per vehicle (28%) higher than the $3,600 per vehicle for the tiered and flat rate scenarios (not shown). Charging off-peak reduces the cost of generation, including carbon allowances, by $740 per vehicle. It also defers or avoids investment in generation, transmission and distribution capacity for a combined benefit of $640 per vehicle. Under the ZEV most likely adoption scenario the present value benefit of TOU as compared to flat rate charging is $1.2 billion.

1.5.2. DYNAMIC CHARGING FOR VEHICLE GRID INTEGRATION

PEVs can potentially support higher penetrations of renewable generation on the electric grid – an additional benefit that is not included in the cost-test results presented above. Because most solar generation in the state is located in Southern California and projects must by online by 2016 to be eligible for the Investment Tax Credit,[10] the southern part of the state will experience levels of renewable penetration close to or exceeding 40% before 2020.[11] This will lead to periods of overgeneration where non-dispatchable fossil and renewable generation exceed load.[12] PEV charging can provide grid benefits by absorbing excess generation and reducing the size of the evening ramp in net load.

To illustrate the potential benefits, we compare the cost of delivering electricity for PEV charging under a seasonal TOU and dynamic vehicle grid integration (VGI) rate scenario with 40% renewable penetration. The dynamic VGI scenario reduces the present value of charging costs per vehicle from over $1,400 to under $600 for a net benefit of $850 per PEV. These results were developed using methods and assumptions developed for the SDG&E VGI Application (A. 14-04-014) that is currently before the CPUC. They are not directly comparable to the results presented elsewhere in this report, but are presented to highlight VGI charging as a potential benefit that warrants further investigation.

1.6. New Metrics are Needed to Evaluate PEVs as a GHG Reduction Strategy

We show that PEVs can pass current cost-effectiveness evaluation methods that were developed to evaluate supply and demand side resources on a comparable basis in utility resource planning. In the existing framework, demand side resources that reduce or shift load are valued for reducing the costs and emissions required to meet forecasted demand for energy. These values are based largely on the costs of today's conventional supply side resources that are avoided with distributed resources.

[10] Business Energy Investment Tax Credit, 26 USC § 48 enacted January 2, 2013. See http://dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&re=1&ee=1

[11] "Valuing Energy Storage as a Flexible Resource", Energy and Environmental Economics, June 2014. https://ethree.com/documents/E3_Storage_Valuation_Final_Phase_1.pdf

[12] "Investigating a Higher Renewables Portfolio Standard in California", Energy and Environmental Economics, January 2014. https://ethree.com/documents/E3_Final_RPS_Report_2014_01_06_with_appendices.pdf

Meeting GHG goals and air quality requirements will require transformative acceleration of PEV adoption and unprecedented levels of coordination and cooperation between the utility and transportation sections. New cost-effectiveness metrics are needed to support the infrastructure development to accomplish these goals.

1.6.1. ACCELERATING PEV ADOPTION REQUIRES INFRASTRUCTURE INVESTMENT

By August 2014, over 100,000 PEVs had been sold in California, accounting for roughly 40% of the US market and exceeding sales of hybrid electric vehicles in their first four years on the market a decade ago.[13] We compare current adoption against two future projections in Figure 3. The ZEV "Most Likely" PEV adoption scenario from the TEA Phase 1 Report exceeds 2 million PEVs by 2030, and CARB's 2012 "Vision for Clean Air" includes a scenario to meet 2050 climate goals that exceeds 4 million PEVs by 2030.[14] As ambitious as these scenarios are, EPA ambient air quality standards will require even more rapid early adoption of PEVs. Neither scenario meets the 2023 or 2032 compliance deadline for ozone attainment in South Coast and San Joaquin regions.[15] PEV adoption must not just exceed the historical pace of HEV sales, but continue to grow through 2030 at an arithmetic rate in the ZEV Most Likely scenario and a geometric rate under the CARB vision scenario to achieve 2050 GHG reduction targets.

[13] Lee, Morgan. "CA Has 100K Plug-in Cars, and Counting." San Diego Union-Tribune 8 Sept. 2014.
[14] CARB. Vision for Clean Air : A Framework for Air Quality and Climate Planning. 2012
[15] Greenblatt, Jeffery B. "Estimating Policy-Driven Greenhouse Gas Emissions Trajectories in California." 2013

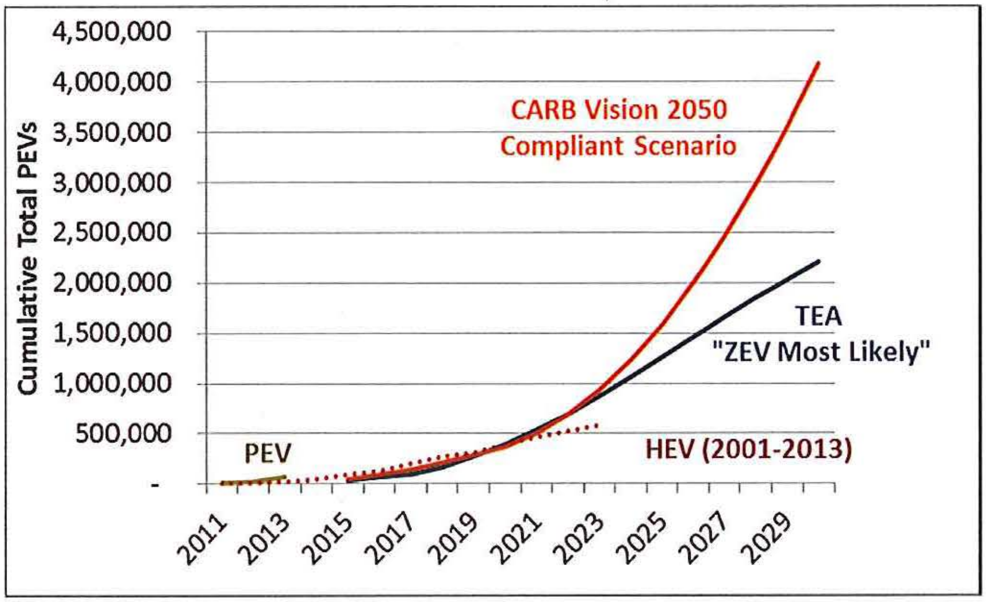

Figure 3. PEV Adoption Scenarios

Most PEV charging is expected to occur at home, but public and workplace charging is nevertheless critical to motivate PEV purchases by reducing range anxiety and to increase electric vehicle miles traveled (eVMT). There are approximately 5,800 public charging outlets and an additional 1,000 private outlets in California (not including home chargers).[16] The California Statewide Plug-In Electric Vehicle Infrastructure Assessments find that public and workplace charging stations must support roughly 230,000 to 410,000 PEV charging sessions daily in 2020 to support the ZEV adoption goal of 1.5 million vehicles by 2025.[17] By 2020, the number of PEVs must increase by a multiple of 3.5 from today, whereas public and workplace charge points will have to increase by more than a factor of 18 at the lower of the above estimates.

[16] http://www.afdc.energy.gov/fuels/electricity_locations.html accessed October 2, 2014.

[17] National Renewable Energy Laboratory (NREL). California Statewide Plug-In Electric Vehicle Infrastructure Assessment. For the California Energy Commission, CEC-600-2014-003. May 2014. Public and workplace charge points from Table 4, p. 16 and charge events per day from Table 8, p. 32. http://www.energy.ca.gov/2014publications/CEC-600-2014-003/CEC-600-2014-003.pdf

1.6.2. NEW METRICS FOR EVALUATING COST-EFFECTIVENESS ARE NEEDED

PEVs are fundamentally different from other distributed energy resources in two key respects. First, PEV's provide net benefits and emissions reductions to California, but the generation needed to serve PEV load will result in emissions increases in the power sector. Second, whereas the primary purpose of promoting DER has been to reduce the costs and emissions required to meet forecasted load, California seeks to accelerate PEV adoption to meet GHG reduction and air quality targets. Furthermore, achieving these goals will require fundamental market transformation in both the utility and transportation sectors with new and unconventional technologies that are not widely used today.

Although we show that PEV's can be cost-effective using existing CPUC and CARB methodologies, these tests were not developed to address these statewide challenges. We propose that new tests are needed to evaluate initiatives designed to meet long-term GHG reduction 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.[18] 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.

[18] Emerging technology programs in energy efficiency are a prime example - the purchase price and cost of ownership for LED bulbs, compact florescent bulbs (CFLs) and front-loading clothes washers have fallen even as performance has increased.

2. Introduction

California has set itself the ambitious challenge of reducing its greenhouse gas emissions to 80% below 1990 levels by 2050. Achieving this goal will require changes in many sectors of the Californian economy, but few will be as important as those that take place in transportation. Transportation accounts for about 38% of California's total emissions, the largest of any economic sector.[19] The path that California's transportation sector takes in the next decade will thus be a key determining factor in whether California is able to meet its climate goals. Governor Jerry Brown's goal and CARB's regulation to have 1.5 million zero emissions vehicles on the road by 2025 are an important step toward California's 2050 climate goal.

Electric vehicles and their connection to California's electric grid are one of the most rapidly evolving clean transportation options. Relative to their gasoline counterparts in California, plug-in hybrid electric vehicles (PHEV) reduce "well-to-wheel"[20] GHG emissions and smog forming emissions by 60%. For battery electric vehicles (BEV) the reductions are even higher - 85% for GHG and 90% for smog forming emissions.[21]

The first commercially available plug-in electric vehicle was introduced in 2010,[22] and new models from a variety of companies have been introduced every year since.[23] Studies evaluating the technology pathways needed to meet 2050 climate goals find that 70% of vehicle miles traveled — including almost all light-duty vehicle miles — must be powered by electricity.[24,25,26,27] Battery manufactures and

[19] "2014 Edition: California Greenhouse Gas Emission Inventory: 2000-2012." California Air Resources Board, 2014. Accessed 13 Oct 2014. http://www.arb.ca.gov/cc/inventory/pubs/reports/ghg_inventory_00-12_report.pdf

[20] "Well-to-wheel" includes emissions from fuel production and delivery (well-to-tank) and vehicle use (tank-to-wheel)

[21] CARB. "Advanced Clean Car Summary." Figure 6 and Figure 7, p. 16. http://www.arb.ca.gov/msprog/consumer_info/advanced_clean_cars/acc.htm. Accessed October 15, 2014

[22] "The History of the Electric Car." U.S. Department of Energy, 2014. Accessed 13 Oct 2014. http://www.energy.gov/articles/history-electric-car

[23] "Electric Vehicle Timeline: Electric Cars, Plug-In Hybrids, and Fuel Cell Vehicles." Union of Concerned Scientists, 2014. Accessed 13 Oct 2014. http://www.ucsusa.org/clean_vehicles/smart-transportation-solutions/advanced-vehicle-technologies/electric-cars/electric-vehicle-timeline.html#.VDx9USlkFps

[24] Williams, James H et al. "The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity." 2012.

[25] Wei, Max et al. "Deep Carbon Reductions in California Require Electrification and Integration across Economic Sectors." Environmental Research Letters 8.1 (2013): 14038.

[26] Greenblatt, Jeffery B. "Estimating Policy-Driven Greenhouse Gas Emissions Trajectories in California." 2013.

[27] Scown, Corinne D et al. "Achieving Deep Cuts in the Carbon Intensity of U.S. Automobile Transportation by 2050: Complementary Roles for Electricity and Biofuels." Environmental science & technology 47.16 (2013): 9044–52.

auto makers are focused on reducing the cost and increasing the capability of electric vehicles, and the number and variety of PEV models is growing each year. To enable and encourage accelerated PEV adoption, infrastructure must be deployed to provide readily accessible charging not just in single-family homes, but also in multi-family, public and workplace locations. This report suggests that charging stations and the distribution infrastructure required to serve them can be deployed with net benefits for the economy, environment and all utility ratepayers.

2.1. Transportation Electrification Assessment

The California Transportation Electrification Assessment Phase 1 Report (TEA Phase 1 Report)[28] describes the market size, environmental and societal benefits of transportation electrification (TE), focusing on four segments in particular: plug-in electric vehicles (PEVs), forklifts, truck stop electrification and transport refrigeration units. The Phase 1 Report found that 2.3 million PEVs could displace 5.8 million metric tons (MMT) of GHG in 2030, 50% of the total GHG reduction for all TE sectors in the "In Between" adoption scenario. On an individual basis, a battery electric vehicle (BEV) displaces 252 gallons of gasoline equivalent (GGE) and 2.06 metric tons (MT) of GHG in 2030 relative to an ICE.[29]

Achieving these environmental benefits and meeting long-term GHG goals with increased PEV adoption will also require a corresponding acceleration in the deployment of charging stations and their supporting infrastructure on both the utility and customer side of the electric meter. Widespread PEV adoption must be supported by dramatically increased access to charging at single-family, multi-family and workplace locations alike.[30]

This TEA Phase 2 Report provides an in-depth analysis of electric infrastructure costs that will be incurred to support PEV charging, with an emphasis on utility distribution systems. We use the inputs, scenarios and results from the Phase 1 Report to describe the impacts, costs and benefits of PEV adoption for electric utilities, their customers and the state as whole. We perform the analysis collectively for PG&E, SCE, SDG&E and SMUD, all of which provided detailed distribution system data for the study.

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

[29] TEA Phase 1 Report, Table 54, p. 86.

[30] Traut, Elizabeth J. et al. "US Residential Charging Potential for Electric Vehicles." Transportation Research Part D: Transport and Environment 25 (2013): 139–145.

2.2. PEV Cost-Effectiveness Evaluation

The TEA Phase 1 Report presents results largely following the CARB cost-effectiveness method that evaluates the incremental cost of emission-reducing technologies against the quantity and societal value of the emissions reduced.[31] CARB uses this method to determine which programs are providing the most cost-effective emissions reductions.

In this TEA Phase 2 Report, we present results using California Public Utilities Commission (CPUC) Standard Practice Manual (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 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.

We describe the PEV adoption and load shape scenarios employed for the analysis in Section 3. In Section 4, we describe how we mapped PEV clusters to specific locations on the distribution systems of the utilities to quantify load impacts and the costs of PEV related distribution upgrades. We describe how we perform cost-effectiveness analysis following CARB and CPUC methods in Section 5. The results, which show that PEVs provide economic, societal and ratepayer benefits are presented in Section 6. In Section 7 we describe the potential for daytime PEV charging to provide addition benefits under higher levels of renewable penetration. Section 8 describes why we must develop new cost-effectiveness metrics to evaluate PEVs and a GHG reduction strategy. Finally, we summarize our conclusions in Section 9.

[31] 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

2.3. Infrastructure Investment Needed to Support PEV Adoption

By August 2014, over 100,000 PEVs had been sold in California, accounting for roughly 40% of the US market and exceeding sales of hybrid electric vehicles in their first four years on the market a decade ago.[32] We compare current adoption against two future projections in Figure 4. The ZEV "Most Likely" PEV adoption scenario from the TEA Phase 1 Report exceeds 2 million PEVs by 2030, and CARB's 2012 "Vision for Clean Air" includes a 2050 scenario that exceeds 4 million PEVs by 2030.[33] As ambitious as these scenarios are, EPA ambient air quality standards will require even more rapid early adoption of PEVs. Neither scenario mentioned above meets the 2023 or 2032 compliance deadline for ozone attainment in South Coast and San Joaquin regions.[34] PEV adoption must not just exceed the historical pace of HEV sales, but continue to grow through 2030 arithmetically in the ZEV Most Likely scenario exponentially under the CARB vision scenario to achieve 2050 GHG reduction targets.

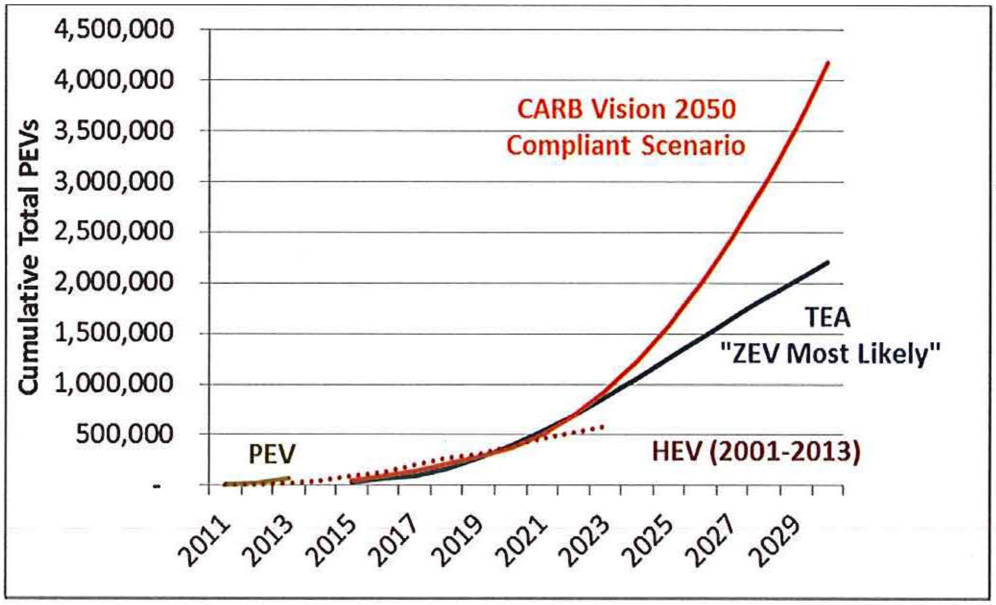

Figure 4. PEV Adoption Scenarios

[32] Lee, Morgan. "CA Has 100K Plug-in Cars, and Counting." San Diego Union-Tribune 8 Sept. 2014.
[33] CARB. "Vision for Clean Air : A Framework for Air Quality and Climate Planning." 2012.
[34] Greenblatt, Jeffery B. "Estimating Policy-Driven Greenhouse Gas Emissions Trajectories in California." 2013.

Most PEV charging is expected to occur at home, but public and workplace charging is nevertheless critical to motivating PEV purchases by reducing range anxiety and increasing electric vehicle miles traveled (eVMT). If PEVs are to reach substantial penetration levels in the passenger and commercial vehicle markets, new infrastructure must be deployed to support them. Home charging is convenient in many aspects, but alone is not sufficient to support the high market penetration of EVs envisioned to meet GHG and air pollution targets. At home charging is not currently available for most renters or multi-family residences, which limits PEV adoption. Furthermore, if owners rely solely on at home charging, eVMT for PEVs is limited to the range provided by a single battery charge. If EVs are to gain widespread popularity and contribute substantially to emissions reductions in the transportation sector, a readily accessible network of publicly available chargers will be essential.

From today's starting point, it appears that the number of public and workplace charge points must grow at an even faster rate than PEVs themselves. There are approximately 5,800 public charging outlets and an additional 1,000 private outlets California (not including home chargers).[35] The California Statewide Plug-In Electric Vehicle Infrastructure Assessments find that public and workplace charging stations must support roughly 230,000 to 410,000 PEV charging sessions daily in 2020 to support the ZEV adoption goal of 1.5 million vehicles by 2025.[36] By 2020, the number of PEVs must increase by a multiple of 3.5 from today, whereas public and workplace chargers will have to increase by a more than a factor of 18 at the lower of the above estimates.

2.4. PEVs as a GHG Reduction Strategy

The cost tests presented above were developed to evaluate supply and demand side resources on a comparable basis in utility resource planning. Demand side resources that reduce or shift load are valued for reducing the costs and emissions required to meet forecasted demand for energy.

Programs promoting PEV adoption and charging infrastructure deployment are uniquely positioned to provide GHG reductions and utility customer benefits. However, PEVs are fundamentally different from distributed energy resources heretofore considered in utility integrated resource planning in two key respects.

[35] http://www.afdc.energy.gov/fuels/electricity_locations.html accessed October 2, 2014.
[36] NREL. " California Statewide Plug-In Electric Vehicle Infrastructure Assessment." 2014. Public and workplace charge points from Table 4, p. 16 and charge events per day from Table 8, p. 32

First, PEV's provide net benefits and emissions reductions to California, but the generation needed to serve PEV load will result in emissions increases in the power sector. Second, whereas the primary purpose of promoting DER has been to reduce the costs and emissions required to meet forecasted load, California seeks to accelerate PEV adoption to meet GHG reduction and air quality targets. Evaluating PEVs as a GHG reduction strategy will require a more comprehensive evaluation of utility and transportation sector costs and benefits, including long-term GHG and criteria pollutant emissions benefits.

Public Utility Code (PUC) Sections 740.3 and 740.8 suggest one step in this direction.[37] The code describes direct benefits from low-emission vehicles that are "interests" of ratepayers, including:

+ Providing safer, more reliable, or less costly gas or electrical service
+ Promoting energy efficiency
+ Reducing health and environmental impacts from air pollution and greenhouse gas emissions and
+ Increased use of alternative fuels.

This report describes how PEV's, even without vehicle-to-grid (V2G) capability, can reduce average rates and increase the beneficial use of existing utility infrastructure. With properly designed dynamic rates or managed charging, PEV's increase grid reliability under high RPS scenarios by absorbing overgeneration and reducing morning and evening ramps. PEVs compared to their gasoline counterparts on a "well-to-wheel" basis[38] increase electric loads, but reduce total energy use, providing significant reductions in GHG and criteria pollutant emissions (see Introduction, p. 24). Finally, with accelerated vehicle adoption, the electric (and natural gas) utilities can provide increased quantities of alternative transportation fuel in the near-term with existing and ubiquitous transmission and distribution infrastructure.

[37] See http://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=PUC&division=1.&title=&part=1.&chap ter=4.&article=2.

[38] Well-to-wheel basis means including all of the fuel related emissions from fuel feedstocks (e.g. crops or fossil fuel mines and wells) and fuel production and delivery(e.g. power plant or refinery), jointly well-to-tank, and vehicle use (tank-to-wheel).

3. PEV Adoption and Load Shape Scenarios

3.1. Vehicle Forecasts

A working group of utility and consultant staff developed three vehicle adoption scenarios included in the Phase 1 report and used for this analysis. The scenarios are designed not to be precise predictions of future vehicle adoption, but rather to illustrate grid impacts and cost and benefits under a low, medium and high adoption scenario (Figure 5). The three scenarios are:

- **ZEV Compliance**: ZEV compliance assuming a 50/50 split between PEVs and fuel cell vehicles.
- **ZEV Program "Most Likely Compliance Scenario"**: In the development of the Zero Emission Vehicle Program, CARB staff developed a most likely compliance scenario.[39] This scenario was modified to reflect recent PEV sales data and to extend out to 2030.
- **ZEV Program Scenario x 3**: This scenario is three times larger than the ZEV program's most likely compliance scenario.

[39] CARB. "Staff Report: Initial Statement of Reasons: 2012 Proposed Amendments to the California Zero Emission Vehicle Program Regulations." http://www.arb.ca.gov/regact/2012/zev2012/zevisor.pdf

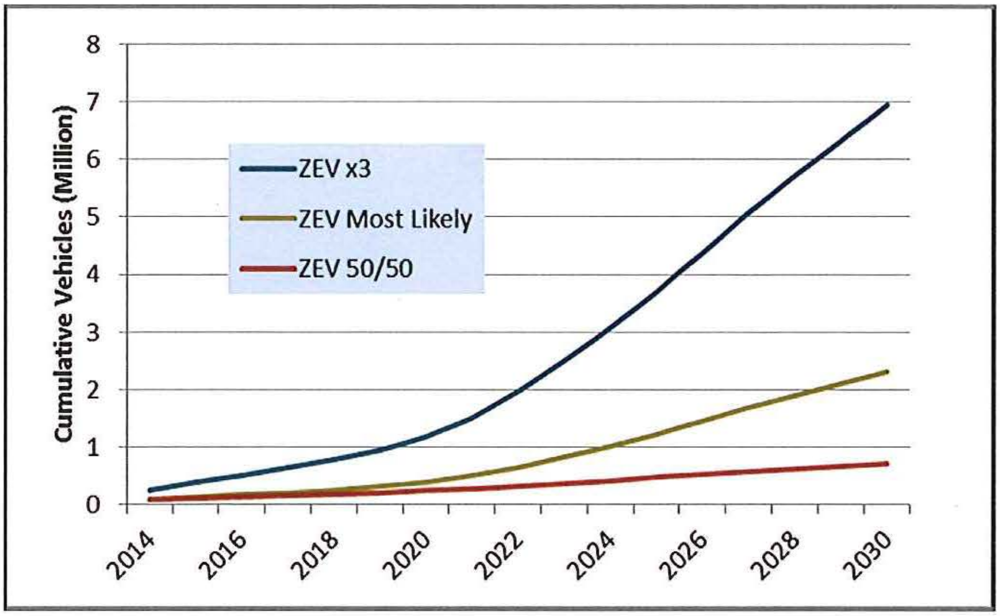

Figure 5. PEV Adoption Scenarios

3.2. Energy Consumption

The working group developed energy consumption estimates based on vehicle miles traveled and energy consumption by PEV type data from the EV Project (Table 1). Data from utilities in California and reported by The EV Project indicates that about 74-80 percent of charging is happening at home and 20-26 percent is happening away from home. The working group assumed that 80 percent of charging will occur at home for most of the scenarios.

Table 1. PEV Energy Consumption (kWh), by Vehicle Type[40]

Vehicle Type	Vehicle Miles Traveled		eVMT		Energy Consumption (kWh)					
					Daily			Annual		
	Daily	Annual	Daily	Annual	Res	Non-Res	Total	Res	Non-Res	Total
PHEV10	41	14,965	10.0	3,650	2.8	0.7	3.5	1,022	256	1,278
PHEV20			20.0	7,300	5.6	1.4	7.0	2,044	511	2,555
PHEV40			30.6	11,169	8.6	2.1	10.7	3,127	782	3,909
BEV	29.5	10,768	29.5	10,768	8.3	2.1	10.3	3,016	754	3,770

3.3. Load shapes

The working group developed several normalized load shapes with the general characteristics described below and illustrated in Figure 6.

- **L1 Home** with TOU rate: Level 1 charging at home is a proxy for charging of PHEVs with smaller batteries, like the PHEV10 or PHEV20. The normalized profile is based on a similar start time as L2 charging; however, it is stretched out over a longer period.
- **L2 Home** with TOU Rate: Level 2 charging at home is a proxy for BEV or PHEV40 charging.
- **Non TOU Home**: Residential charging in the non-TOU case is a modified version of what is reported in the EV Project for Nashville, Tennessee – a region without a TOU rate. The modifications were made based on the at-home arrival times reported in the National Household Transportation Survey (NTHS).

[40] TEA Phase 1 Report, Table 35, p. 68

+ **L2 Non-Residential:** The non-residential charging is a proxy for workplace charging (weekdays) and public charging (weekends) and is used in the TOU scenario and the Flat Rate Scenario. Assumed to be all Level 2 charging.

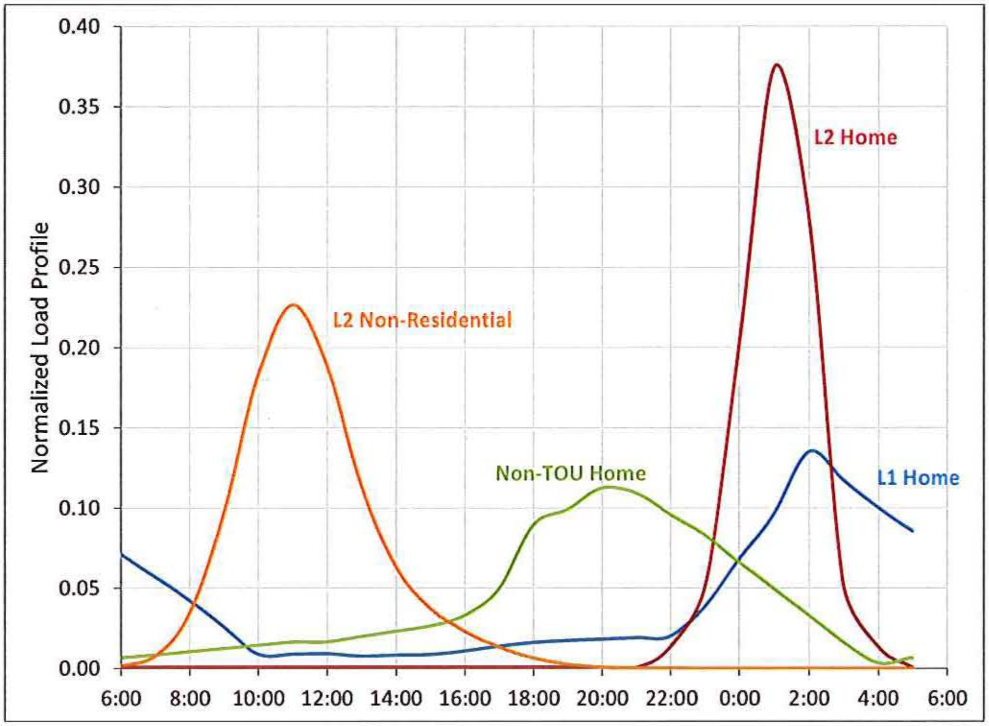

Figure 6. Load Profiles for Various Charging Scenarios

3.4. Rate and Load Shape Scenarios

The working group developed four scenarios that represent a combination of rates and load profiles (Figure 7):

+ **Tiered Rate Scenario:** This scenario assumes that PEV drivers charge immediately when they arrive at a destination (Flat Rate Scenario Load Shape). A tiered, non-TOU rate applies to residential charging and a flat rate applies to commercial charging

+ **Flat Rate Scenario**: This scenario assumes that PEV drivers charge immediately when they arrive at a destination (Flat Rate Scenario Load Shape). A flat rate applies to residential and commercial charging (no tiers or TOU variation).
+ **Mixed Rate Scenario:** This scenario assumes a 50-50 split between the TOU Rate Scenario (below) and the Flat Rate Scenario. This includes both load shapes and retail rates.
+ **TOU Rate Scenario**: PEVs are assumed to charge on TOU rates with the majority of charging shifted to off-peak times.

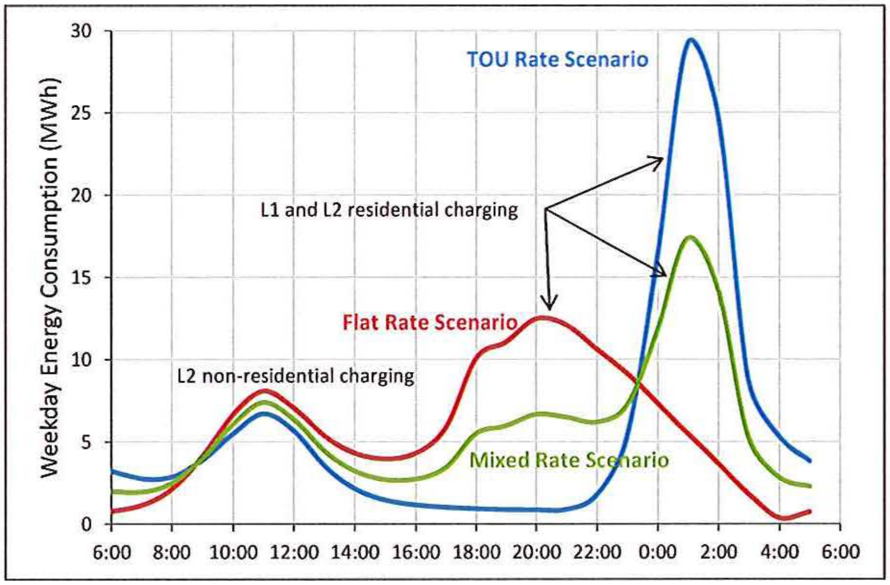

Figure 7. Illustrative Charging Load Shapes for 15,000 PEVs

4. Analysis of PEV Grid Impacts

The potential impact on the utility distribution system is one of the primary concerns related to PEV charging. For this study, with significant support from utilities, we performed an in-depth analysis of the PEV-related load growth and associated distribution feeder and substation upgrades.

4.1. PEV Clustering

PEVs, like HEVs and rooftop solar photovoltaics (PV), will cluster in certain areas. Clustering presents a potential challenge for the utility distribution system, as a few PEVs charging coincident with the distribution peak could exceed the rated capacity of installed equipment. To account for clustering, we allocated the forecasted PEV adoption to ZIP+4 zones with weightings based on historical hybrid electric vehicle (HEV) adoption.

Polk vehicle registration data provides the number of HEVs located in each ZIP+4 area in California. We used this data in combination with census demographic data to apportion PEV vehicle adoption forecasts by ZIP+4 area based on historical HEV adoption. We assume that the majority of PEV buyers will also want to install convenient home charging equipment. We therefore assume that PEV adoption will be more heavily weighted towards areas with single family (SF) and owner occupied dwellings and use census data to adjust PEV allocations accordingly. An example of the adjusted HEV numbers used to apportion PEV adoption for ten ZIP+4 areas is shown in Table 2.

Table 2: Example HEV Registration Data by ZIP+4

ZIP+4	SF Owner	MF Owner	SF Renter	MF Renter	Census Modifier	# of HEVs	Adj. HEVs
92127-1708	47%	20%	21%	9%	54%	15	8.1
92130-2122	100%	0%	0%	0%	100%	15	15.0
92131-2965	31%	35%	14%	16%	41%	15	6.2
92101-1128	4%	15%	17%	61%	10%	13	1.3
92111-7319	23%	37%	12%	19%	34%	13	4.4
92123-3839	55%	12%	22%	5%	60%	13	7.8
92117-5531	50%	6%	37%	4%	55%	7	3.8
92121-2312	66%	16%	14%	3%	72%	7	5.0
92009-7516	19%	27%	16%	23%	27%	4	1.1
92009-7802	64%	19%	11%	3%	70%	4	2.8

4.2. Utility Distribution Systems

Utility staff was very helpful in gathering and providing detailed distribution system data for use in this study. Distribution system data was provided by PG&E, SCE, SDG&E, and SMUD. For consistency across all utilities, we developed a common topology for use in describing each system (Figure 8). The distribution system equipment categories and their approximate size ratings are:

+ **Substation** (~75-150 MVA): Distribution substation, including high-voltage (high-side) switches, fuses, etc.
+ **Substation Transformer** (~12-70 MVA): Low-voltage (low-side) transformers, bus, breakers, fuses, switches, etc.
+ **Feeder** (~2-30 MVA): Primary voltage feeder connected to low side bus of substation, primary conductor, breakers, fuses, switches, and pad mount transformers.
+ **Circuit** (75-2,000 kVA): Secondary voltage circuit between feeder and customer interconnection, distribution transformer, final line/network/pole mount transformer, secondary conductor, distribution panel.

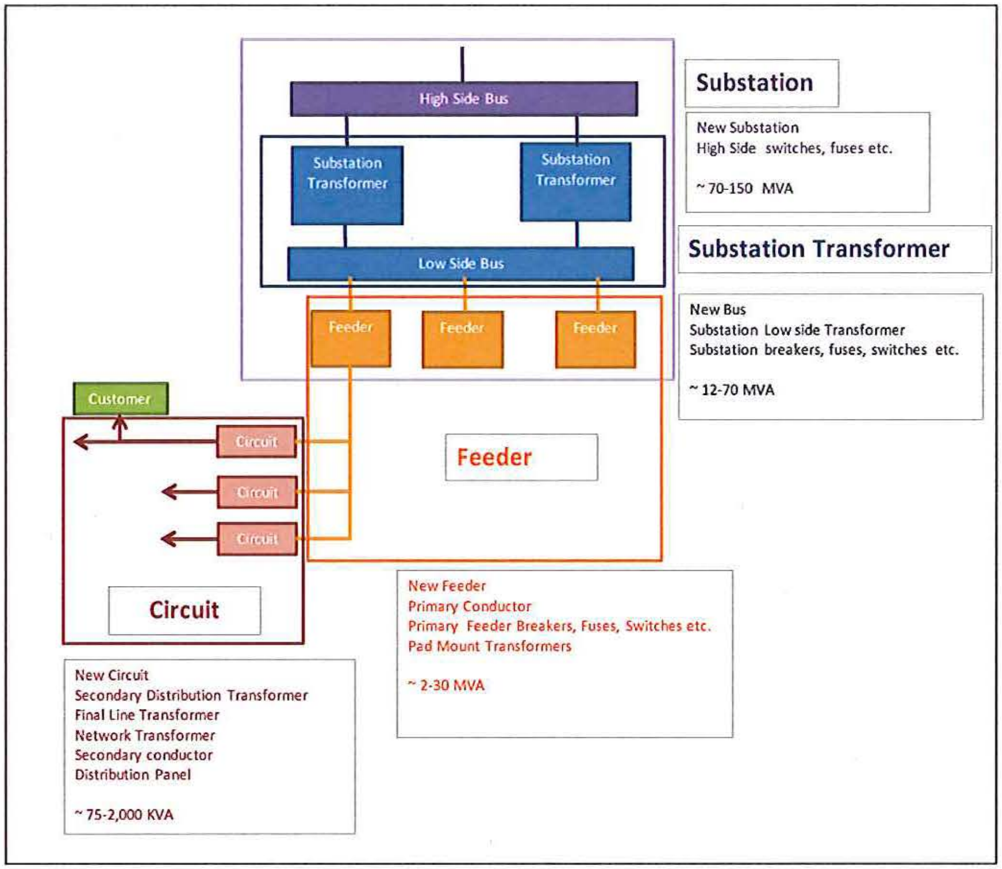

Figure 8. Distribution System Topology

4.2.1. DATA PROVIDED

The data provided by the utilities is illustrated in Table 3. Each utility provided detailed information on the circuits, feeders and substations in their service territory, including capacity rating, utilization, peak loads, and number of residential and commercial accounts and forecasted load growth. The utilities also provided latitude and longitude location information for each data point.

Table 3: Example Utility Distribution Data

	Substation Name	Rating (kV)	Sub Rating (MVA)	Bank Rating (MVA)	Feeder Capability (MW)	Peak kW	Peak Day for Feeder	Available Capacity (kW)	Utilization	Growth	Non Res	Res
Circuit	Valley	21	151	45	19.0	14,267	6/29/2013	4,733	75%	1.25%	288	3,612
Circuit	Valley	21	151	45	21.3	15,224	7/1/2013	6,076	71%	1.25%	168	3,498
Circuit	Valley	21	151	45	21.8	5,056	7/1/2013	16,744	23%	1.25%	116	1,249
Substation Bus					45.0	34,545		10,455	77%	1.25%		
Circuit	Valley	21	151	45	22.6	18,750	6/29/2013	3,850	83%	1.25%	256	3,730
Circuit	Valley	21	151	45	19.0	13,905	7/1/2013	5,095	73%	1.25%	253	4,212
Substation Bus					45.0	32,566		12,434	72%	1.25%		
Circuit	Valley	21	151	45	21.5	13,903	7/1/2013	7,597	65%	1.25%	357	4,097
Circuit	Valley	21	151	45	22.6	17,290	7/3/2013	5,310	77%	1.25%	312	3,753
Circuit	Valley	21	151	45	19.0	5,103	7/1/2013	13,897	27%	1.25%	114	1,581
Substation Bus					45.0	36,051		8,949	80%	1.25%		
Circuit	Valley	12	151	16	9.1	6,067	7/1/2013	3,033	67%	1.25%	105	1,683
Circuit	Valley	12	151	16	5.0	2,421	7/1/2013	2,579	48%	1.25%	22	710
Substation Bus					14.1	8,488		5,612	60%	1.25%		
Substation			151.0		149.1	111,223		37,450	75%	1.25%		

In all, the investor-owned utilities (IOUs) provided data for 7,894 feeders and 1,607 substations located in their respective service territories. SMUD provided data at the circuit level, for a much larger number of data points, over 73,000. SMUD's substations also tend to be smaller than those of the IOUs', accounting for the larger number substations relative to its size as compared to the IOUs.

Table 4: Distribution Data Provided by Each Utility

	Circuits & Feeders	Substations
PG&E	3,186	780
SCE	4,031	706
SDG&E	677	121
SMUD	73,786	637

4.2.2. 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 5 and Table 6). 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 5. 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%

Table 6. Substation Upgrade Costs

	PG&E	SCE	SDG&E	SMUD
Expansion Size (MVA)	30	30	30	30
Expansion Cost ($)	$3,800,000	$5,000,000	$1,500,000	$2,500,000
New Size (MVA)	60	60	60	35
New Cost ($)	$18,400,000	$47,000,000	$31,800,000	$5,000,000
Utilization Upgrade Trigger	90%	90%	90%	90%
Pct. Eligible for Expansion	50%	50%	60%	33%

4.3. Mapping PEV Clusters to Distribution System

The final step in the clustering analysis is mapping each ZIP+4 cluster of PEVs to circuits and feeders on the utility distribution systems. Geographic Information System (GIS) analysis mapped each ZIP+4 area to the closest utility circuit or feeder according to its latitude and longitude information. In nearly all cases, there is a one to one mapping of PEV ZIP+4 clusters to a single circuit (for SMUD) or feeder (for the IOUs).

Schedule DRI-3

4.4. PEV Load Impacts

With the combination of the PEV adoption scenarios, PEV load shapes and PEV clusters, we calculated the PEV-related peak load growth that would occur at each location on the distribution system for each scenario. With the utility distribution system data, we are able to calculate utilization at each point with the total forecasted load growth, including incremental PEV charging load. The results are illustrated for the San Francisco Bay Area in (Figure 9). This figure shows the percentage utilization of each point on the distribution system with the ZEV Most Likely adoption scenario and Mixed Rate scenario, assuming no additional capacity-related upgrades. In 2010, most locations are green or light yellow, indicating utilization below 100%. By 2020 several locations have changed from green to yellow and a few are red, indicating utilization of close to 150% or more. By 2030, most, but not all locations are close to or greater than 100% utilization.

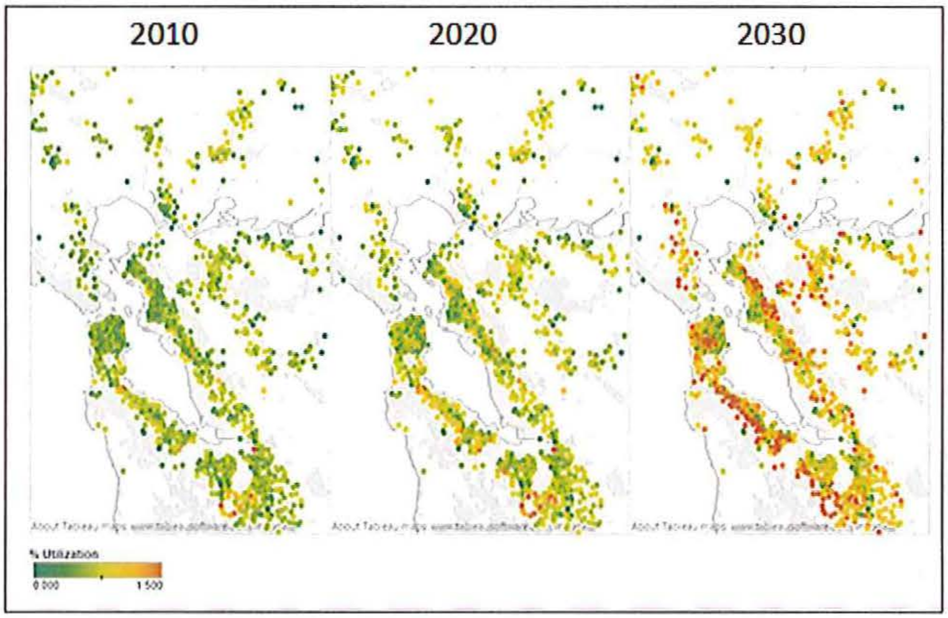

Figure 9. Distribution System Utilization with PEV Charging

4.5. PEV Related Distribution Upgrades

To examine the grid impacts specific to PEV charging, we first model distribution upgrades required to meet the base case forecasted load growth provided by each utility. We then add the hourly PEV-charging load for each adoption and rate scenario to the base case load forecast and model the required distribution upgrades. We count the incremental distribution upgrades in the PEV charging case as being PEV related. The additional distribution upgrade cost with PEV 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 PEVs.

The upgrades associated specifically with PEV loads are illustrated in Figure 10 and Figure 11. The maps on the left show upgrades required under the ZEV Most Likely – Mixed Rate scenario for the Los Angeles and San Francisco Bay areas respectively. The maps on the right show the upgrades required under the higher ZEV x 3 adoption scenario.

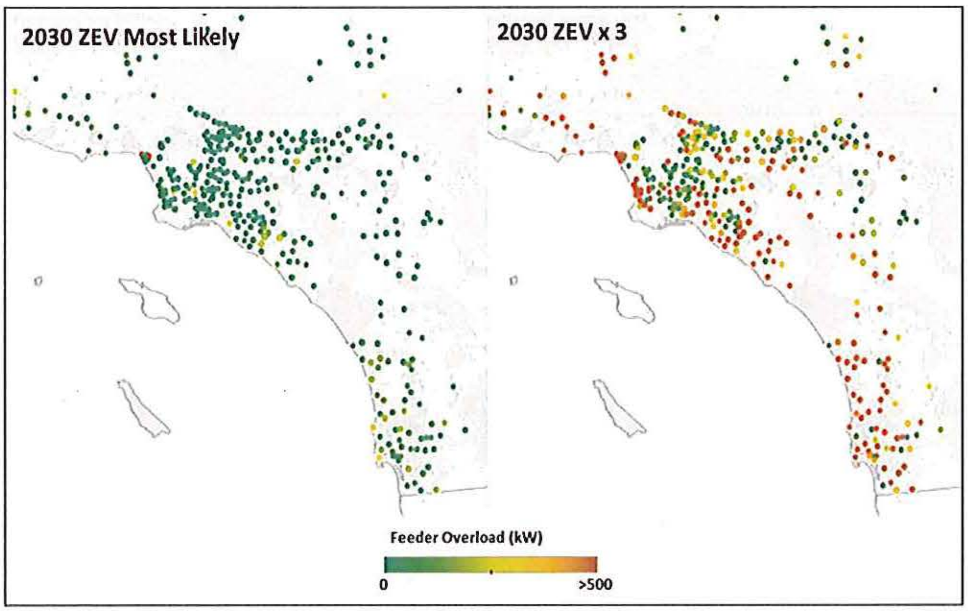

Figure 10. 2030 Distribution System Upgrades Driven by PEV Charging: Los Angeles Area

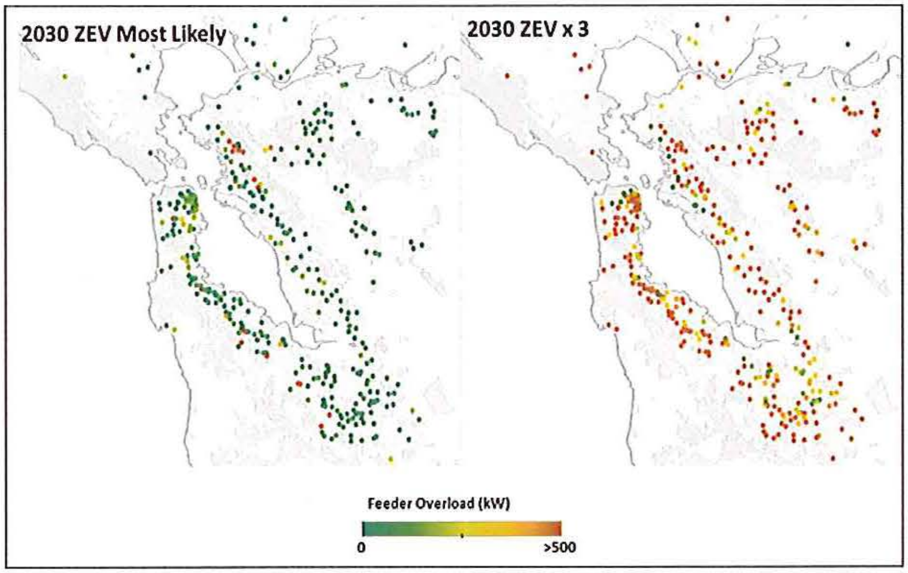

Figure 11. 2030 Distribution System Upgrades Driven by PEV Charging: San Francisco Bay Area

4.6. PEV Charging and Infrastructure Costs

The input assumptions for this Phase 2 report are largely the same as those used in the TEA Phase 1 Report. One difference is that the utility working group members suggested they are experiencing higher costs to install service for commercial Level 2 (L2) charging than the ~$1,700 assumed in Phase 1. Cost varies widely due to a number of factors at each specific site and is difficult to quantify precisely at this early stage of adoption. We use a more conservative estimate of $8,000 per commercial Level 2 charger. Costs to provide new electric service are $1,700 and borne by the utility. The "make-ready" costs to deliver electricity from the point of utility interconnection to the charger and charger itself are assumed to cost $6,300 and to be paid by the customer. For fleet vehicles, one Level 2 charger is installed per vehicle. For residential PEVs, we assume two Level 2 commercial chargers are installed for every ten vehicles (0.2 chargers per PEV).

Table 7. PEV Charging and Infrastructure Costs

	Charging Infrastructure Cost		
	L1 Residential	L2 Residential	L2 Commercial
Customer	$200	$1,000	$6,300
Utility		$700	$1,700
Total	$200	$1,700	$8,000

4.7. Distribution System Costs

4.7.1. DISTRIBUTION COSTS FOR AT HOME CHARGING

Recall that the scenarios assume the 80 percent or more of vehicle charging will occur at home. Under these scenarios studies, we find that the incremental feeder and substation upgrades driven specifically by incremental PEV charging to be relatively small. In the non-TOU rate scenarios, the present value costs are just under $400 million in the ZEV Most Likely adoption case (Figure 12). TOU Rates shift charging off-peak and reduce upgrade costs by over 40% to under $150 million. Under the more aggressive ZEV x 3 adoption case, the present value distribution costs increase to $910 million (Figure 13). Note that the distribution upgrade costs do not increase linearly between the ZEV Most Likely and ZEV x 3 case. At higher levels of adoption, the available capacity of the existing system is exhausted more quickly, and the PEV related upgrades are larger in both number and size. Nevertheless, even at the ZEV x 3 adoption case, annual distribution costs are roughly $9 million per year - less than 1% of the 2012 distribution revenue requirement of $9 billion for the four utilities.

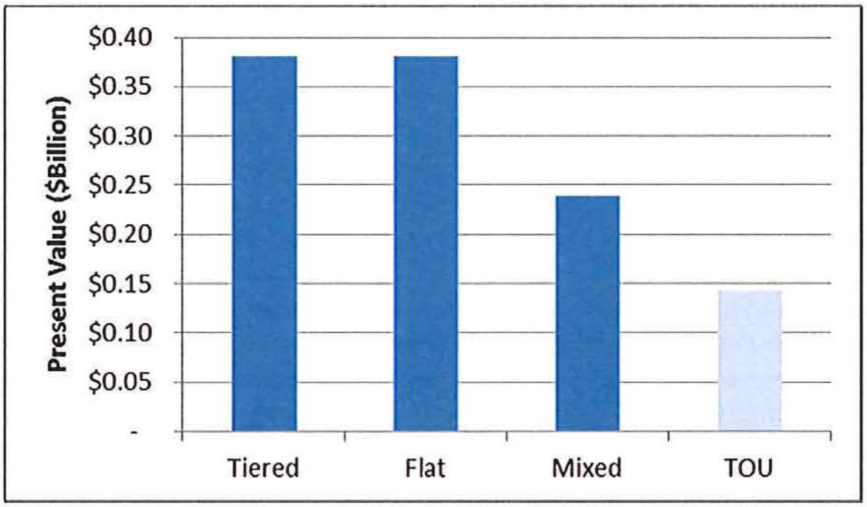

Figure 12. Present Value Distribution Upgrade Costs by Rate/Load Shape Scenario

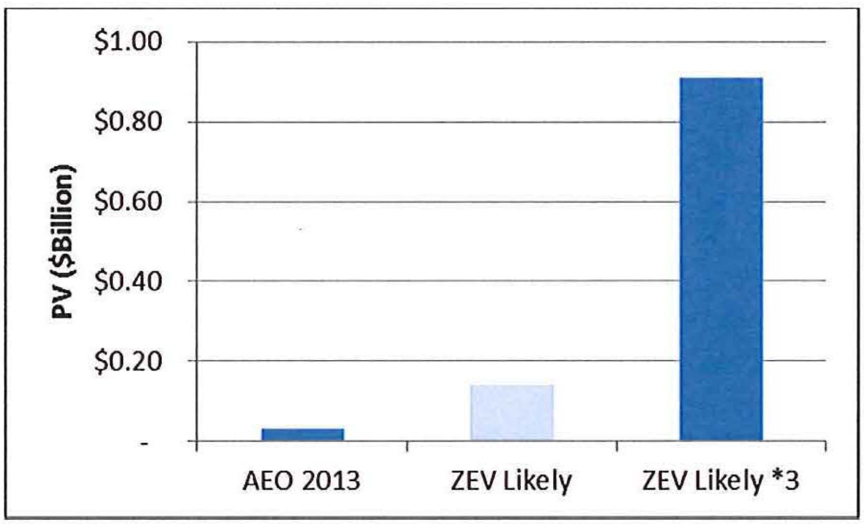

Figure 13. Present Value Distribution Upgrade Costs by Adoption Scenario

4.7.2. INFRASTRUCTURE COSTS FOR MULTI-FAMILY, PUBLIC AND WORKPLACE CHARGING

The adoption and load shape scenarios developed for this study do not include high levels of public and workplace charging. Furthermore, we use an average cost of

$8,000 to represent make ready costs for multi-family and workplace Level 2 charging. Other studies propose that higher access to multi-family, public and workplace charging will be necessary to promote PEV ownership beyond single family home owners. Public and workplace charging will also be needed to maximize the eVMT realized from PEVs. Dramatically increasing charging at these locations may well require make-ready and other infrastructure costs not fully represented in this study.

In addition, in Section 7 below, we discuss the potential benefits of daytime PEV charging to manage higher penetrations of renewables on the grid. Higher levels of daytime charging to absorb excess generation will provide benefits, but may also coincide at times with peak loads on the distribution system. Avoiding PEV charging coincident with peak distribution loads can be achieved with managed charging, but alternative strategies to absorb overgeneration will be required during those hours. Maximizing the availability of PEVs as a resource for renewable integration may require additional fortifications to the distribution system not contemplated in this study.

5. Cost-Effectiveness Analysis

5.1. Cost-Effectiveness Framework

5.1.1. 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."[41] 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).

5.1.2. CPUC COST-EFFECTIVENESS FRAMEWORK

5.1.2.1. 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

[41] 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

approaches used for evaluating DER programs across the United States.[42] The five cost tests are summarized in Table 8.

Table 8. 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[43]	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.

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[42] 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/

[43] 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.

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

Table 9: 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

5.1.2.2. 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 10.

Table 10: 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 14 and Figure 15. On an illustrative spring weekday, generation energy is the dominant cost (Figure 14). Generation capacity and T&D capacity costs are allocated predominately to a limited number of summer peak hours (Figure 15).

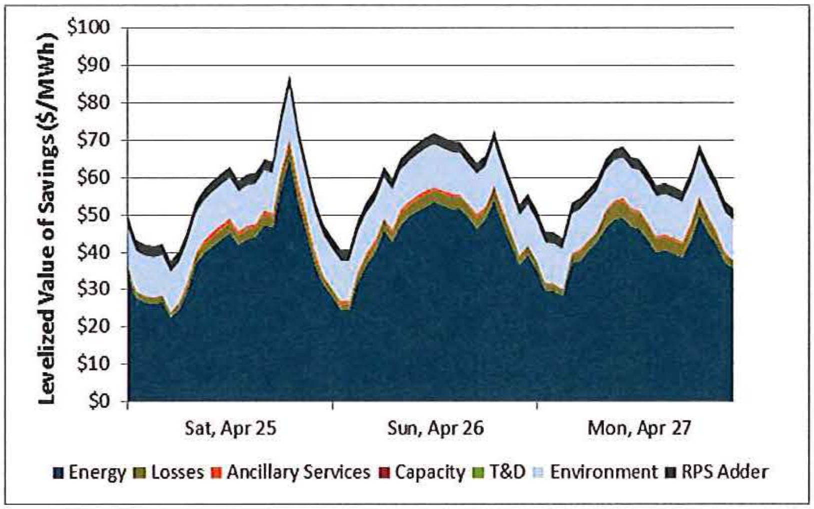

Figure 14. DER Avoided Costs – Spring Weekdays

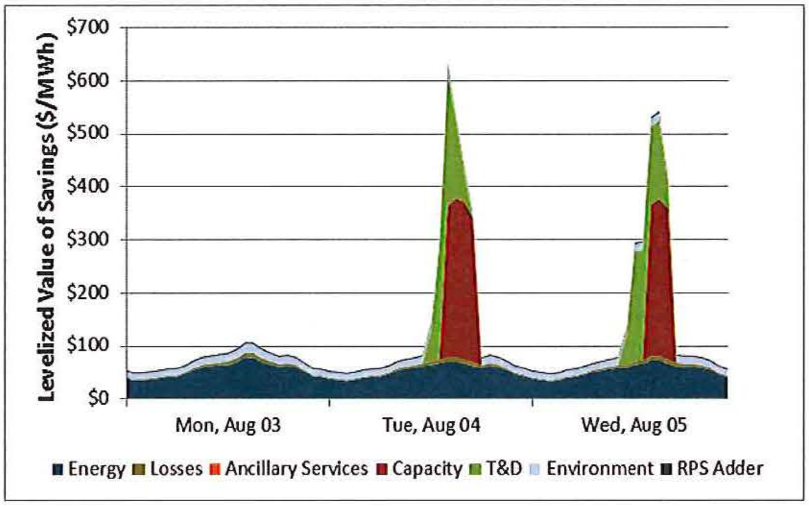

Figure 15. DER Avoided Costs – Summer Peak Days

5.1.3. 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."[44] 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[45]. In order 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 11, 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 12). 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.[46]

[44] "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

[45] "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

[46] 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