Application of SAN DIEGO GAS & ELECTRIC COMPANY (U902-E) for Approval of SB 350 Transportation Electrification Proposals	Application No. _______________ (Filed January 20, 2017)

PREPARED TESTIMONY OF

J.C. MARTIN

ON BEHALF OF SAN DIEGO GAS & ELECTRIC COMPANY

CHAPTER 8

BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

January 20, 2017

TABLE OF CONTENTS

PREPARED TESTIMONY OF

J.C. MARTIN

CHAPTER 8

I. OVERVIEW OF AIR QUALITY IMPACTS AND BENEFIT COST ANALYSIS

San Diego Gas & Electric Company ("SDG&E") proposes six priority review projects as well as a residential charging program for Commission review and approval. This chapter addresses the following requirements articulated in the Assigned Commissioner's Ruling ("ACR") Appendix A:[1]

- Emissions benefits;
- Cost; and
- Grid impacts.[2]

In accordance with the ACR, my testimony includes: 1) a discussion of qualitative benefits and estimates of air quality benefits and fuel impacts for the priority review projects; and 2) quantitative benefits in the form of standard cost effective tests, air quality benefits and fuel impacts for the residential charging program.

SDG&E believes its proposals align with ratepayers' interests by providing environmental benefits, reducing greenhouse gas ("GHG") emissions and supporting transportation electrification ("TE") in a sustainable, grid-integrated manner that serves all ratepayers' interests.

---

[1] Rulemaking ("R.") 13-11-007, ACR, Appendix A.
[2] R.13-11-007, ACR at A3.

A. Energy and Environmental Economics ("E3") Methodology

The data provided in my testimony is based on the evaluation framework introduced in SDG&E's Vehicle-Grid Integration Pilot Program ("VGI")[3], as envisioned in the Energy Division Staff's Vehicle-Grid Integration White Paper dated March 2014.[4] The framework methodology relies on an analytical model developed by E3 using assumptions provided by SDG&E.[5] The results from E3's model are generally described in this chapter and more fully documented in Appendix A, E3's Technical Appendix.

B. Residential Charging Program Methodology

Two implementation cases are used to determine net impacts of the residential charging program. The "Program Case" represents the residential charging program as described in Chapter 4 with 90,000 electric vehicles ("EVs") charging on the residential grid-integrated rate ("GIR") using Level 2 (240-volt) chargers. The "Reference Case" is intended to represent residential charging growth in the absence of the residential charging program -- in other words, the SDG&E service territory EV adoption absent SDG&E's program. This case includes 30,678 EVs charging on either the residential time-of-use rate or the domestic residential rate ("DR") (i.e., tiered rate) using Level 1 (120-volt) chargers. Net impacts are estimated by subtracting the Reference Case from the Program Case. This methodology is used throughout my testimony.

---

[3] Application of San Diego Gas & Electric Company for Authority to Implement a Pilot Program for Electric Vehicle-Grid Integration, A.14-04-014.

[4] Vehicle-Grid Integration: A Vision for Zero-Emission Transportation Interconnected throughout California's Electricity System, R.13-11-007 (2014) at 13-14, http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=7744.

[5] E3 methodology and model builds upon standard cost-effectiveness tests familiar to the Commission in Energy Efficiency (EE), Demand Response (DR), and Distributed Energy Resources (DER) proceedings.

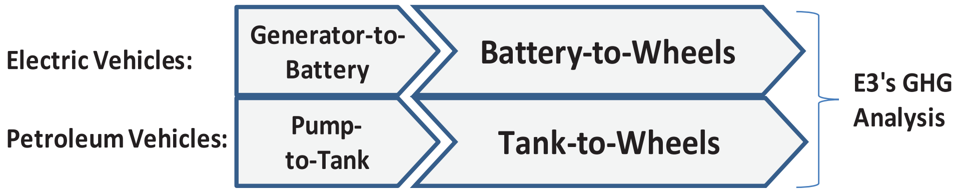
II. AIR QUALITY BENEFITS FOR PRIORITY PROJECTS & RESIDENTIAL CHARGING PROGRAM

This section describes the air quality improvements associated with the six priority review projects and residential charging program. The methodology for estimating air quality improvements is described below, including the method to estimate underlying fuel usage of vehicles (i.e., gasoline for petroleum vehicles and electricity for EVs). Finally, this section discusses how annual electricity usage is translated to hourly charging profiles which are used to determine air impacts from electricity generation.

A. Air Quality Improvements

For my testimony, estimated air quality improvements are calculated using E3's GHG analysis. The following Figure 8-1 illustrates the methodology used by E3 to estimate emission impact on air quality and CO_2. The air quality impacts from petroleum vehicles are estimated using a Pump-to-Wheels method, and air impacts from EVs are estimated using a Generator-to-Wheels method.[6]

Figure 8-1

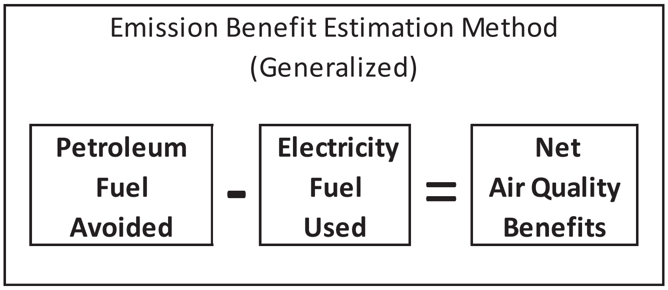


The net air quality benefits are then calculated by subtracting the petroleum fuel vehicle emissions from the EV emissions, as illustrated in Figure 8-2.

---

[6] These emission impact methodologies are further discussed in Appendix A, Section 3.4.

Figure 8-2



Net air quality benefits are associated with the EVs identified in the SDG&E priority review projects and residential charging program. These air quality benefits can be attributed to the efforts of SDG&E's proposals, vehicle drivers, site hosts, as well as Federal, State and regional policies and laws.[7]

Air quality benefits for the vehicles associated with SDG&E's proposals are summarized in Table 8-1A and 8-1B. Estimated net air quality benefits over the vehicle lifetime are provided in Table 8-1A.[8] Annual air quality benefits in 2025 are provided in Table 8-1B.[9] The net results

---

[7] For examples of Federal policies and laws, *see U.S. Department of Energy: Alternative Fuels Data Center, Federal Laws and Incentives*, http://www.afdc.energy.gov/laws/fed_summary. For examples of State policies and laws, *see Executive Order ("EO") S-3-05* (2005), https://www.gov.ca.gov/news.php?id=1861; *Assembly Bill ("AB") 32* (2006), http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0001-0050/ab_32_bill_20060927_chaptered.pdf; *Senate Bill ("SB") 350* (2015), https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB350#; *2016 ZEV Action Plan* (October 2016), https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf; *EO B-16-2012* (March 2012), https://www.gov.ca.gov/news.php?id=17472. For examples of Regional Policies, *see SANDAG, Plug-in SD: Supporting the Region's Plug-in Electric Vehicle Readiness*, http://www.sandag.org/index.asp?classid=17&subclassid=46&projectid=511&fuseaction=projects.detail.

[8] Data source for Table 8-1A is E3 Analysis. Dealership Incentives Project air quality improvements are not reported in Table 8-1 due to likely overlap with other projects, such as Electrify Local Highways and Green Taxi/Rideshare/Shuttle projects, as well as overlap with the residential charging program. Lifetime net emission reductions associated with the Dealership Incentives Project are estimated at 41,346 MT CO_2, 5.39 MT NOx, and 11.99 MT VOC.

[9] Data source for Table 8-1B is E3 Analysis. Dealership Incentives Project air quality improvements are not reported in Table 8-1 due to likely overlap with other projects, such as Electrify Local Highways and Taxi/Rideshare/Shuttle projects, as well as overlap with the residential charging program. 2025 annual net emission reductions associated with the Dealership Incentives Project are estimated at 2,517 MT CO_2, 0.33 MT NOx, and 0.70 MT VOC. 2025 annual data is used since all vehicles are in use for all six priority projects and the residential charging program.

for the residential charging program use the difference between the Program Case and Reference Case, and are described in Section I.B.

Table 8-1A

Air Quality Improvements - Impact Estimates
Life Time Impacts

SB 350 Projects	GGE[1] Avoided CO2 (MT)	Electricity Fuel CO2 (MT)	Net Emission Reductions CO2[2] (MT)	Net Emission Reductions NOx (MT)	Net Emission Reductions VOC (MT)
Priority Review Projects:					
Airport GSE	54,090	28,961	25,130	156.85	76.32
Electrify Local Highways	3,657	994	2,663	0.18	0.42
Dealership Incentives [3]					
Fleet Delivery	28,925	14,906	14,019	12.83	0.02
MD/HD and Forklift	6,138	2,035	4,102	17.96	8.82
Green Taxi/Shuttle/Rideshare	17,206	5,174	12,032	3.05	2.30
Total Priority Review Projects	110,016	52,070	57,946	190.87	87.88
Residential Charging Program:					
Program Case	2,711,022	1,037,353	1,673,669	217.18	455.47
Reference Case	829,050	496,990	332,060	43.99	116.86
Net Residential Program Impacts	1,881,972	540,363	1,341,609	173.19	338.61
Grand Total	1,991,988	592,433	1,399,555	364.07	426.49

[1] Gallons of Gasoline Equivalent (GGE).

[2] Net Reductions is GGE Avoided minus Electric Fuel.

[3] Dealership Incentives impacts are not listed due to likely overlap with other projects and program.

Table 8-1B

Air Quality Improvements - Impact Estimates 2025 Annual Impacts					
	GGE[1] Avoided	Electricity Fuel	Net Emission Reductions		
SB 350 Projects	CO2 (MT)	CO2 (MT)	CO2[2] (MT)	NOx (MT)	VOC (MT)
Priority Review Projects:					
Airport GSE	2,529	1,354	1,174	7.33	3.57
Electrify Local Highways	205	50	155	0.01	0.02
Dealership Incentives [3]					
Fleet Delivery	1,826	932	894	0.81	0.00
MD/HD and Forklift	341	113	228	1.00	0.49
Green Taxi/Shuttle/Rideshare	1,030	261	769	0.19	0.14
Total Priority Review Projects	5,930	2,710	3,220	9.34	4.22
Residential Charging Program:					
Program Case	247,893	93,362	154,531	20.05	41.83
Reference Case	76,577	45,272	31,305	4.14	10.87
Net Residential Program Impacts	171,315	48,090	123,226	15.90	30.96
Grand Total	177,245	50,800	126,445	25.25	35.18

[1] Gallons of Gasoline Equivalent (GGE).

[2] Net Reductions is GGE Avoided minus Electric Fuel.

[3] Dealership Incentives impacts are not listed due to likely overlap with other projects and program.

Net air quality benefits associated with SDG&E's proposals are in line with the GHG reduction goals of SB 350.

B. Fuel Usage Impacts

This section provides details on fuel usage impacts which are the basis for estimated air quality improvements identified in Section II.A. Fuel usage impacts are calculated using vehicle characteristics, vehicle usage requirements, and charger capabilities. Selected vehicle characteristics and charger capabilities are summarized in Table 8-2, as well as resulting lifetime fuel impacts and annual 2025 fuel impacts.[10]

Table 8-2

Selected Vehicle and Charger Characteristics and Fuel Impacts

				Life Time Fuel Impacts		2025 Annual Fuel Impacts	
SB 350 Project	**Vehicles[1] (Count)**	**Assumed Vehicle Life (Years)**	**Charger Demand (kW)**	**GGE Fuel Avoided (Gals 000's)**	**Electricity Fuel Used (MWhrs)**	**GGE Fuel Avoided (Gals 000's)**	**Electricity Fuel Used (MWhrs)**
Priority Review Projects:							
Airport GSE	90	15 to 25	30	6,010	89,087	281	4,164
Electrify Local Highways	120	10	6.6 & 50	406	4,227	23	211
Dealership Incentives[2]	1,500	10	NA				
Fleet Delivery	90	8	19	3,214	47,138	203	2,946
MD/HD and Forklift	13	8	12	682	6,186	38	344
Green Taxi/Shuttle/Rideshare	58	8 to10	6.6 & 50	1,912	19,712	114	996
Total Priority Review Projects	1,871			12,224	166,350	659	8,662
Residential Charging Program:							
Program Case	90,000	10	6.6	301,225	3,940,980	27,544	354,688
Reference Case	30,679	10	1.6	92,117	1,206,585	8,509	109,910
Net Residential Program Impacts	59,321			209,108	2,734,396	19,035	244,778
Grand Total	61,192			221,332	2,900,746	19,694	253,440

[1] Vehicles represent the number of vehicles charged per day or otherwise associated with the project.
[2] Dealership Incentives fuel impacts are not listed due to likely overlap with other projects and program.

The methodology used to estimate the fuel impacts are further detailed in Appendix A.

C. EV Charging Under a Dynamic Rate

EV charging under an hourly grid-integrated rate results in energy consumption influenced by the rate's hourly prices. SDG&E assumes that a driver needs sufficient charging to meet his or her driving needs, and that a driver wants to minimize overall charging costs. The E3 model is configured to charge vehicles to minimize charging costs, subject to the driver's

---

[10] Data source for Table 8-2 is E3 Analysis. Dealership Incentives Project fuel impacts are not reported in Table 8-2 due to likely overlap with other projects, such as Electrify Local Highways and Green Taxi/Rideshare/Shuttle projects, as well as overlap with the residential charging program. Lifetime fuel impacts associated with the Dealership Incentive Project are estimated at 8,337 thousand GGE, and 107,481 MWh. 2025 annual fuel impacts associated with the Dealership Incentive Project are estimated at 467 thousand GGE, and 5,374 MWh.

charging constraints and driving needs.[11] The model's output results in an hourly charging profile for the entire year, for each vehicle type. The hourly charging profiles are used to calculate electricity fuel air quality impacts reported in Section II.A, as well as costs used in the cost-effectiveness tests presented in Section III.B.

D. Qualitative Benefits of Priority Review Projects

The ACR acknowledges that, "At this point in time, a strictly quantitative 'optimal solution' may be difficult to determine with high degrees of certainty…."[12] Quantitative cost-benefit analysis was not contemplated for the priority review projects. SDG&E's priority review projects are expected to provide qualitative benefits like increasing TE adoption, advancing EV-related technologies, and providing data necessary to continue EV innovation. Ratepayer and societal benefits of the priority review projects include:

- Test grid-integrated rates in nascent market segments such as public charging, taxi/shuttle/rideshare, and fleet delivery markets;
- Test grid-integrated hourly rate communication at public charging stations;
- Provide load research metering consumption data;
- Provide data logging metrics for individual vehicle usage and charging patterns;
- Learn from optimized grid-integrated charging and understand electric fuel economy;
- Increase understanding of renewable resources and EV charging interactions;
- Analyze Dealership Incentives to better understand impacts on EV sales and EV rate adoption;

---

[11] Driving needs are defined as electric Vehicle Miles Traveled (eVMT) per day, which are specific to each vehicle type.

[12] ACR at 19.

- Analyze fleet EV adoption associated with the projects;
- Better understanding of EV impacts on disadvantaged communities ("DAC") and associated GHG emissions; and
- Educate stakeholders and CPUC through reporting of findings and data.

These qualitative benefits are further described in the Monitoring and Evaluation Plans sections in Chapter 3 for each of the priority review projects.

III. COST & BENEFITS FOR THE RESIDENTIAL CHARGING PROGRAM

Quantitative analysis for the residential charging program includes standard cost-effectiveness tests familiar to the Commission through prior proceedings[13]. Each cost test is designed to answer a key policy question relating to TE market development. Table 8-3 describes the key questions answered for each of the Cost-Effectiveness Tests.[14] The California Standard Practice Manual cost tests are: Ratepayer Impact Measure ("RIM"), Participant Cost Test ("PCT"), Total Resource Cost ("TRC"), and Societal Cost Test ("SCT"). Standard Practice tests are appropriate since TE provides load-modifying capabilities like shifting and shaping similar to Demand Response and distributed energy resources.

---

[13] *See* Application of SDG&E for Authority to Implement a Pilot Program for Electric Vehicle-Grid Integration, A.14-04-014 (filed April 11, 2014); *see also* energy efficiency rulemakings, R.13-11-005, R.13-12-011, R.09-01-019, R.06-04-010, and R.01-08-028; demand response rulemakings, R.13-09-011 and R.07-01-041; and distributed energy resources rulemaking, R.14-10-003.

[14] *See Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers* (2008) at 2-2, Table 2.2, https://www.epa.gov/sites/production/files/2015-08/documents/understanding_cost-effectiveness_of_energy_efficiency_programs_best_practices_technical_methods_and_emerging_issues_for_policy-makers.pdf.

Table 8-3

Cost-Benefit Tests Key Questions Answered		
Cost Test	**Acronym**	**Key Question Answered**
Ratepayer Impact Measure	RIM	Will utility rates increase?
Participant Cost Test	PCT	Will the participants benefit over the measured life?
Total Resource Cost	TRC	Will the total costs of energy in the utility service territory decrease?
Societal Cost Test	SCT	Is the utility, state, or nation better off as a whole?

A. Cost-Effectiveness Tests Components

The E3 Model provides inputs for each test component. Once each test component is estimated, the standard cost-effectiveness tests are calculated. Test components for the cost-effectiveness tests are as follows:

- **EV Customer Costs and Benefits:** relate to the actions of the EV driver;
- **Utility Charger Costs and Administration Cost:** are SDG&E's capital and O&M costs associated with the residential charging program;
- **Electricity Supply Costs:** are SDG&E's costs to supply program vehicles with electric fuel in order to avoid usage of petroleum fuel; and
- **Air Quality Benefits:** relate to reduced CO_2 as part of the Low Carbon Fuel Standard ("LCFS") and Criteria Pollutants (e.g., Nitrogen Oxides, Volatile Organic Compounds ["VOC"], and Particulate Matter ["PM"]).

Table 8-4 lists the test components and their relationship to the cost-effectiveness tests used in this analysis. The gray cells in Table 8-4 indicate that a test component is not applicable to a particular cost-effectiveness test.

Table 8-4

SB 350 Project Cost-Effectiveness Tests					
		Cost-Effectiveness Tests			
Test Components		RIM	PCT	TRC	SCT
EV Customer Costs & Benefits	Incremental Vehicle Cost		Cost	Cost	Cost
	Vehicle O&M Savings		Benefit	Benefit	Benefit
	Gasoline Savings		Benefit	Benefit	Benefit
	Utility Bills	Benefit	Cost		
	Federal Tax Credits		Benefit	Benefit	Benefit
	State Rebates		Benefit		
Charger Costs	Utility Capital Costs	Cost		Cost	Cost
Admin. Costs	Utility O&M Costs	Cost		Cost	Cost
Electricity Supply Costs	Energy Cost	Cost		Cost	Cost
	Losses Cost	Cost		Cost	Cost
	Ancillary Services Cost	Cost		Cost	Cost
	Capacity Cost	Cost		Cost	Cost
	T&D Cost	Cost		Cost	Cost
	RPS Cost	Cost		Cost	Cost
Air Quality Benefits	LCFS Benefits	Benefit			
	Criteria Pollutants				Benefit

Under the residential charging program certain electricity supply costs can be reduced. The program will allow for EV charging to become a more flexible load, as discussed in greater detail in Section III.C. The electricity supply costs components are further described in Table 8-5.

Table 8-5

Electricity Supply Cost Components	
Component	**Description**
Energy	Estimated hourly wholesale value of energy
Losses	Line losses across the T&D system
Ancillary Services	Costs of providing system operations and reserves for electricity grid reliability
Capacity	Cost of generation capacity to meet system peak loads
T&D	Cost of transmission and distribution capacity to meet peak loads
RPS Cost	Cost of renewable generation above-market prices required to meet the RPS standard

B. Residential Charging Program's Cost-Effectiveness Analysis

This section provides Cost-Effectiveness test results of the residential charging program. Cost and benefit results are presented for two market scenarios (Scenario A and B). The scenarios represent a range of three key assumptions: state and federal incentives, incremental vehicle costs, and gasoline prices.[15] Scenario A assumes: 1) federal tax credits and state incentives expire after 2020; 2) incremental EV purchase prices slowly decrease through 2030; and 3) gasoline prices are E3's EIA-based estimate.[16] Scenario B assumes: 1) federal tax credits and state incentives are extended through 2025; 2) comparable EV purchase prices become equivalent to conventional vehicles by 2025; and 3) gasoline prices increase 25% above the forecast used in Scenario A.

---

[15] Total Air Quality Benefits and Fuel impacts are the same in both scenarios (i.e., no change net emission reductions (Tons), and no change fuel impacts (Gals. and MWhrs) between the scenarios).

[16] Energy Information Administration ("EIA"), 2016 California weekly average gasoline price escalated at the escalation trajectory of the 2017 EIA Annual Energy Outlook U.S. Motor Gasoline Price Forecast.

Results for Scenario A are presented in Figure 8-3, and results for Scenario B are presented in Figure 8-4. The TRC test and SCT results are positive in Scenario B. The TRC and SCT results reflect a range of costs to achieve GHG goals based on the different assumptions used in the two scenarios. The TRC and SCT test results range from a net cost in Scenario A to a net benefit in Scenario B. Although the RIM test results are negative, the bill revenues cover the electric supply costs and a portion of the charger and administrative costs associated with the program in the Program case. PCT test results show net benefits for participants in both scenarios.

Figure 8-3

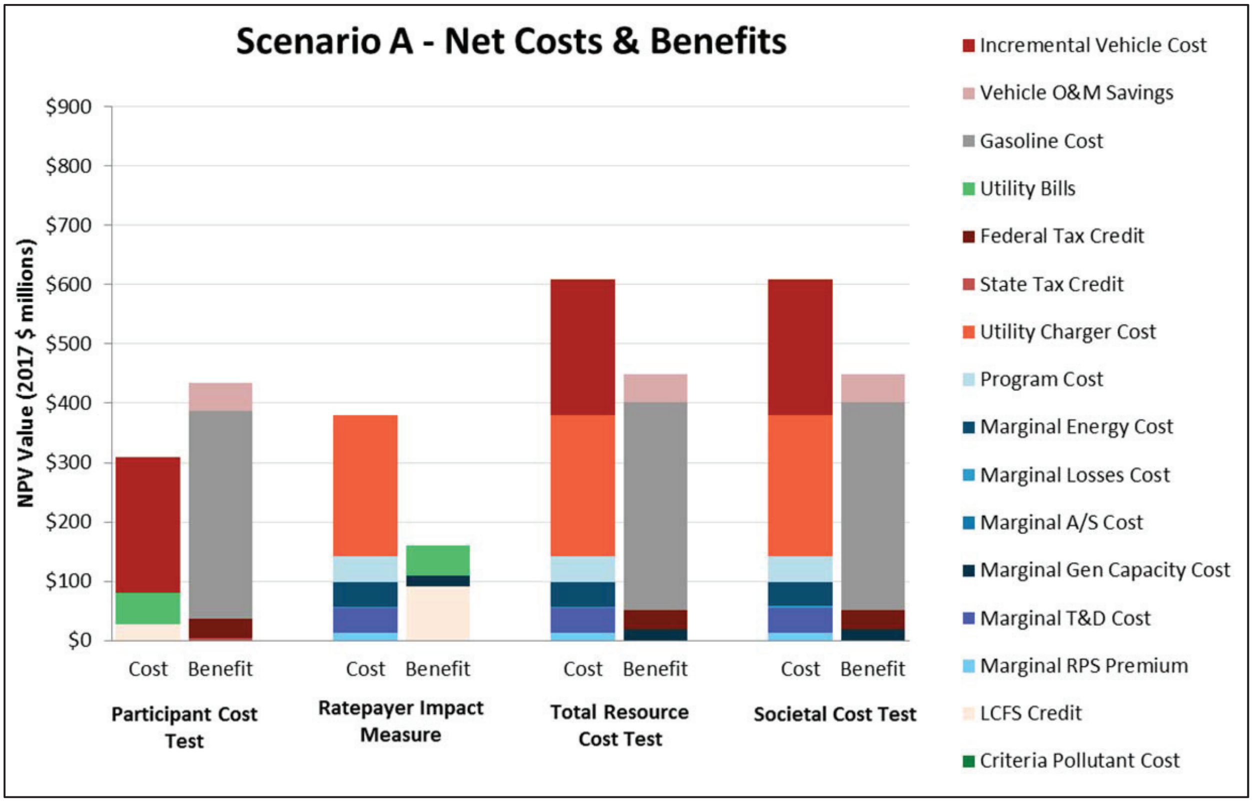
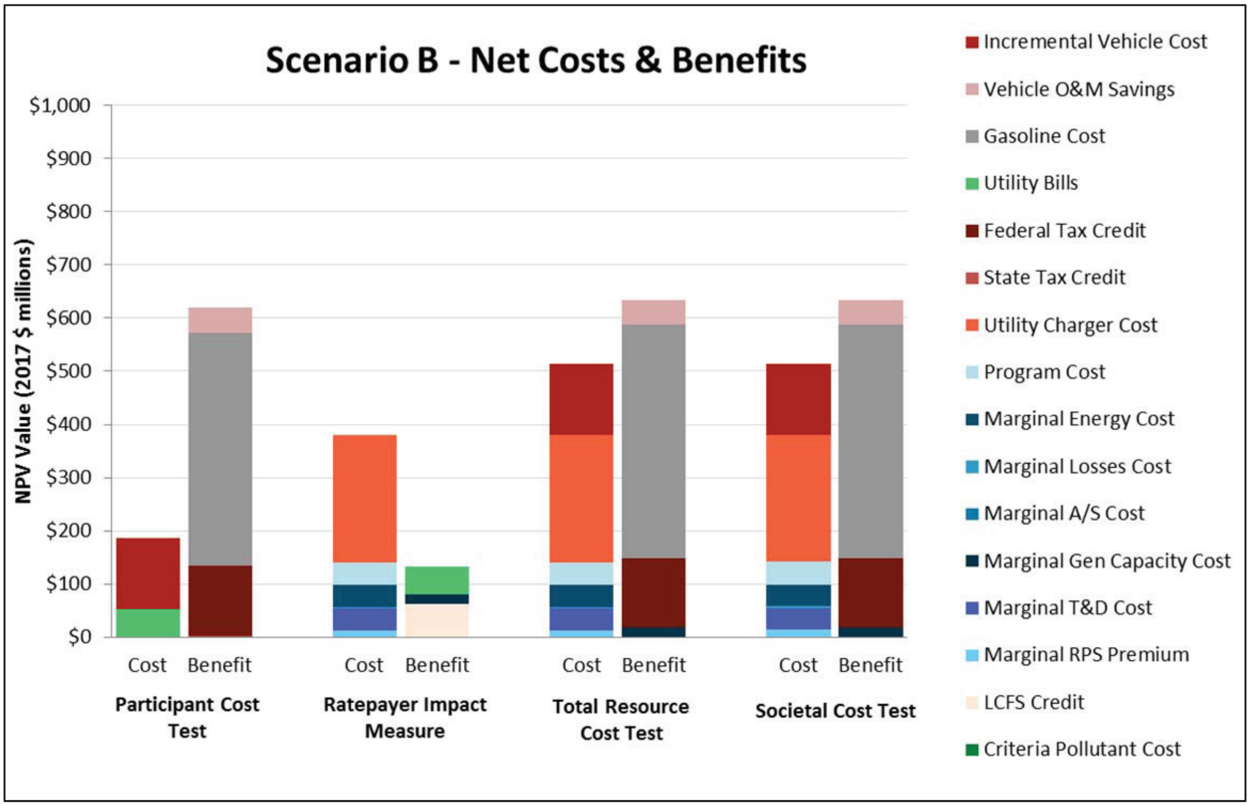


Figure 8-4



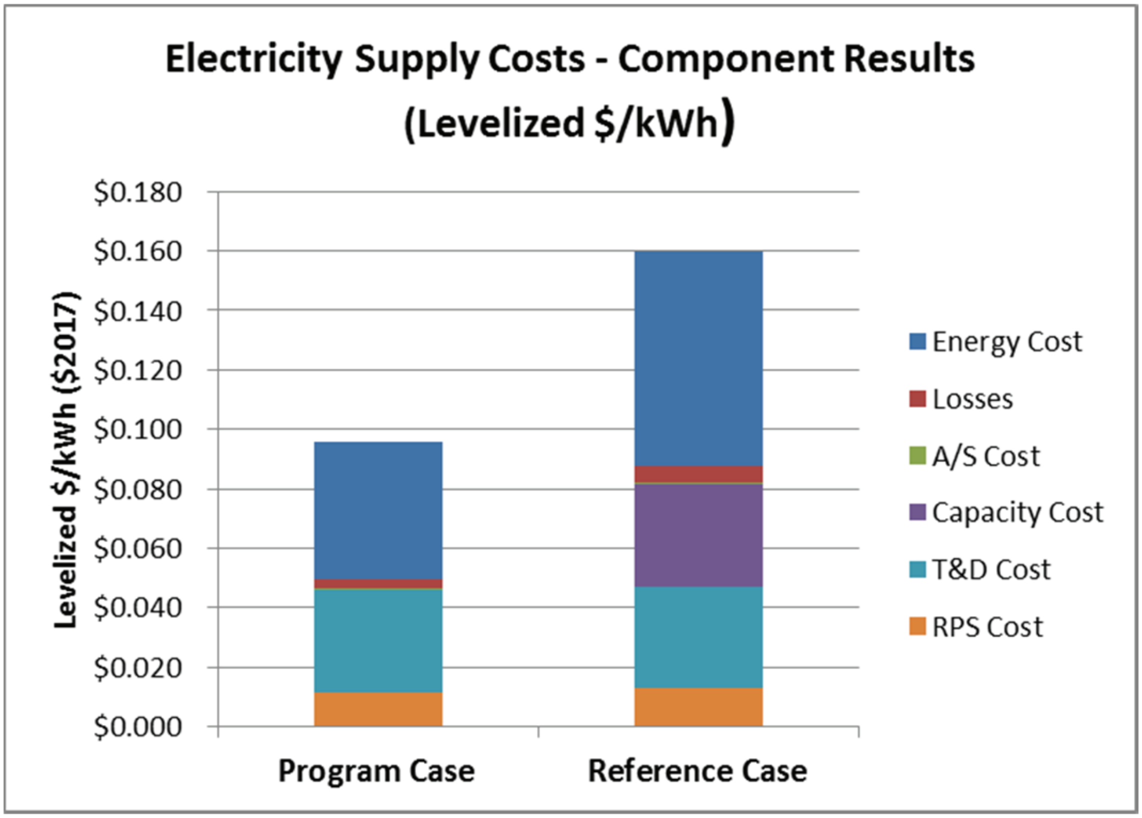
C. Residential Charging Program's Electricity Supply Cost Analysis

Figure 8-5 provides details for the electricity supply costs for the residential charging program. Figure 8-5 compares the Reference and Program cases previously described in Section I.B. Results show that the Program case (utilizing the grid-integrated rate) results in lower electricity supply costs per kilowatt-hour ("kWh") than the Reference case (utilizing TOU and tiered rates).[17] This is due to the grid-integrated rate better reflecting the costs associated with electric supply.[18] A discussion of the general benefits of flexible EV charging is presented in Section IV of this chapter.

---

[17] Primarily due to reduced energy and capacity costs.
[18] *See* Direct testimony of Cynthia Fang (Chapter 5) for further details.

Figure 8-5



D. Alternative Method to Cost Evaluation

Standard cost effectiveness tests are only one of many methods to analyze costs and benefits. These tests have limitations that should be considered when evaluating certain types of programs. When applied to EV programs, standard practice manual tests do not reflect benefits associated with market transformation, and do not adequately recognize non-economic barriers to TE adoption (e.g., consumers' dealership experience). Also, the ratepayer impact measure compares costs to today's rates and does not show how rates might reduce over time as a result of a program. Viewing TE program benefits in a more comprehensive manner would capture these benefits and allow for a more equitable comparison between TE programs and alternative GHG reduction strategies. An example of this comparison is the cost per ton of CO_2 avoided.

The residential charging program avoided cost per ton of CO_2 ranges between a net cost of $271/ton in Scenario A, and a benefit of $203/ton in Scenario B, based on the TRC test results.

IV. GRID IMPACTS

The residential charging program, and some of the priority projects, utilize grid integrated charging to help minimize electricity supply costs. SDG&E's load shape has changed as more solar and wind renewable resources come online.[19] This has increased the value of flexible customer load that is responsive to changing grid needs. The residential charging program, described in Chapter 4, will utilize the dynamic, hourly, grid-integrated rate described in Cynthia Fang's direct testimony (Chapter 5), along with EV and charger capabilities to make EV charging more flexible and responsive to grid needs, while still meeting the needs of the driver.

A. How Grid Integrated Charging Reduces Electricity Supply Costs

EV charging flexibility and responsiveness is intended to better utilize SDG&E's existing grid assets and provide the lowest cost fuel for EV drivers. Better utilization of grid assets is reflected in lower electricity supply costs, which are reflected in the results shown in Section III.C. above. A California Independent System Operator ("CAISO") analysis has shown that the net load curves are highly correlated with market electricity prices. When net load is lowest, wholesale electricity costs are generally the lowest. When net load is highest in the evening, wholesale electricity costs are generally the highest.[20]

---

[19] *CAISO's proposed TOU periods to address grid needs with high numbers of renewables* at Slide 2 (May 5, 2016), http://www.caiso.com/Documents/CAISOTOUperiodsCPUC_5_5_2016_final.pdf.

[20] *Id.* at Slides 8-12.

B. Improving Grid Net Load Factor

SDG&E's net load shape has changed due to the increased adoption of renewable generation.[21] The net load shape (customer load minus renewable generation) influences the hours of high prices in the California wholesale electricity market and the hours where additional generation infrastructure may be needed.[22]

The net load impact of solar and wind is illustrated by the CAISO with the well-known "duck curve" charts. Duck curve charts have been used to describe the changes in net load occurring as more variable renewables are added to California's electric system.[23] In typical examples of the duck curve, there is a significant ramp in the net load around the sunset. This increased ramp rate requires flexible generation including gas generation and storage. The peak then shifts to early evening as residential customers return home after work. This early evening peak load could be increased if drivers return home after work and begin to charge their EVs. Additional early evening peak load will increase the need for new generation capacity investments.[24]

---

[21] *See Decision Adopting Policy Guidelines to Assess Time Periods for Future Time-of-Use Rates and Energy Resource Contract Payments* at 5 and 71, FOF 11 (adopted January 19, 2017 in R.15-12-012). "Net Load" is the load serving customers less the energy generated by wind and solar technologies.

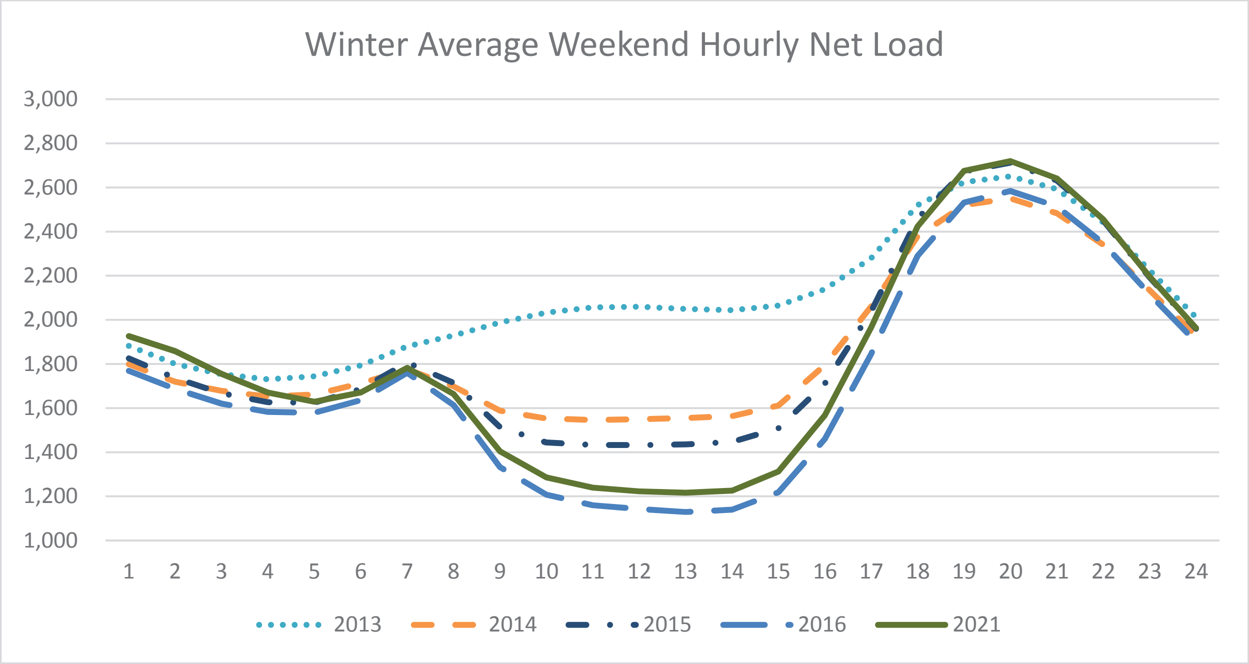
[22] *See Decision Adopting Policy Guidelines to Assess Time Periods for Future Time-of-Use Rates and Energy Resource Contract Payments* at 70-71, FOF 4, 6, and 7 (adopted January 19, 2017 in R.15-12-012). *See also CAISO's proposed TOU periods to address grid needs with high numbers of renewables* at Slides 8-12 (May 5, 2016), http://www.caiso.com/Documents/CAISOTOUperiodsCPUC_5_5_2016_final.pdf (presented in R.15-12-012).

[23] The charts have been introduced in the California Public Utilities Commission's ("CPUC") "Residential Rate Reform" proceeding (R.12-06-013) and the Rulemaking to Assess Peak Electricity Usage Patterns and Consider Appropriate Time Periods for Future Time-of-Use Rates…, R.15-12-012.

[24] *See* D.16-06-007 at 26, OP 4; *see also* Energy and Environmental Economics, Inc., *Avoided Costs 2016 Interim Update* at 24 (Aug. 1, 2016), http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=12504.

The impact of renewable resources, especially solar, on the net load shape in SDG&E's service territory has increased over the years as shown in Figures 8-6 and 8-7.[25] Summer peak conditions have shifted from afternoon to the evening hours due to the effects of added solar generation. Winter afternoon net load shape shows a steep upward curve as solar production declines, requiring significant ramping resources to meet peak net demand occurring in early evening. Renewable generation adoption will continue in the SDG&E service territory and will continue to impact the net load.

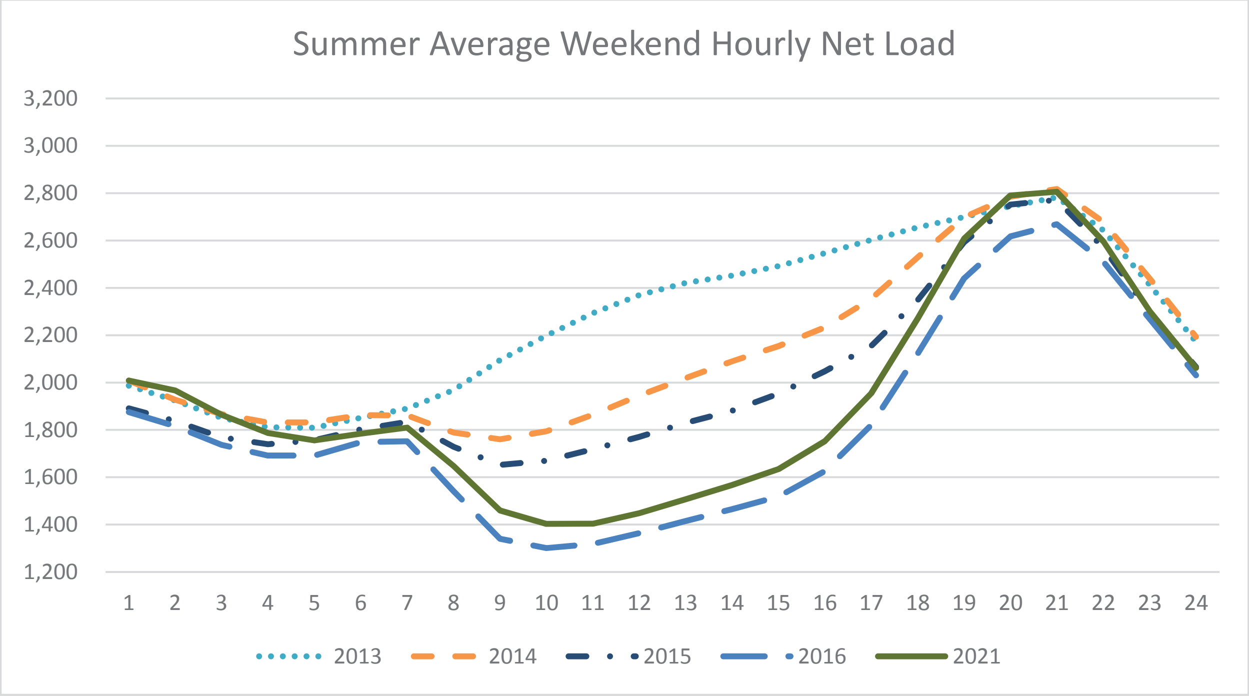
Figure 8-6: SDG&E Winter (November-May) Average Hourly Net Load



---

[25] Based on SDG&E service area loads and wind and solar generation including rooftop solar in the Greater San Diego reliability area (which includes Imperial Valley solar and wind resources contracted with SDG&E). 2013-2015 are based on actual data; 2021 is based on forecast data presented in SDG&E's General Rate Case Phase 2, A.15-04-012.

Figure 8-7: SDG&E Summer (June-October) Average Hourly Net Load



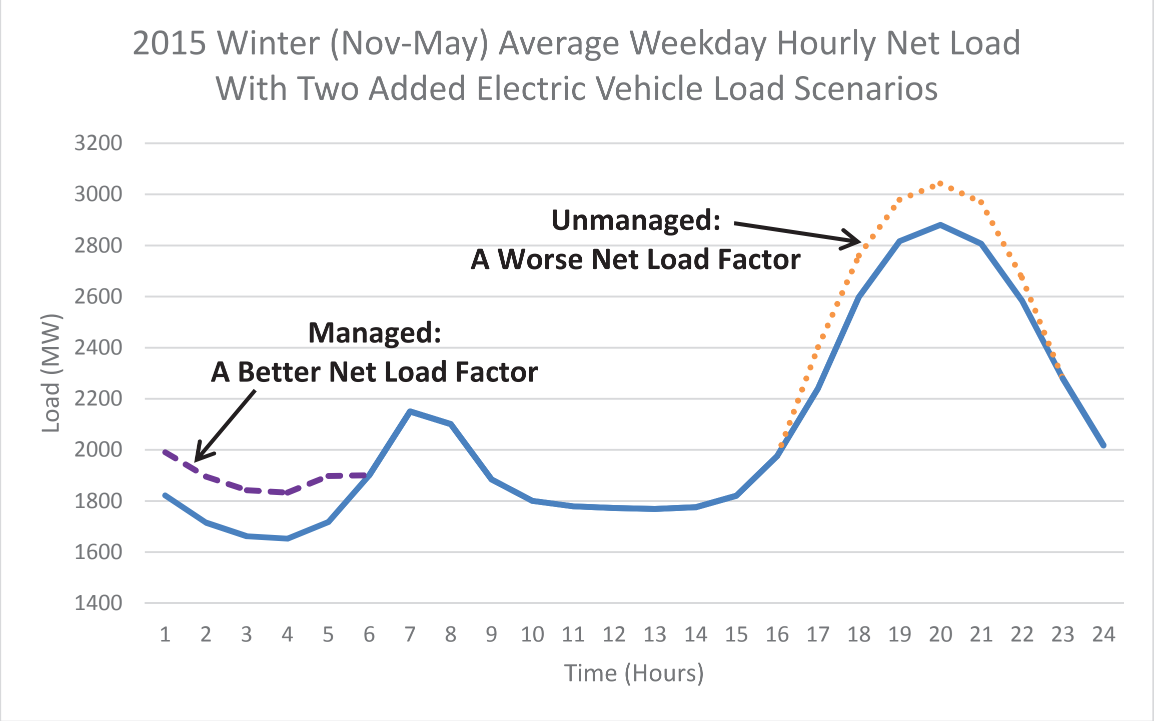
EV charging needs to be flexible enough to avoid the adverse effects of charging during peak net load hours. The terms "Managed" and "Unmanaged" charging are used in this section to illustrate the benefits of a Level 2 EVSE and a GIR. "Managed" refers to Level 2 customers on a GIR. "Unmanaged" refers to Level 1 customers on the standard domestic residential rate.

Unmanaged charging can increase peak net load, potentially leading to the need for additional local generation resources and capacity investments. Increased peak net load also creates a steeper afternoon ramp, which may increase the need for additional flexible ramping resources (e.g., gas-fired generation or storage).

Managed charging, on the other hand, encourages EV charging when net load is lower and discourages EV charging when net load is higher. Charging when the grid's net load is lowest improves the system load factor, providing better utilization of generation assets.

The difference between adding 90,000 EVs with unmanaged charging as compared to 90,000 with managed charging is illustrated in Figures 8-8 and 8-9.[26]

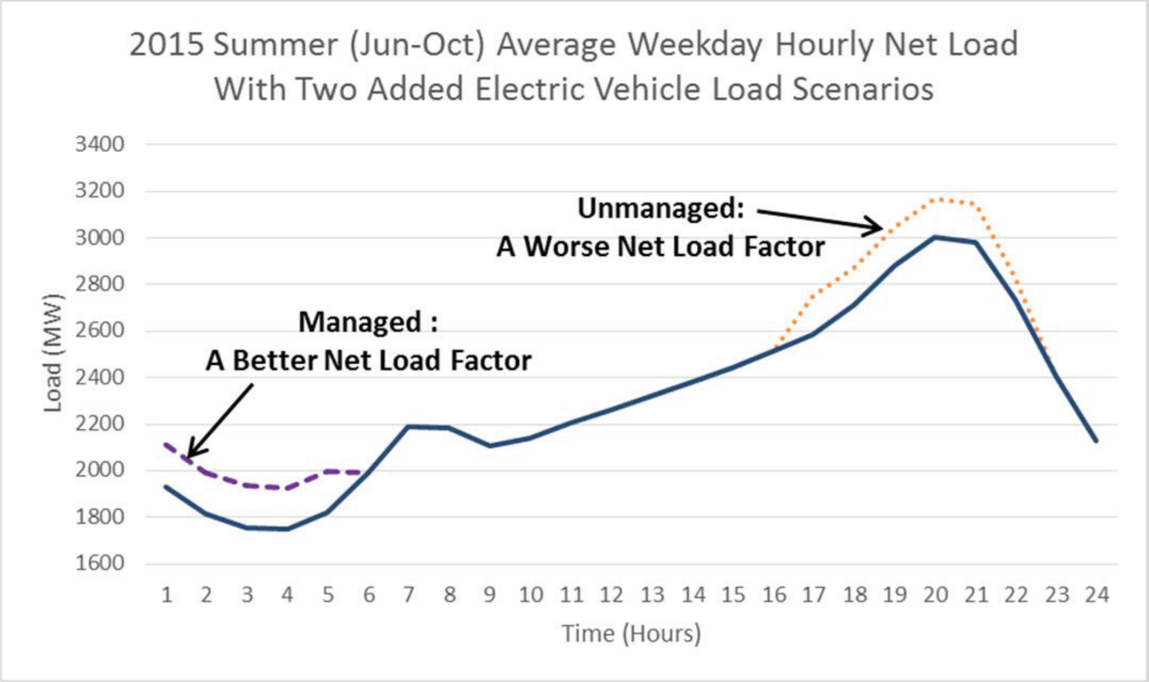
Figure 8-8: Winter Average Hourly Net Load with Managed and Unmanaged Charging



---

[26] The charts are developed under the following assumptions: 1) unmanaged drivers charge during hours of 5 p.m. – 10 p.m., when they get home from work, while managed drivers charge during hours of 12 a.m. – 5 a.m when electricity market prices are low; 2) ZEV population mix is split 60% and 40% for BEV and PHEV, respectively, 3) L2 EVSE charges at a rate of 6.6 kW and 3.3 kW for BEV and PHEV, respectively; and 4) average commute is 30 miles, assuming approximately 3 miles/kWh, for an energy demand of 10 kWh/vehicle.

Figure 8-9: Summer Average Hourly Net Load with Managed and Unmanaged Charging



The recently released *Draft Demand Response Potential Study* points out that EV charging has the potential to immediately provide demand response benefits by shaping load and shifting load from peak usage periods to off-peak periods with appropriate pricing for EV charging.[27] The proposed residential charging program with its grid-integrated rate provides pricing to encourage flexible EV loads to charge at low price hours corresponding to low net load hours.

C. Benefits of an Improved Net Load Factor

There are four main benefits of an improved net load factor: 1) lower wholesale electricity costs for SDG&E ratepayers; 2) deferral of new generation capacity investments; 3) deferral of distribution infrastructure investments; and 4) spreading fixed costs over more sales,

---

[27] Lawrence Berkeley National Laboratory, E3, and Nexant, *2015 California Demand Response Potential Study, Charting California's Demand Response Future* at 7-15, R.13-09-011 (November 14, 2016), http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442451541.

reducing average cost per kWh. First, an improved load factor can help reduce the amount of higher priced wholesale energy that needs to be procured and increase the amount of lower cost wholesale energy that is procured, resulting in lower average procurement costs for all SDG&E ratepayers.

Second, an improved load factor can help defer new generation capacity investments. New peak generation capacity investments will be avoided if the EV load is managed to avoid system peak usage and avoid triggering new generation investments.

Third, an improved load factor can help defer new distribution infrastructure investments. Because SDG&E has a diverse territory, distribution circuits peak at times different from the system peak. Similar to the case of generation, peak loads on the circuits and substations determine the need for adding distribution infrastructure. Adding EV load to a circuit and substation in an unmanaged fashion can lead to an increase in the circuit peak. These circuit peaks can trigger distribution infrastructure investments, such as installing a new circuit, upgrading conductors on the circuit, or moving load from the overloaded circuit to an adjacent circuit with available capacity.

Fourth, an improved load factor can spread fixed electricity supply costs over more electricity sales, reducing the average cost per kWh for all ratepayers. Other ratepayers receive a benefit from managed EV charging to the extent the GIR collects revenues from EV customers beyond variable costs, and therefore contributes toward the fixed costs of the utility. As described in Chart 5-1 in the direct testimony of Cynthia Fang (Chapter 5), there are many fixed costs collected in rates other than for generation and distribution capacity, including customer costs, mandated public purpose costs, and transmission costs. Most of these fixed costs are not expected to change as a result of the residential charging program, so the net revenue collected toward these fixed costs reduces rates for other ratepayers.

In summary managed EV charging can help improve the net load factor resulting in lower wholesale energy costs, lower generation and distribution capacity investments, and lower average costs per kWh. Lower energy and avoided capacity costs are reflected in lower electricity supply costs.

V. CONCLUSION AND SUMMARY

The SB 350 TE projects proposed by SDG&E provide emission benefits, including air quality improvement and fuel usage impacts.

- SDG&E's six priority review projects result in 0.06 million MTs of lifetime net CO_2 emission reductions;
- SDG&E's residential charging program results in 1.3 million MTs of lifetime net CO_2 emission reductions;
- The residential charging program proposed by SDG&E can yield positive results associated with the Cost-Effectiveness Tests and grid impacts. A summary of these positive results are as follows:
  - The potential for a positive TRC test reflects that total costs for TE in the service territory can decrease;
  - The potential for a positive SCT test reflects the service territory as a whole can be better off;
  - The residential charging program's positive PCT test results illustrate the program benefits to EV drivers; and illustrate the fuel cost savings of EV charging under the grid-integrated rate.

- Flexible EV charging has the potential to improve the grid’s net load factor and avoid system peaks, deferring new generation capacity investments;
- Flexible EV charging under the grid-integrated rate has the potential to avoid circuit peaks and defer distribution infrastructure investments;
- Flexible EV charging under the grid-integrated rate has the potential to lower average costs per kWh for all ratepayers;
- Priority review projects will yield positive qualitative benefits that have been described in Section II.D., including:
  - Benefits to SDG&E ratepayers through research demonstration that increases EV adoption;
  - Development of new EV-related technology advancement; and
  - Providing data necessary to continue EV innovation.

This concludes my testimony.

VI. STATEMENT OF QUALIFICATIONS

My name is John C. Martin. My business address is 8306 Century Park Court, San Diego, California 92123. I am employed by SDG&E as Team Lead in Clean Transportation. I have over 23 years of energy industry experience. My current duties involve project and team management to support SDG&E's electric transportation efforts, including EV rates, program support, and implementing a pilot using third-party EV submetering.

Prior duties focus on costs and benefits associated with the capabilities of Smart Metering and Home Area Networks, and conservation based information feedback and Vehicle-Grid Integration. My prior electricity work experience includes demand response program and tariff development, electricity trading and scheduling, demand side management program evaluation, and load research of customer energy use. This work draws upon my broad experience in the electricity and oil industry, including the oil trading, refining and marketing industries.

My EV driving experience began in 1997. I currently own and previously leased a plug-in hybrid EV since January 2013. I actively charge my vehicle at home, at my workplace, and at public facilities.

My education is in the general area of resource economics. I graduated from Cornell University in 1988 with a master's degree in agricultural economics. My bachelor of science degree was granted by Purdue University in 1984 in business and farm management. I have previously testified before the Commission.

APPENDIX A

TECHNICAL APPENDIX FOR E3 ANALYSIS DOCUMENTATION

E3 Technical Appendix

Prepared to Support San Diego Gas & Electric Company's
SB 350 Transportation Electrification Application

January 2017

Energy+Environmental Economics

Table of Contents

1. Overview

Energy and Environmental Economics, Inc (E3) was retained by SDG&E to estimate customer charging usage and associated emissions and marginal costs from SDG&E's SB 350 Transportation Electrification (TE) proposals. E3 leveraged analytical models that the firm previously used to support SDG&E's VGI application (A.14-04-014) and the *Phase 3-Part A: Commercial and Non-Road Grid Impacts* report for the California Transportation Electrification Assessment (CalETC Phase 3a). E3 also used PEV technology specifications, performance characteristics and driving patterns provided to SDG&E by ICF International (ICF) and light duty vehicle (LDV) vehicle cost data from Ricardo, a global engineering and environmental consultancy focusing on transportation, energy and scarce resources. E3's analysis focuses on simulating plug-in electric vehicle (PEV) charging behavior that minimizes customer electricity bills under SDG&E grid-integrated tariffs. Given the estimated bill-minimizing behavior of the customers, E3 then estimates the emissions and grid impacts consistent with the California Public Utilities Commission (CPUC) Assigned Commissioner's Ruling (ACR) issued in R.13-11-007 on 9-14-16. Due to fundamental differences in the nature of the proposal, E3 considers the residential charging program and the priority review projects separately.

For the residential charging program, E3 supplements analysis of behavior and grid impacts with full cost-benefit tests, consistent with the California Standard Practice Manual (SPM). E3 presents the SPM cost-benefit tests to inform regulators and stakeholders by using an established methodology for Distributed Energy Resources (DER). The residential charging program is similar to other DER emerging technology and market transformation programs in that it seeks to promote customer acceptance and adoption of new technologies with benefits for the electric grid, ratepayers and the environment. However, TE is fundamentally different from the DER historically evaluated with the SPM cost-benefit methodology in that it promotes efficiency through fuel switching across the utility and transportation sectors and with the primary goal of reducing Greenhouse Gas (GHG) emissions as opposed to reducing electricity generation. The SPM cost-benefit tests do not provide a full comparison of the long-term costs and benefits for TE's market transformation effects as a GHG reduction strategy. Nonetheless, cost-benefit results are presented herein for completeness and to inform the near-term impacts of the residential charging program.

This Appendix A addresses the key methods, assumptions, and sources behind the aforementioned analyses. Section 2 provides an overview of E3's PEV Grid Impacts Model methods and approach. Section 3 focuses on the methods, assumption, and sources used to estimate physical impacts, including PEV charging behavior, fuel usage, emissions impacts, and electric grid impacts. This includes physical impacts of the priority review projects and the residential charging program. Section 4 describes the methods and assumptions employed in the residential charging program cost-benefit analysis.

Chapter 8 of SDG&E's Application provides a discussion of results.

2. Physical Impacts Analysis: Priority Review Projects and Residential Charging Program

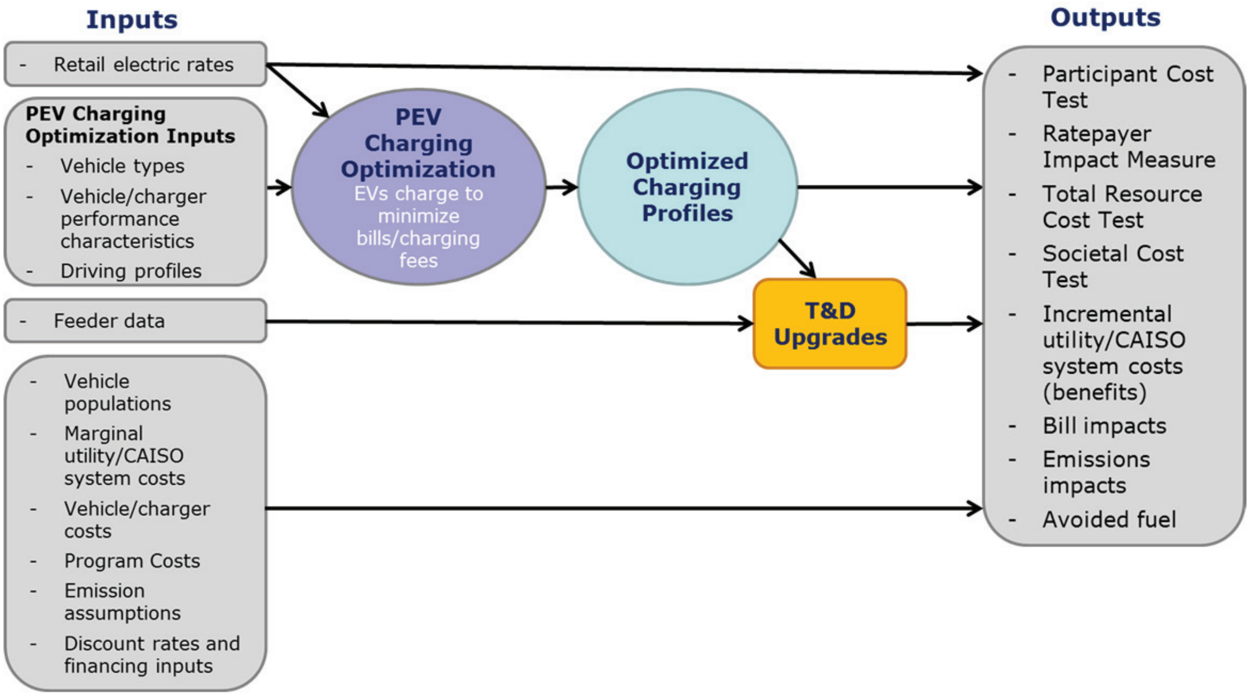
2.1. PEV Grid Impacts Model Overview

2.1.1. Model Structure

The E3 PEV Grid Impacts model takes a PEV adoption scenario and calculates several physical and economic impacts. A PEV adoption scenario is defined by a myriad of assumptions that reflect a particular state-of-the-world and, if applicable, a specific PEV program. Each scenario evaluates the impacts of one PEV adoption trajectory by comparing outcomes with that PEV adoption trajectory to outcomes with identical levels of internal combustion engine (ICE) vehicle adoption. PEV charging behavior determines many physical and economic impacts on the grid; thus, the model's PEV charging optimization is a significant driver of the PEV impacts.

Figure 1 provides an overview of the model logic, including the key inputs and outputs. Model inputs include tariffs, vehicle characteristics, driving patterns, incremental costs of PEVs above internal combustion engine (ICE) vehicles, vehicle and charger population forecasts, and emissions assumptions.

Figure 1: E3 PEV Grid Impact Model Logic Progression



The E3 PEV Grid Impacts model calculates charging usage patterns for each vehicle type and rate combination under the assumption that customers will meet their driving needs while minimizing their electricity bills. The model determines only the PEV charging behavior, and it does not alter the usage pattern for the customer's other home or business load. The model optimizes charging profiles for each customer segment based on vehicle type, charging level and the total charging load as determined by electric vehicle miles traveled (eVMT). The charging optimization is described more fully in Section 2.1.2.

After calculating optimized charging profiles, the E3 PEV Grid Impacts model uses utility circuit information to calculate the incremental cost of distribution upgrades triggered or accelerated by PEV charging. Section 3.5.2 describes these calculations in more detail.

Other model outputs include:

- Other electric utility marginal costs to provide charging
- Customer electricity bills from charging loads
- Avoided fuel (e.g., gasoline and diesel) amounts
- Net avoided criteria pollutant emissions (NOx, PM-10, VOC)
- Change in electricity sector carbon emissions
- Change in transportation sector carbon emissions

For the residential charging program, E3 also used the PEV Grid Impacts Model to calculate cost test results consistent with the California Standard Practice Manual (SPM). Of the SPM cost tests, the Participant Cost Test (PCT) and the Total Resource Cost (TRC) test are the most informative for SDG&E's residential charging program. The PCT test provides an indication of the economics to a participating customer that would influence likely adoption levels. The TRC is the standard and dominant cost test used by the CPUC for DER program evaluation. Cost test results are not presented for the priority review projects, as they are pilot programs involving emerging technologies with a short duration focus.

The following section describes the PEV charging optimization in more detail.

2.1.2. PEV Charging Optimization

E3's PEV Grid Impacts model uses an hourly, linear optimization program designed to produce load profiles representative of electric vehicle operators under a given tariff to minimize customer bills.[1] The optimization model determines the hourly charging profile that minimizes customer electricity bills under the applicable electricity tariffs on a monthly basis, co-optimizing volumetric charges and demand charges when applicable. This analysis includes vehicles with fast charging that can complete charging in less than one hour. E3 accounts for the impact of subhourly charging on the peak demand of these customers. Tariff charges that are not associated with the monthly load profile of a customer (e.g. monthly fixed charges) do not change with charging behavior and thus, while included in revenue calculations, are not included in the optimization. For fleets controlled by a single operator, the model jointly optimizes charging of all of the fleet vehicles.

The optimization model is also subject to the physical and behavioral constraints listed in Table 1. Inputs to the optimization include vehicle characteristics, driving behavior for each vehicle and corresponding eVMT, charging levels, and applicable retail tariffs. The result of the optimization is optimal hourly electricity charging demand.

---

[1] The model also includes the ability to penalize the probability of insufficient charge when the driver is likely to take an impromptu trip, but this functionality is only used in this analysis to the extent that the model frontloads charging during time periods with constant price signals.

Table 1: PEV Grid Impacts Model Optimization Constraints

Physical Constraints
• **State of Charge Limits:** The state of charge for each vehicle cannot be less than zero nor greater than the stated vehicle's battery size (kWh)
• **Charging Rate Limit:** The hourly increase in state of charge for each vehicle cannot exceed the stated vehicle's maximum charging capacity (kW)
• **Charger Limit:** The sum of the demands for each vehicle in a given hour cannot exceed capacity of the charger (kW)
Behavioral Constraints *Beyond the physical constraints of a PEV battery and charger, further behavioral constraints are implemented to capture the daily driving needs of a PEV operator*
• **Availability**: PEVs may only charge when not in use and parked at a site with available charging. Each vehicle modeled has a weekday and weekend availability profile; in hours when charging is unavailable, the corresponding vehicle cannot charge
• **Driving Profile**: Each vehicle modeled has a weekday and weekend driving profile with a corresponding charging load based on required eVMT. PEVs must charge sufficiently so that they have enough stored energy to complete all scheduled drives

Figure 2 and Figure 3 illustrate the results of the optimization model for a residential vehicle under Schedule DR: Domestic Service (DR) and the Residential GIR, respectively, on a winter weekday. Under the tiered DR rate, the customer sees a constant rate throughout the day. The customer plugs in their PEV when they return home at hour ending (HE) 18 in the evening and continues charging until the battery is full in HE 21. There is no pricing incentive for the customer to avoid charging during evening peak load hours. In contrast, the Residential GIR provides a dynamic hourly price signal to the customer. With the dynamic rate, the customer has an economic incentive to shift charging to nighttime hours, when charging is least costly to the grid (Figure 3). This illustrative battery-electric vehicle (BEV) charges at level one (L1) in Figure 2. Under the residential charging program, the customer charges the BEV with a level two (L2) charger provided by SDG&E (Figure 3). This causes more condensed charging and higher charging demand under the Residential GIR. Under the EV-TOU-2 rate, a customer also has an incentive to charge away from the on-peak periods and during the lowest cost super off-peak period in the early morning. However, the Residential GIR still provides a more dynamic price signal with a stronger incentive for the customer to charge during the hours with the lowest marginal cost and highest benefits for the grid, which will vary from day to day and across seasons. For example, the residential GIR incents charging in the middle of the day during overgeneration hours in some cases.

Figure 2: Charging Optimization Under Tiered Schedule DR: Domestic Service Rate on a Winter Weekday

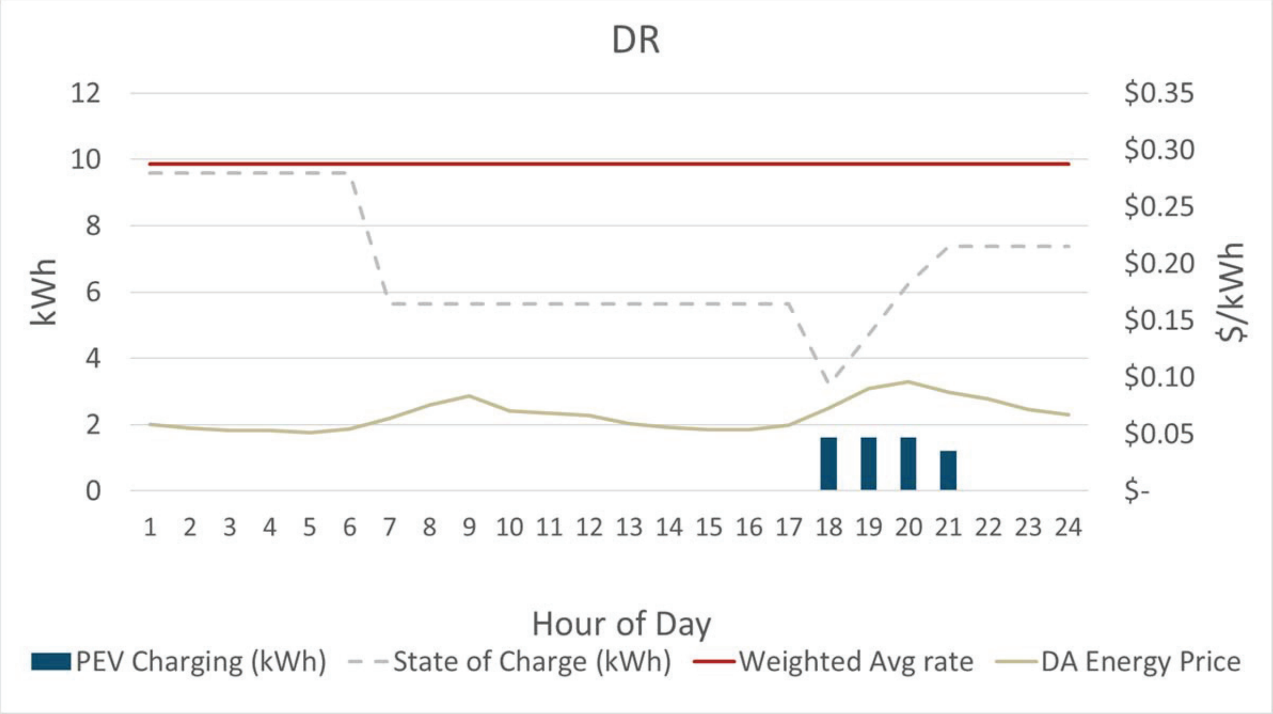
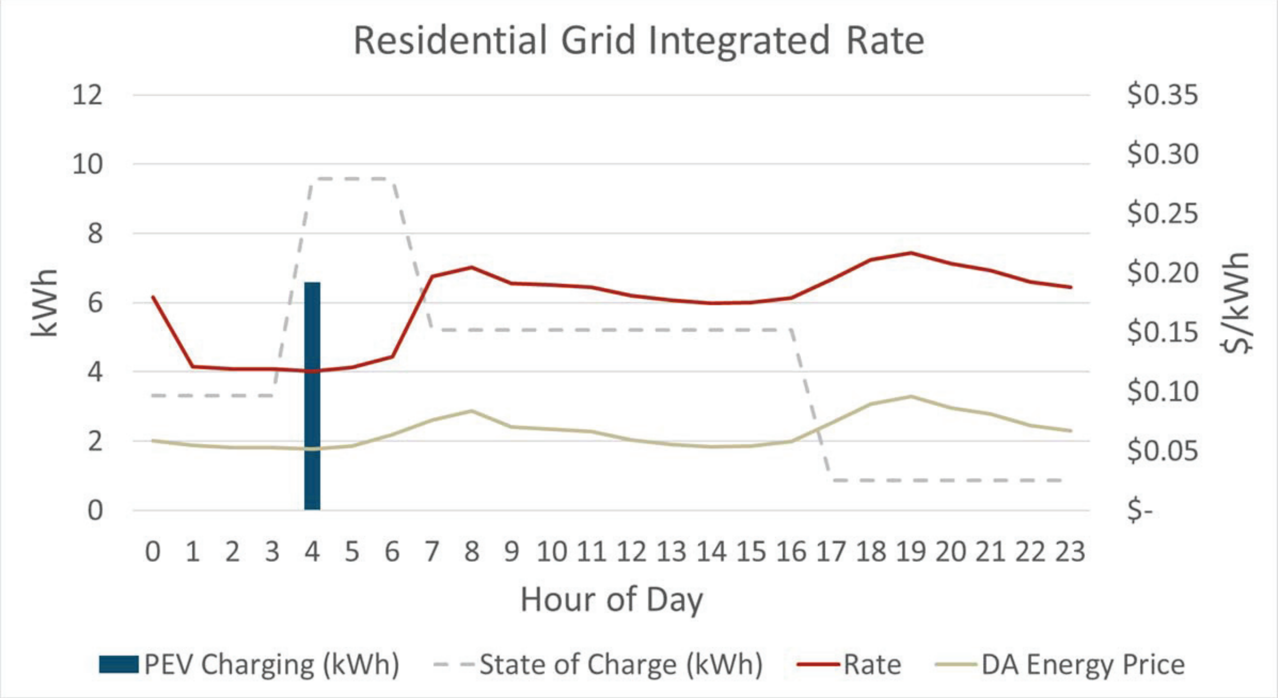


Figure 3: Charging Optimization Under the Residential GIR on a Winter Weekday



Most of the technologies modeled in this analysis operate in the same location on essentially the same schedule. For example, all forklifts are expected to be fully charged by a certain hour in the morning and are unavailable to charge during the same periods of the workday. This enables a group of vehicles to be modeled with a single consistent charging pattern. A few technologies, including taxis, however, have more of a staggered schedule. That is, while one taxi may begin driving at 7am, another might begin at 8am, and yet another at 9am. Likewise, the taxi drivers may have varied schedules in terms of their access to a charger. To best model this behavior, E3 implemented fleet scheduling logic into the optimization model. If, for example, one charging location is responsible for providing power to 14 taxis, E3 accounts for the varying taxi driving schedules while minimizing fleet-wide costs. Scheduling assumptions are based on ICF research.

The following sections describe the methods for calculating several physical outputs and present key relevant assumptions used in this analysis.

3. Inputs and Assumptions

3.1. Vehicle and Charger Forecasts

Vehicle and charger forecast trajectories drive many physical and economic outputs. E3 considers vehicle adoption forecasts an input of the model. The model calculates charger forecasts based on the vehicle adoption forecasts and assumptions of vehicles per charger.

SDG&E provided vehicle and charger forecasts associated with the priority review projects and the residential charging program. The following sections describe these forecasts.

3.1.1. Vehicle and Charger Forecasts for Priority Review Projects

Table 2 shows the scales of the priority review projects and the assumed vehicles per charger, as provided by SDG&E. The priority review projects encompass multiple vehicle technologies. E3 captured some of this granularity by analyzing multiple technologies for several of the Priority Review Projects, which is reflected in Table 2. The quantities presented throughout this document represent the impacts of the pilot project itself; they do not capture the benefits of research and improved understanding on future TE.

Table 2: Priority Project Scales and Market Potentials

Project	Project Scale: Vehicle Population (2018-2030)	Vehicles per Charger (2018-2030)
Airport GSE		
Belt Loader	17	2
Baggage Tractor	47	2
Forklift	9	2
Push Back Tug	17	2
Airport GSE Total	90	
Electrify Local Highways		
BEV DCFC	40	5
BEV L2	48	1
PHEV L2	32	1
Electrify Local Highways Total	120	
Fleet Delivery[1]	90	1
MD/HD Port Electrification[2]	13	1
Green Taxi/Shuttle/Rideshare		
Taxi	54	10
Parking Shuttle	4	4
Taxi/Parking Shuttle Total	58	
Dealership Incentives		
BEV	900	-
PHEV	600	-
Dealership Incentives Subtotal	1,500	-

[1] Modeled as MHD BEVs per specifications provided by ICF

[2] Modeled as forklifts

E3 did not include the Dealership Incentives Project in this analysis due to likely overlap with other projects, such as Electrify Local Highways and Taxi/Rideshare/Shuttle projects, as well as overlap with the Residential Charging Program. E3 did provide a rough estimate of gross GHG emissions savings from this project (see Section 3.4).

E3 modeled a variety of chargers for the Priority Review Projects, including: L1 chargers, which require little, if any, infrastructure upgrades and provide a charging capacity of 1.6 kW; L2 chargers, which can require some infrastructure upgrades and provide a maximum charging capacity of 6.6 kW; and direct current fast chargers (DCFCs) and commercial-scale chargers, both of which require additional infrastructure investment. Table 3 displays the number of chargers and the charging levels associated with each Priority Review Project. SDG&E provided these assumptions with some guidance from ICF.

Table 3: Priority Review Projects Charger Details

Project	Chargers	Max Charger Power (kW)
Airport GSE	45	30
Electrify Local Highways	88	L2: 6.6 DCFC: 50
Fleet Delivery	90	19
MD/HD Port Electrification	13	12
Green Taxi/Shuttle/Rideshare	6	50

3.1.2. Residential Charging Program Vehicle and Charger Forecasts

SDG&E provided estimates of the total residential charging program penetration. The program aims to both encourage TE adoption and minimize grid costs from vehicle charging. Some residential customers would purchase PEVs even without the SDG&E program. In SPM cost-effectiveness methodology, such customers are represented as *free riders*. To capture this issue, SDG&E also supplied a forecast of residential customers that would purchase an electric vehicle with a L1 charger under a standard retail tariff in the absence of this program.

The gross vehicle forecast, free rider forecast, net incremental vehicle forecast, and implied net to gross ratios can be found in Table 4. For the residential charging program, E3 assumes one charger per vehicle, so the charger and vehicle forecasts are identical.

Table 4: Residential Program Vehicle Forecast and Net-to-Gross Ratios

		2020	2022	2024	2030
Total Vehicles	**BEV**	6,000	26,400	54,000	54,000
	PHEV	4,000	17,600	36,000	36,000
	Total	10,000	44,000	90,000	90,000
Free Riders	**BEV**	1,800	8,327	18,407	18,407
	PHEV	1,200	5,551	12,271	12,271
	Total	3,000	13,878	30,678	30,678
Net Incremental Vehicles	**BEV**	4,200	18,073	35,593	35,593
	PHEV	2,800	12,049	23,729	23,729
	Total	7,000	30,122	59,322	59,322
Implied Net-to-gross Ratio	**All**	0.70	0.68	0.66	0.66

A higher net-to-gross ratio improves a program's cost-effectiveness in SPM tests. These implied net-to-gross ratios for the residential charging program are comparable to the ratios typically used in energy efficiency program evaluation. In other words, this analysis assumes a percentage of free riders that is comparable to those typically used in energy efficiency program valuation in California. For comparison, the "default" net-to-gross ratio that was used for many years in California was 80%, and the recent values from the Energy Efficiency Policy Manual average about 65%.

3.2. Fuel Usage

The model calculates reductions in fossil fuel usage due to displacement of ICE vehicles with PEVs. Two sets of assumptions drive the accounting of displaced fuel consumption realized by replacing ICE vehicles with PEVs: 1) the amount of gasoline fueled VMT that are replaced by electricity (eVMT); and 2) the fuel efficiency of the ICE vehicles that they replace. The electricity (kWh) needed to satisfy the PEV's driving demand (see "Driving Profile" in section 2.1.2 above) can be calculated from eVMT and electric efficiency (miles/kWh). In this analysis, electricity requirements vary only by day of the week, with large differences between weekday and weekend usage for some vehicle types.

ICF provided assumptions for six parameters that drive fuel efficiency of an ICE vehicle: conventional miles per gallon (MPG), improvement in conventional MPG over time, and conversion factors for tons of CO_2, NO_x, PM-10 and VOC emitted per gallon of gasoline, respectively. E3 uses conventional MPG to convert the eVMT of a PEV to the expected amount of gasoline used to meet the same usage. For airport-related technologies, ICF directly provided electric usage (kWh) and gallons of gasoline consumed per day. Table 5 summarizes fuel usage assumptions by vehicle type in gallons per week. Conventional MPG improvement reflects efficiency advances of new ICE vehicles over time, consistent with increasing fuel efficiency and emissions standards. The respective conversion factors are used to calculate how much of each pollutant a given ICE would emit for each gallon of gasoline it combusts.

Table 5: Fuel Usage Assumptions for Priority Review Projects by Vehicle Type

	Gallons Gasoline Avoided per Week	MPG Improvement (MPG/year)
Airport GSE		
Baggage Tractor	47	0
Belt Loader	60	0
Airport Forklift	16	0
Push Back Tug	97	0
Fleet Delivery		
Fleet Delivery Vehicle	43.3	0.02
Green Taxi/Shuttle/Rideshare		
Taxi	35.3	1.2
Shuttle	94.6	0.44
Port Electrification		
Port Forklift	55.9	0
Electrify Local Highways		
BEV with L2 charger	9.3	0.9
PHEV with L2 charger	2.2	0.9
BEV with DCFC charger	2.2	0.9

Table 6: Fuel Usage Assumptions for Residential Charging Program by Vehicle Type

	Gallons Gasoline Avoided per Week	MPG Improvement (MPG/year)
Residential		
BEV LDV	**7.1**	0.9
PHEV40 LDV	**7.4**	0.9

3.3. Incremental Load

In addition to calculating reduction in fossil fuel usage due to displacement of ICE vehicles with PEVs, the model calculates incremental electricity generated to serve the additional PEV load. As the model optimizes PEV charging profiles to minimize monthly customer bills, each vehicle's monthly charging load equals the amount of energy needed to fulfill the vehicle's monthly driving constraints (see "Driving Profile" in section 2.1.2 above), scaled up for roundtrip vehicle losses (assumed to 5% for each technology modeled). Charging on individual days within the month may be higher or lower than the driving requirements depending on the applicable driving pattern and tariff. Table 7 shows assumption for daily electricity usage due to driving, provided by ICF and SDG&E.

Table 7: Electricity Usage Assumptions for Priority Review Projects by Vehicle Type

	Weekday Usage (kWh/day)	Weekend Usage (kWh/day)	Total Weekly Usage (kWh)
GSE Equipment			
Baggage Tractor	119.6	119.6	837.2
Belt Loader	94.5	94.5	661.5
Airport Forklift	32.9	32.9	230.3
Push Back Tug	195	195	1365
Fleet Delivery			
Fleet Delivery Vehicle	85.2	85.2	596.4
Green Taxi/Shuttle/Rideshare			
Taxi	45.5	45.5	318.5
Shuttle	34.7	34.7	242.9
Port Electrification			
Port Forklift	68.8	68.8	481.6
Electrify Local Highways			
BEV with L2 charger	4	0	20
PHEV with L2 charger	4	0	20
BEV with DCFC charger	12	0	60

Table 8 provides driving-related daily electricity usage for residential vehicles. ICF provided values for eVMT under L1 charging. SDG&E estimates that upgrading chargers to L2 will increase eVMT by 10% due to increased flexibility associated with reduced charging time. The values in Table 8 reflect this 10% adder, as all of the vehicles in the residential charging program have access to L2 charging.

Table 8: Electricity Usage Assumptions for Residential Charging Program by Vehicle Type

	Weekday Usage (kWh/day)	Weekend Usage (kWh/day)	Total Weekly Usage (kWh)
Residential			
BEV LDV	9.6	11.3	70.6
PHEV40 LDV	9.9	11.7	72.9

3.4. CO_2 Emissions and Air Quality Impacts

The model also calculates carbon dioxide (CO_2) and criteria pollutant emissions impacts of displacing ICE vehicles with PEVs. Specifically, it calculates the impacts of a PEV adoption scenario on combustion-related carbon dioxide, particulate matter 10 (PM-10), and Volatile Organic Compounds (VOC) emissions. The gross emissions analysis covers two emission impacts of the program:

1. A decrease in emissions from reduced combustion of petroleum fuel in vehicles
2. An increase in emissions from incremental electricity usage

The gross emissions impact equals the magnitude of the decrease in petroleum-related emissions less the magnitude of the increase in electricity-related emissions.

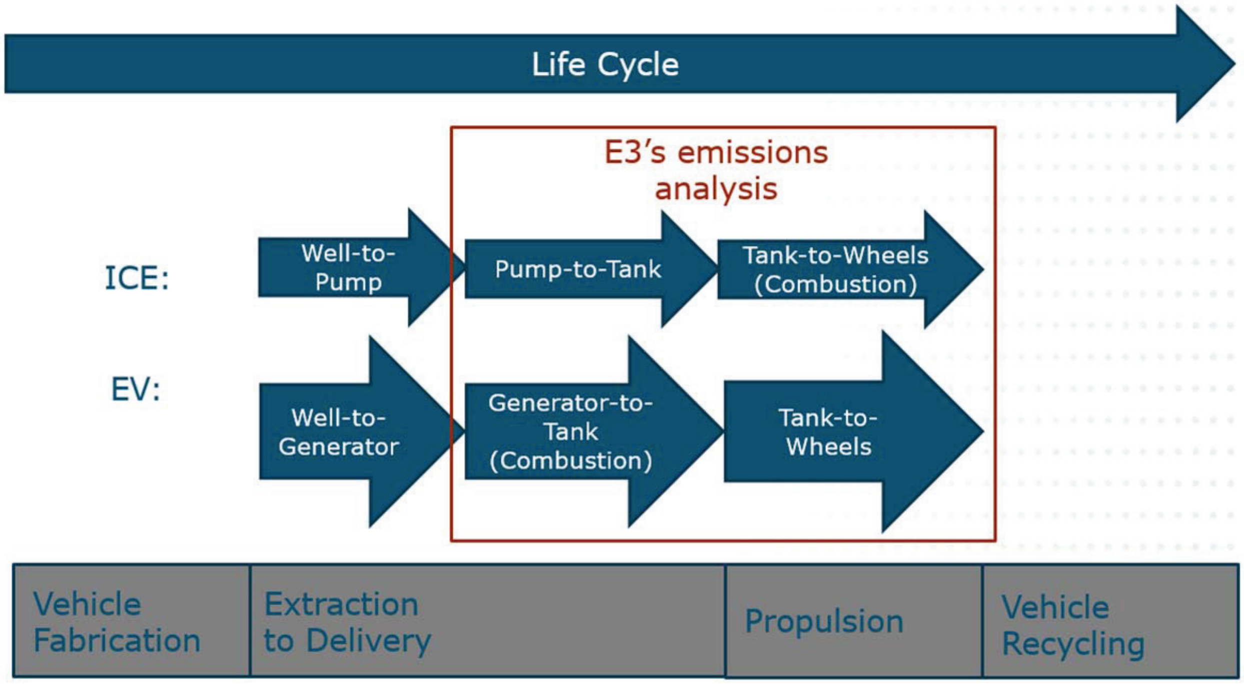
This analysis does not consider emissions from fossil fuel extraction, refining, or delivery. Emissions tracking for ICE vehicles is often categorized by its span along the lifecycle spectrum which includes the following stages:

- Vehicle fabrication
- Extraction
- Delivery
- Propulsion
- Vehicle recycling

Accounting that includes all of these stages is referred to as *lifecycle accounting*, whereas the extraction, delivery and propulsion stages are referred to as *well-to-pump*, *pump-to-tank* and *tank-to-wheels*, respectively. However, in comparing the emissions of ICE vehicles to PEVs, it is important to note that merely comparing one of these stages under one technology to the same stage under the other technology misaligns the emissions components. In particular, whereas the primary combustion of fossil fuels occurs during the tank-to-wheels phase for ICE vehicles, this phase is emission-free for PEVs. Likewise, while the *pump-to-tank* phase produces negligible emissions for ICE vehicles, the majority of PEV-related emissions occur during this phase. For this reason, in comparing the emissions profiles of ICE vehicles and PEVs, E3 accounts for both the pump-to-tank (generator-to-tank for PEVs) emissions and the tank-to-wheels emissions.

Figure 4 summarizes the CO_2 and criteria pollutant emissions tracked in E3's PEV Grid Impacts model.

Figure 4: Emissions Methodology



E3 calculates emission reductions from reduced petroleum fuel usage by multiplying the gallons of displaced fuel by the following factors:

Table 9: ICE Emission Factors by Vehicle Type

	Metric Tons CO2 / GGE	Metric Tons NOx / million GGE	Metric Tons PM / million GGE	Metric Tons VOC / million GGE
GSE Equipment				
Baggage Tractor	0.009	26.7	0.667	13.3
Belt Loader	0.009	26.7	0.667	13.3
Airport Forklift	0.009	26.7	0.667	13.3
Push Back Tug	0.009	26.7	0.667	13.3
Fleet Delivery				
Fleet Delivery Vehicle	0.009	4.57	0.0446	0.585
Green Taxi/Shuttle/Rideshare				
Taxi	0.009	1.77	0.326	1.77
Shuttle	0.009	2.93	0.169	0.152
Port Electrification				
Port Forklift	0.009	26.7	0.667	13.3
Residential and Local Highway Electrification				
BEV LDV	0.009	0.681	0.0936	1.21
PHEV40 LDV	0.009	1.83	0.262	3
Source	EIA FAQ, accessed Sep 2016	ICF Analysis: EMFAC 2014, Port of SD Emissions Inventory; San Diego Airport Emissions Inventory	ICF Analysis: EMFAC 2014, Port of SD Emissions Inventory; San Diego Airport Emissions Inventory	ICF Analysis: EMFAC 2014, Port of SD Emissions Inventory; San Diego Airport Emissions Inventory

The gasoline emissions factor of 0.009 tons/gal comes from the Energy Information Administration (EIA) Frequently Asked Questions. ICF provided the NOx, PM, and VOC emission factors. The San Diego Airport Emissions Inventory and the Port of San Diego Airport Emissions Inventory were the primary sources for criteria pollutant emission factors for airport ground support equipment (GSE) and port TE, respectively. ICF compiled all other criteria pollutant emissions factors from the California Air Resources Board EMFAC model (2014).

The marginal emissions from electricity are calculated by multiplying the gross hourly PEV charging load by an hourly marginal heat rate, which reflects a 40% RPS (per guidance provided by SDG&E), and the following emissions factors:

Table 10: Electricity Emission Factors

	Value	Source
CO2 Content of Marginal Emissions	0.0531 metric tons/MMBtu	EIA Carbon Dioxide Emissions Coefficients, accessed Feb 2016
PM10 Content of Marginal Emissions	0.0077 lbs./MMBtu	CPUC/E3 Net Energy Metering Successor Tariff Public Tool
NOx Content of Marginal Emissions	0.0146 lbs./MMBtu	CPUC/E3 Net Energy Metering Successor Tariff Public Tool
VOC Content of Marginal Emissions	0.0006 lbs./MMBtu	EPA National Action Plan for Energy Efficiency

This method effectively assumes that the marginal generator is fueled by natural gas in all hours for which the marginal generator is not a zero-marginal cost resource, such as a renewable generator.

To calculate net emissions, E3 uses the same method applied to the estimate of the free riders' PEV charging load absent the program[2] and then subtracts this value from the gross hourly PEV charging load.

3.5. Electric Grid Costs

3.5.1. System Marginal Costs

The EV Grid Impacts Model calculates physical electric grid impacts of increased PEV charging as well as associated incremental electric grid costs. E3 used the CPUC Avoided Costs 2016 Interim Update[3] to estimate marginal $/kWh grid impacts of the TE Program. Historically, these marginal costs have been used to calculate the value of reduced loads resulting from implementing DER, hence the term 'avoided cost'. However, they are equally applicable to calculate the cost of increased loads from PEV charging. The Interim Update provides hourly avoided costs forecasts disaggregated by the following categories:

- Generation Energy
- Generation Capacity
- Ancillary Services
- Losses
- Renewable Portfolio Standard (RPS) Above-market Procurement Costs

The Interim Update also contains marginal costs for transmission and distribution capacity, but those values are supplanted by the circuit analysis described later in this section.

---

[2] Recall that free riders drive 10% more miles with the program chargers

[3] Available at: http://www.cpuc.ca.gov/General.aspx?id=10710

E3 calculates the costs of PEV charging by multiplying the hourly change in electricity usage by the hourly avoided costs. E3 uses a 2025 single snapshot year of marginal costs to enable efficient PEV charging optimization for a variety of vehicle technologies and customer segments. The 2025 snapshot year avoided costs correspond to a 40% RPS level, and they are assumed to remain constant in real terms.

A full description of the avoided (marginal) cost components, the avoided cost methodology,[4] and the avoided cost model[5] can be found on the CPUC website.

3.5.2. Transmission & Distribution Upgrade Costs

E3's PEV Grid Impacts model calculates the costs associated with upgrades to distribution systems driven by incremental PEV charging. In place of the $/kW-yr T&D capacity costs in the CPUC Avoided Costs, the PEV Grid Impacts model allocates PEV charging load to individual SDG&E distribution circuits and calculates costs associated with upgrading those circuits, as needed to continue to meet circuit peak demands. SDG&E provided the following circuit information, which is used to calculate PEV-driven upgrade costs:

- Load growth percentage: the rate at which already-existent load is expected to increase
- Peak day shape: the 24-hour shape representing the load on the given circuit on the day of highest local demand. While the non-PEV load level increases over time, the peak demand shape only changes with PEV adoption
- Capacity rating (kW): the maximum demand that the given circuit can physically serve
- Trigger percentage: the percent of the capacity rating (kW) that necessitates an upgrade to the circuit's capacity rating
- Upgrade size (kW): the increase in capacity rating for the given circuit
- Upgrade cost: the cost of upgrading the given circuit

With these data, the T&D module follows the following procedure:

(1) **Calculate net present value (NPV) upgrade costs without PEV**: For each circuit, the peak day shape grows at the corresponding load growth percentage over the time horizon of the model. If this load growth causes the circuit's peak demand to exceed the trigger capacity, an upgrade occurs. For example, if a 10 kW-rated circuit with a 90% trigger percentage experiences a peak demand above 9 kW, an upgrade will be triggered. This circuit incurs the upgrade cost and results in a new, increased kW capacity rating. This process continues throughout the analysis timeframe. Some circuits may experience multiple upgrades during this timeframe. Using circuit upgrade cost assumptions, the model then calculates net present value costs of upgrades in the absence of PEV adoption.

(2) **Calculate NPV with-PEV upgrade cost:** The above process is repeated. However, in addition to non-PEV load growth, incremental PEV load is also added to the circuits. The addition of PEV load triggers upgrades earlier in the analysis period for some circuits, which increases the net present value of upgrades. E3 maps PEV load to circuits based on customer type. For example, there is one circuit that corresponds to San Diego International Airport, so E3 allocates 100% of airport

---

[4] Available at: http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=12504

[5] Available at: http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=12509

load to that circuit. E3 allocates residential PEV charging load across all circuits with residential loads pro rata by residential non-PEV load. E3 did not perform a clustering analysis based on vehicle registration data as was done for the CalETC Transportation Electrification Assessment. The CalETC analysis found modest distribution upgrade costs even with clustering of LDVs. E3 maps cost to technologies by circuit; when an upgrade is triggered, the costs of this upgrade are distributed to the PEVs whose load falls on that circuit pro rata based on PEV load.

(3) Determine incremental T&D cost associated with PEVs: E3 calculates the PEV-driven T&D costs as the difference between (2) and (1). 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.

For the T&D analysis, E3 extends the analysis period through 2055, which is 31 years after the last incremental PEV purchase and 25 years after the last PEV replacement. E3 discounts all costs at SDG&E authorized weighted average cost of capital (WACC).

4. Residential Charging Program Cost-benefit Analysis

4.1. Cost-benefit Analysis Overview

The residential charging program is of a larger scale than the priority review projects and involves technology that has been more widely deployed. E3 uses the PEV Grid Impacts Model to perform SPM cost-benefit analysis and quantify the potential benefits of the residential program. While the market transformation nature of the program prevents the SPM cost tests from capturing all indirect costs and benefits of the program, these cost tests are useful for understanding direct costs and benefits.
The PEV Grid Impacts Model calculates results for four SPM cost tests. The Total Resource Cost test is currently the dominant test used for evaluating demand-side programs before the CPUC and is defined below:

> *The Total Resource Cost Test measures the net costs of a demand-side management program as a resource option based on the total costs of the program, including both the participants' and the utility's costs.*
>
> *The test is applicable to conservation, load management, and fuel substitution programs. For fuel substitution programs, the test measures the net effect of the impacts from the fuel not chosen versus the impacts from the fuel that is chosen as a result of the program. TRC test results for fuel substitution programs should be viewed as a measure of the economic efficiency implications of the total energy supply system (natural gas and electric).*
> California Standard Practice Manual p.18, http://www.calmac.org/events/spm_9_20_02.pdf

The TRC cost test has been used to evaluate fuel substitution of electricity versus natural gas within the utility sector. The TRC cost test is, in concept, equally applicable to substituting electricity for gasoline. The additional considerations for evaluating fuel substitution between the utility and transportation sectors pursuant to SB 350 transportation electrification goals are discussed further in Section 4.5

E3 also calculates the participant cost test (PCT), the ratepayer impact measure (RIM), and a societal cost test (SCT) for completeness. The PCT estimates the impacts to the participant and is generally used as an indicator of the ability of a program to achieve participation. The RIM test represents the impact on customer rates, and has been referred to as the non-participant cost test. The CPUC does not use the RIM test for evaluating DER program cost-effectiveness. The SCT incorporates non-monetized total program costs and benefits. It should be noted that the CPUC is currently considering either modifications to the TRC test or a more prominent use of the SCT. Those ongoing considerations involve changes such as the use of a lower discount rate, the use of a higher cost of carbon to reflect above-market long-run carbon costs or abatement costs, and the inclusion of health impacts. E3, however, has not incorporated any of these changes into this analysis because of the early nature of those SCT considerations.

Section 4.3 discussed these cost tests in more detail.

4.2. Evaluating Program Impacts

In the residential charging program, SDG&E is proposing to install L2 chargers at customer homes and require that customers take service for their home usage and PEV charging under a new Residential Grid Integrated Rate (Residential GIR). E3 estimates the gross program impacts and the net program impacts accounting for potential free ridership. In this analysis, free riders are customers who would have purchased an electric vehicle and charged it at L1 under a standard retail tariff in the absence of this program.

- To estimate gross program impacts, E3 assumes that the TE program exclusively leads to incremental adoptions of electric vehicles. E3 estimates the charging behavior, electricity emissions, marginal electric system costs, and bill impacts based on the entire increased electricity usage from charging. In addition, E3 estimates the customer fuel cost savings from avoided ICE fuel purchases and reduced emissions from avoided combustion of that fuel.
- To estimate net program impacts, E3 analyzes a reference case with SDG&E-provided estimates of the number of customers who have purchased EVs and using a Level 1 charger under a non-grid integrated rate. For these customers, E3 evaluates the *difference* between the hourly charging patterns under the Residential GIR and under standard tariffs. In these cases, E3 only includes the value for *incremental* avoided vehicle fuel purchases or emissions due to increased eVMT with access to higher charge capacities. This allows for a more detailed representation of potential impacts than a simple net-to-gross adjustment for free riders.

To calculate these gross and net impacts, E3 first uses the PEV Grid Impacts model to analyze the impacts of two cases - *Gross Program Impacts* and *Reference Impacts* - relative to identical levels of ICE adoption. E3 then calculates net impacts by subtracting the *Reference Impacts* from the *Gross Program Impacts* results. These two cases differ only in three assumptions:

Table 11: Structure of Residential Charging Program Analysis

	Gross Program Impacts	Reference (Free Ridership) Impacts
PEV Adoption Trajectory	90,000 vehicles[1]	30,678 vehicles[1]
Retail Rates for PEV Charging	Residential Grid Integrated Rate	DR and EV-TOU-2 Tariffs
Charging Level	L2	L1

[1] See Table 4 for breakdown of BEVs and PHEVs

All other assumptions remain unchanged across these two analysis cases.

Because many state-of-the-world assumptions that drive the total costs and benefits of a TE Program are highly uncertain, E3 also performed sensitivity analysis on three key drivers that are particularly uncertain: 1) Extension of state and federal tax credits for purchasing PEVs, 2) incremental capital costs of PEVs; and 3) gasoline prices. Specifically, E3 developed the following two state-of-the world scenarios for analyzing costs and benefits of the Residential Charging Program:

Table 12: Scenarios Analyzed

	Scenario A	Scenario B
Last Year of Federal and State Tax Credits	2020	2024 (incentive levels reduced over time)
Incremental Vehicle Capital Costs (PEV vs. ICE)	Direct Current Fast Charging Mapping forecast (Ricardo)	Parity by 2025 (Bloomberg New Energy Finance)
Gasoline Prices	EIA forecasts	High forecast (25% higher than EIA-based forecast)

Sections 4.4.1 and 4.4.5 specify the precise assumptions used in each scenario.

4.3. Cost Test Definitions

E3 analyzes the direct costs and benefits of the Residential Charging Program from four perspectives:

- The *Participant Cost Test (PCT)* analyzes the financial proposition of participating in the program from a participating customer's perspective. For most customers, this test captures the financial proposition of purchasing a PEV instead of an ICE vehicle and charging the PEV at L2 on the Residential GIR.
- The *Ratepayer Impact Measure* (RIM) calculates the impact of the program on average utility retail rates, which can be considered the impact on non-participating utility customers. The RIM test compares charger costs, program costs, and marginal costs from providing incremental electricity to increased utility revenue collected for PEV charging. While this test captures the costs of increased electricity usage, it does not capture the countering benefits of reduced

energy consumption in non-electric sectors, which affects the appropriateness of using this test to evaluate fuel switching TE programs.

- The *Total Resource Cost Test (TRC)* captures the total direct monetary impact of participants and non-participants. This cost test excludes monetary transfers, such as state tax credits and electricity bills, between parties within California. It also excludes benefits that cannot be directly monetized through existing channels. Note that the TRC does include emissions-related costs and benefits to the extent that the cost of emissions are embedded in energy prices.
- The *Societal Cost Test (SCT)* aims to quantify the total impact of the TE program on participants and non-participants when externalities are included. In this analysis, the SCT differs from the TRC only in its inclusion of some societal net health impacts due to a change in emission levels.

Cost and benefit components differ by cost test. Some components even represent costs from some perspective and benefits from another perspective. Table 13 shows the cost and benefit components by cost test for the TE program.

Table 13: Cost and Benefit Components by Cost-effectiveness Perspective

SB 350 Project Cost-Effectiveness Tests					
		Cost-Effectiveness Tests			
Test Components		RIM	PCT	TRC	SCT
EV Customer Costs & Benefits	Incremental Vehicle Cost		Cost	Cost	Cost
	Vehicle O&M Savings		Benefit	Benefit	Benefit
	Gasoline Savings		Benefit	Benefit	Benefit
	Utility Bills	Benefit	Cost		
	Federal Tax Credits		Benefit	Benefit	Benefit
	State Rebates		Benefit		
Charger Costs	Utility Capital Costs	Cost		Cost	Cost
Admin. Costs	Utility O&M Costs	Cost		Cost	Cost
Electricity Supply Costs	Energy Cost	Cost		Cost	Cost
	Losses Cost	Cost		Cost	Cost
	Ancillary Services Cost	Cost		Cost	Cost
	Capacity Cost	Cost		Cost	Cost
	T&D Cost	Cost		Cost	Cost
	RPS Cost	Cost		Cost	Cost
Air Quality Benefits	LCFS Benefits	Benefit			
	Criteria Pollutants				Benefit

Table 14 describes each of these cost test components in more detail.

Table 14: Cost Test Components

Cost/Benefit Component	Description
Incremental Vehicle Costs	Capital costs of PEVs above the costs of the ICEs they replace
Vehicle O&M Savings	Reduction in net vehicle operation and maintenance (O&M) costs associated with replacement of ICEs with PEVs, including fewer oil changes and parts repairs
Gasoline Savings	Reduction in gasoline purchases due to lower demand for gasoline
Utility Bills	PEV adoption increases electricity consumption, which, in turn, can increase participant electricity bills. This results in increased costs for participants and increased utility revenue, which reduces average rates
Federal Tax Credits	PEVs under 14,000 lbs. are currently eligible for a $7,500 federal tax credit
State Rebates	The Air Resources Board (CARB) Clean Vehicles Rebate Project provides rebates of up to $7,000 for PEV adopters in California
Utility Capital Costs	Utility-funded charging infrastructure, including make readies
Utility O&M Costs	Utility marketing, charger maintenance, and billing/administration costs associated with the program
Electricity Supply Costs	PEV adoption increases electricity consumption, which increases electric grid costs, including costs associated with electric generation, ancillary service provision, RPS procurement, and electric transmission and distribution
LCFS Benefits	CARB's LCFS program provides a financial incentive for switching to transportation fuels with lower carbon intensities; SDG&E receives credits for PEVs on a per gallon avoided basis
Criteria Pollutants	Quantification of health impacts associated with changes in NO_x, VOC, and PM emission levels due to reduced conventional fuel combustion and increased electricity combustion. This analysis does not assess location-specific emissions impacts, such as increased health costs of criteria pollutant emissions in densely-populated areas

E3 assesses the present values of these annual cost and benefit streams using SDG&E's 7.79% authorized WACC. The following section summarizes the key assumptions that drive the values of each of these costs and benefits.

4.4. Key Assumptions by Cost Test Component

4.4.1. Incremental Vehicle Costs and Tax Credits

Currently, the upfront capital cost of an electric vehicle exceeds that of its ICE counterpart, although the trajectory is trending towards parity. E3 collaborated in 2016 with U.C. Davis, PlugShare, Ricardo and PG&E on the EPIC-funded DC Fast Charging Mapping Report, which includes EV adoption and cost scenarios developed by Ricardo.[6] As incremental vehicle cost projections vary, E3 uses two different forecasts for the incremental vehicle cost of a PEV: one from Ricardo (used in scenario A), the other starting at Ricardo's 2017 projection and decreasing linearly to 0 by 2025 to reflect the Bloomberg New Energy Finance (BNEF) assumption of parity by 2025 (used in scenario B). Table 15 summarizes these forecasts.

Table 15: Incremental Vehicle Costs

		2020	2022	2024	2030	Source
Scenario A	**BEV**	$7,454	$5,698	$3,941	$1,809	Ricardo (2016). *Direct Current Fast Charging Mapping*
	PHEV	$7,821	$6,842	$5,864	$3,173	
Scenario B	**BEV**	$6,680	$4,008	$1,336	$0	Ricardo (2016). *Direct Current Fast Charging Mapping; BNEF*
	PHEV	$6,083	$3,650	$1,217	$0	

California PEV adopters are eligible for both federal- and state-level tax incentives. The federal incentive is determined as follows:

- All eligible vehicles receive a $2,500 tax incentive
- If the size of the customer’s PEV battery exceeds 5 kWh, the customer receives an additional $417 per incremental energy capacity
- This total benefit is limited to $7,500 per vehicle

Given E3's modeling assumptions, BEV LDVs are eligible for the full $7,500 credit per vehicle. Due to their smaller battery size, PHEVs are eligible for a credit of only $4,745 per vehicle.

State tax incentives offer additional credits that vary only by vehicle type. For BEVs, this credit is equivalent to $2,500 per vehicle; for PHEVs, the credit is $1,500 per vehicle.

As a conservative assumption, E3 has the federal and state tax incentives expire after 2020 under Scenario A. In Scenario B, E3 assumes that both the federal and state tax incentives are extended through 2024.

E3 assumes that the tax credits decline as incremental vehicle costs decrease to ensure that the tax credits do not exceed the incremental vehicle costs in any year. E3 assumes that the state tax credit decreases before the federal tax credit decreases.

4.4.2. Vehicle Maintenance Costs

While ICE vehicles incur various O&M-related costs, such as oil changes, Ricardo’s data show that replacing an ICE vehicle with a PEV produces significant vehicle O&M savings. E3 includes these maintenance cost savings as an economic benefit in the cost-benefit analysis. The lifetime LDV O&M cost savings are $1,498 per BEV and $915 per PHEV40.

---

[6] EPIC Final Report - Project 1.25 DC Fast Charging Mapping, Appendix C. Available at: https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/EPIC-1.25.pdf

4.4.3. Charger and Program Costs

SDG&E provided charger and program cost revenue requirements line items, which are described in Chapter 6 of SDG&E's Application. For this analysis, E3 directly uses these annual values through 2049. The 2050 costs include the 2050 present value of all post-2050 costs.

4.4.4. Tariffs and Utility Bills

Tariffs influence many components of the analysis, including utility bills, charging behavior, and all of the costs, benefits, and quantities impacted by charging shape. E3 estimates PEV-related bill impacts for representative customers; E3 did not perform a full bill impacts analysis commensurate with that of Chapter 5 of SDG&Es' Application.

The Residential Charging Program encourages PEV adoption and increased eVMT and requires all participants to receive service under the Residential GIR. Hence, the Residential Charging Program impacts participant electric bills in two ways:

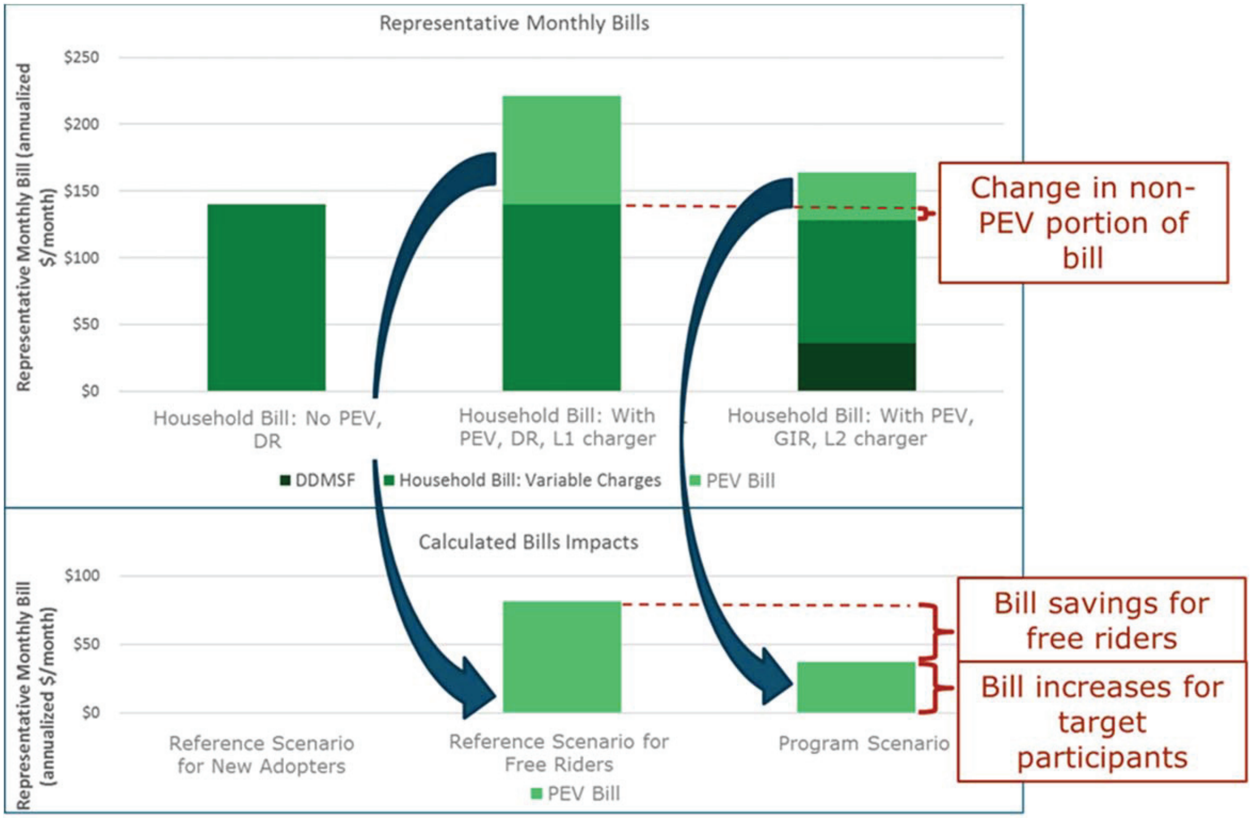
- Increases total usage due to PEV charging, and bills this charging under the Residential GIR
- Bills the non-PEV household usage under the Residential GIR

E3 focuses the analysis exclusively on the former effect and excludes the impact of switching the non-PEV household usage from the current retail rates to the Residential GIR. There is considerable variation in residential non-PEV usage patterns, so the latter effect may vary substantially across participants.

Figure 5 illustrates the bill impact calculations. The top graph presents E3's bill impact analysis of one representative customer including both of the effects enumerated above. In this case, the customer's usage pattern is similar to the class average, so there is little change in the non-PEV household usage portion of the total bill (the difference indicated using the dashed red line).

The bottom graph illustrates the bill impact calculations used in this analysis. It focus on the portion of bills that corresponds to PEV charging. E3 calculates gross bill impacts as the charging bills for participants with PEVs and L2 chargers on the Residential GIR. This reflects the bill impacts for target participants who would not otherwise purchase PEVs. To calculate net bill impacts, E3 compares the PEV charging bills for participants with L2 chargers on the Residential GIR with their hypothetical PEV charging bills if they charged at L1 on current retail rates (DR).

Figure 5: Illustrative Bill Impact Calculation



SDG&E provided the following assumption for the breakdown of the retail rates under which free riders would receive service in the absence of the program:

- 70% Schedule DR: Domestic Service (tiered)
- 30% Schedule EV-TOU-2: Domestic Time-of-Use for Households with Electric Vehicles

In aggregate, SDG&E supplied the assumptions that 42% of participants would be on the DR schedule absent the program, and 58% of participants would otherwise be on a time-of-use rate.

4.4.5. Gasoline Costs

Future gasoline prices are both highly uncertain and one of the largest drivers of TE benefits. Gasoline price forecasts have declined significantly since publication of the first CalETC California Transportation Electrification Assessment in 2014.

For this analysis, E3 escalated the average EIA 2016 California weekly average gasoline price[7] at the escalation trajectory of the 2017 EIA AEO U.S. Motor Gasoline Price Forecast.[8] This gasoline price

---

[7] EIA Weekly California All Grades Reformulated Retail Gasoline Price, available at: https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMM_EPM0R_PTE_SCA_DPG&f=W

[8] AEO2017. Table 3: Energy Prices by Sector and Source.

forecast method represents a slight departure from those of prior E3 analyses, in which E3 has used CEC IEPR gas price forecasts. Because the CEC has not published a gasoline price forecast since 2015, using the most recent CEC IEPR would ignore recent cost declines and, therefore, overestimate program benefits.

The gasoline price for Scenario A starts at \$3.04/gallon in 2017 and escalates to \$9.17/gallon in 2050, in nominal dollars. For Scenario B, E3 increased the gas price forecasts by 25%. This is still a conservative assumption compared to the latest iteration of the CEC IEPR. The CEC IEPR starts at approximately \$3.35/gallon in 2017 and escalates to \$5.17/gallon in 2026, while the 2026 Scenario B gasoline price is only \$4.48/gallon.

4.4.6. LCFS Credits

Providers of electricity for use as a transportation fuel are eligible to earn Low Carbon Duel Standard (LCFS) credits, which can be sold in California's LCFS credit market. Providers, which include Electric Vehicle Service Providers (EVSPs), site hosts, fleet operators, and utilities, must register with the LCFS Credit Bank & Transfer System (LRT-CBTS) to track credits and earn revenue. E3 captures the direct costs and benefits of these LCFS allowances in the cost-benefit analysis. The analysis does not include any administration or transaction costs.

The CARB Monthly LCFS Credit Transfer Activity Report for August 2016 publishes an allowance price of \$75, which translates to a credit of \$0.68/gallon of gasoline displaced. E3 assumes that this price escalates at inflation and remains constant in real terms.

The incorporation of LCFS credits in the cost tests used in this analysis is somewhat subject to assumptions. Under this analysis, E3 considers the LCFS credits to be a benefit accrued by ratepayers. This assumption aligns with SDG&E's guidance that the utility directly passes LCFS revenue onto ratepayers. Because actual SDG&E practices somewhat favor distributing the LCFS credit revenue to PEV owners, it may be appropriate to include a portion of the LCFS credits in the PCT and reduce the RIM LCFS benefit. E3 also assumes that LCFS costs are fully embedded in gasoline prices.

4.4.7. Air Quality and Health Cost Impacts

E3 uses \$/ton figures provided by ICF in the 2014 CalETC Transportation Electrification Assessment to calculate the societal benefits of air quality and health impacts for NOx, PM and VOC.[9] The reduced emissions from ICE vehicles are multiplied by these values to calculate dollar values for air quality improvement. Monetized GHG emission costs are embedded in electricity and gasoline prices.

4.5. SPM Cost Tests and SB 350

The current policy objectives for TE are fundamentally different from the historical goals that the SPM cost tests methods were designed to evaluate. Historically the cost tests have been applied to DER, for

---

[9] ICF. CalETC Transportation Electrification Assessment Phase 1 Final Report. Updated September 2014. Table 16, p. 25. Available at: http://www.caletc.com/wp-content/uploads/2016/08/CalETC_TEA_Phase_1-FINAL_Updated_092014.pdf

which all costs and benefits are contained within the electricity and natural gas sectors. The focus of these DER analyses, especially energy efficiency analyses, have been to evaluate DER as a resource that can reduce the total cost of meeting customer energy and service needs (e.g: lighting, air conditioning, refrigeration). In contrast, SB 350 includes goals for accelerating TE adoption to meet GHG reduction and air quality goals across the utility, transportation and industrial sectors. The focus on TE as a means for achieving GHG reduction and air quality goals, and its interaction with the transportation sector, places the TE program outside of the standard SPM evaluation regime.

Moreover, it is worth noting that the cost-benefit assessments presented here use the carbon values approved by the CPUC in the 2016 Avoided Cost Interim Update, which are only reflective of the carbon value monetized and embedded in current markets. These market-based carbon values are likely far below the marginal carbon abatement cost that would be incurred in the future to achieve California's carbon reduction goals.

The SPM cost tests described here-in are intended to inform stakeholders and policy makers; they are not intended to be determinative or threshold tests for TE.