DOCKETED	
Docket Number:	18-IEPR-09
Project Title:	Decarbonizing Buildings
TN #:	224447
Document Title:	lGas_Renewable_Gas_Final Report
Description:	Attachment from George Minter Email 8.2.18
Filer:	Raquel Kravitz
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	8/8/2018 11:31:28 AM
Docketed Date:	8/8/2018

Analysis of the Role of Gas for a Low-Carbon California Future

Final Report

Prepared for:
Southern California Gas Company

Submitted by:
Navigant Consulting, Inc.
1375 Walnut Street
Suite 100
Boulder CO 80302

213.670.2724
navigant.com

Reference No.: 195582
July 24, 2018

TABLE OF CONTENTS

DISCLAIMER

Copyright

Disclaimer

This report ("report") was prepared for SoCalGas on terms specifically limiting the liability of Navigant Consulting, Inc. (Navigant), and is not to be distributed without Navigant's prior written consent. Navigant's conclusions are the results of the exercise of its reasonable professional judgment. By the reader's acceptance of this report, you hereby agree and acknowledge that (a) your use of the report will be limited solely for internal purpose, (b) you will not distribute a copy of this report to any third party without Navigant's express prior written consent, and (c) you are bound by the disclaimers and/or limitations on liability otherwise set forth in the report. Navigant does not make any representations or warranties of any kind with respect to (i) the accuracy or completeness of the information contained in the report, (ii) the presence or absence of any errors or omissions contained in the report, (iii) any work performed by Navigant in connection with or using the report, or (iv) any conclusions reached by Navigant as a result of the report. Any use of or reliance on the report, or decisions to be made based on it, are the reader's responsibility. Navigant accepts no duty of care or liability of any kind whatsoever to you, and all parties waive and release Navigant from all claims, liabilities and damages, if any, suffered as a result of decisions made, or not made, or actions taken, or not taken, based on this report.

LIST OF ACRONYMS

AFUE	Annual Fuel Utilization Efficiency
Berkeley Lab	Lawrence Berkeley National Laboratory
BCF	Billion Cubic Feet
CEC	California Energy Commission
CLASS	California Lighting and Appliance Saturation Study
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COP	Coefficient of Performance
CPUC	California Public Utilities Commission
DEER	Database of Energy Efficient Resources
EE	Energy Efficiency
EF	Energy Factor
EIA	US Energy Information Administration
EPA	US Environmental Protection Agency
EUL	Effective Useful Life
EV	Electric Vehicle
FSTC	Food Service Technology Center
GHG	Greenhouse Gas
HPWH	Heat Pump Water Heater
HSPF	Heating Seasonal Performance Factor
IEPR	Integrated Energy Policy Report
IOU	Investor-Owned Utility
IRP	Integrated Resource Plan
kWh	Kilowatt-Hour
LADWP	Los Angeles Department of Water and Power
mCHP	Micro Combined Heat and Power
MICS	Measure Input Characterization System
MMCF	Million Cubic Feet
mt	Metric ton
NPV	Net Present Value
NRDC	Natural Resources Defense Council
PG&E	Pacific Gas and Electric
RASS	Residential Appliance Saturation Study
RG	Renewable Gas
ROB	Replace on Burnout
RPS	Renewable Portfolio Standard
RTU	Rooftop Unit
SCE	Southern California Edison
SEER	Seasonal Energy Efficiency Ratio
SF	Square Feet
SoCalGas	Southern California Gas Company
UC	University of California
ZNE	Zero Net Energy

EXECUTIVE SUMMARY

Southern California Gas Company (SoCalGas) engaged Navigant Consulting, Inc. (Navigant) to conduct a technical analysis of the following:

- Potential greenhouse gas (GHG) emissions reductions from building electrification
- Estimated amount of renewable gas (RG) needed to match reductions under different scenarios
- Projected combined annual cost for consumer utility and appliance costs in each scenario
- Cost-effectiveness of each GHG emissions reduction strategy under different assumptions.

This report quantifies the amount of RG that would need to be supplied to SoCalGas' retail customers to decarbonize gas at similar pace as the electric supply. That is, how much RG would have to be supplied so building end uses have the same GHG footprint regardless of whether they use or gas or electric appliances.

Evaluation Methodology

Navigant developed a model to evaluate the potential GHG emissions reductions from appliance electrification in SoCalGas territory and to estimate RG needs under different scenarios. The scenarios represent possible electrification initiatives in California where the installed base of gas-fueled appliances in residential and commercial buildings are replaced with electricity-fueled appliances either overnight (i.e., Overnight Conversion) or at the end of their useful life (Normal Replacement).

Navigant developed a baseline characterization for the residential and commercial building stock and appliance characteristics within SoCalGas territory. The evaluation team used the results of the *2017 California Public Utilities Commission (CPUC) Energy Efficiency Potential and Goals* study[1] as a starting point for its analysis and adjusted as necessary using information from the *2016 California Gas Report and SoCalGas Workpapers*.[2] The business-as-usual baseline calculates GHG emissions from 10 natural gas residential and commercial end uses across the entire SoCalGas service territory. Table ES-1 summarizes the building segment and end-use selections. For this analysis, Navigant selected an electric heat pump water heater (HPWH) as the baseline residential electric option rather than an electric resistance model. The electrification discussion in California generally assumes that the HPWH would be used.

[1] Details on the CPUC Energy Efficiency Potential and Goals Studies are available at: http://www.cpuc.ca.gov/General.aspx?id=2013

[2] 2016 California Gas Report and supporting materials are available at: https://www.socalgas.com/regulatory/cgr.shtml

Table ES-1. Residential and Commercial Gas End Uses Selected by Navigant for Analysis

Building Segment	Appliance/ End Use	Baseline Consumption in SoCalGas Territory (Million Therms per Year)	Gas Technology (Installed Base)	Electric Replacement (Efficiency)
Residential	Space Heating	1,518	Gas Furnace	Electric Heat Pump (COP 3)
	Water Heating	946	Gas Water Heater	Electric Heat Pump Water Heater (EF 2)
	Clothes Dryer	193	Gas Clothes Dryer	Electric Clothes Dryer (Baseline)
Commercial	Space Heating	386	Gas Boiler	Electric Boiler (99%)
	Space Heating	209	Gas Furnace (RTU)	Electric Heat Pump (RTU, COP 3)
	Water Heating	132	Gas Water Heater Boiler	Electric Water Heater (99%)
	Water Heating	19	Small Gas Water Heater (>50 gal)	Electric Heat Pump Water Heater (COP 4)
	Cooking (Convection Oven)	26	Gas Convection Oven	Electric Convection Oven (FSTC Baseline)
	Cooking (Fryer)	20	Gas Fryer	Electric Fryer (FSTC Baseline)
	Clothes Dryer	2	Gas Clothes Dryer	Electric Clothes Dryer (Baseline)

Note: RTU = Rooftop Unit; COP = Coefficient of Performance; EF = Energy Factor; FSTC = Food Service Technology Center
Baseline Scenario details provided in Section 2.1.
Source: Navigant analysis

The following three Normal Replacement scenarios[3] were modeled to understand the impact that these activities may have:

- **Normal Replacement 100%:** 100% of annual gas appliance retirements are replaced on burnout (ROB) with electric appliances. In an average year, approximately 6.6% of natural gas appliances are replaced by electric appliances at the end of their 15-year effective useful life (EUL). By 2030, 87% of the installed base would be electric assuming 2018 as a start year.
- **Normal Replacement 50%:** 50% of annual gas appliance retirements are replaced with electric appliances. In an average year, approximately 3.3% of natural gas appliances are replaced by electric options at the end of their 15-year EUL. By 2030, 43% of the installed base would be electric assuming 2018 as a start year.
- **Normal Replacement 25%:** 25% of annual gas appliance retirements are replaced with electric appliances. In an average year, approximately 1.6% of natural gas appliances are replaced by electric options at the end of their 15-year EUL. By 2030, 22% of the installed base would be electric assuming 2018 as a start year.

[3] The Normal Replacement 100% target represents the most aggressive RG scenario. The results and findings for less aggressive electrification scenarios (Normal Replacement 50%, 25%) are summarized in Section 4.4.

For each electrification scenario, Navigant modeled the number of natural gas appliances that would be replaced in each year by electric appliances and calculated their electricity consumption and GHG emissions based on the hourly load profile and hourly electricity emissions factor in each year. The evaluation team then determined GHG emissions reductions in each electrification scenario by calculating the difference in emissions from the baseline scenario. This value represents the GHG emissions reductions target that must be achieved by the RG GHG emissions reduction strategies.

Navigant then analyzed the economics of each GHG emissions reduction strategy by modeling the consumer utility cost, appliance cost, and combined annual cost (the sum of the consumer utility and appliance costs).

- **Consumer utility costs**[4] represent 2017 Integrated Energy Policy Report (IEPR) rate projections[5] for conventional gas ($/therm) and electricity ($/kWh) and ICF projections for in-state and out-of-state RG supply;[6], it also includes mixed in-state (25%) and out-of-state (75%) RG supply based on a May 2018 ICF memo.[7] To reflect possible distribution, transmission, and generation needs to accommodate increased building loads, the evaluation team also ran a high electricity rate projection as a bookend high electricity rate scenario. The team applied an annual growth rate of 3% to the Southern California Edison (SCE) rates based on projections within Los Angeles Department of Water and Power's (LADWP's) 2016 Final Integrated Resource Plan (IRP)[8] that represent the stacked impacts of increased Renewable Portfolio Standards (RPSs), energy storage, local solar, system reliability, and electrification impacts, as well as other factors that may be unique to LADWP. This high uncertainty projection is meant to capture an upper-case scenario for future electricity rates based on other rate projections in the region, including the LADWP forecast contained in its IRP and other regional estimates. The SCE General Rate Case for 2018[9] projects increased rates of 2.7% in 2018, 4.2% in 2019, and 5.2% in 2020 as part of the distribution infrastructure upgrade planning.[10] A recent University of California (UC) Berkeley/Lawrence Berkeley National Laboratory (Berkeley Lab) analysis on residential water heating electrification uses electricity growth rates of 2%-5% for future projections (2% in base and 5% as upper bound).[11] There is high uncertainty in projecting future electricity rates, and the

[4] Navigant has not independently validated the utility cost estimates from the IEPR nor the RG supply costs.

[5] California Energy Commission (CEC). 2018. "Feb 21, 2018 Workshop for Final 2017 IEPR Adoption, Mid-Mid Forecast." Available at: http://www.energy.ca.gov/2017_energypolicy/documents/2018-02-21_business_meeting/2018-02-21_middemandcase_forecst.php

[6] Sheehy and Rosenfeld. 2017. "Design Principles for a Renewable Gas Standard." 2017. Available at: https://www.icf.com/resources/white-papers/2017/design-principles-for-renewable-gas. Resource assumes levelized cost of energy for RG infrastructure and supply.

[7] Memo from Philip Sheehy of ICF to SoCalGas. "Potential RNG Supply to California." May 2018. Provided by SoCalGas for this analysis.

[8] LADWP. 2016. "2016 Final Power Integrated Resource Plan." Available at: https://www.ladwp.com/ladwp/faces/wcnav_externalId/a-p-doc?_adf.ctrl-state=iirytk0lc_4&_afrLoop=35208544433395

[9] Edison International. 2016. "2018 SCE General Rate Case Overview." September 1, 2016. Available at: https://www.edison.com/content/dam/eix/documents/investors/sec-filings-financials/2018-SCE-general-rate-case-overview.pdf

[10] The SCE General Rate Case only covers 2018-2020 and does not project across the full 2018-2030 range. Historically, there are instances of large increases in several years, followed by several years of low or zero annual rate increases.

[11] Raghavan et al. 2017. "Scenarios to Decarbonize Residential Water Heating in California." *Energy Policy, 109*. 441-451. Available at: https://rael.berkeley.edu/publication/scenarios-to-decarbonize-residential-water-heating-in-california/

3% annual growth rate provides sensitivity over the IEPR values of approximately 1% annual growth rate.

  - Discussed in Section 5.3, additional research is necessary to understand the impacts that appliance electrification, RG, and other GHG emissions strategies could have in future years for natural gas and electricity rates, including time-of-use or multi-tiered rate structures, customer consumption patterns, grid infrastructure needs, stranded assets, and other issues.

- **Appliance costs** represent purchase and installation costs for existing buildings. Residential appliance cost ($ per home) estimates were based on 2016 data compiled by KPF Group based on construction invoice and budget estimates from Southern California builders and contractors.[12] The estimated costs assume the combined purchase, installation, and upgrade costs, including contractor overhead, profit, permit fees, and other factors that homeowners would experience with professional installation.[13, 14] Commercial appliance cost ($ per 1,000 SF) estimates are from the CPUC Potential and Goals study.[15] In many cases, the CPUC Potential and Goals study did not contain cost information for an electric equivalent technology, and the gas appliance costs were scaled using other available resources that provide costs for both gas and electric technologies (e.g., US Energy Information Administration appliance cost database).[16]
- **Electrical infrastructure costs:** This analysis assumes that an existing building has natural gas appliances; therefore, building owners may need to upgrade at least part of their electrical infrastructure to accommodate electric appliances. The evaluation team used electrical infrastructure cost estimates for residential and commercial buildings from the 2016 TRC report.[17] Limited information exists on the average electrical upgrade costs for existing buildings, and anecdotal estimates range widely based on the type of electrical appliance (e.g., electric HPWH, solar PV system, electric vehicle [EV] charger), age of building, contractor prices, and other factors. Recently constructed or new construction buildings will likely have lower electrical infrastructure upgrade costs than most existing buildings, or none at all. In addition, future changes to Title 24 codes to accommodate EVs and other technologies may eliminate incremental costs for electrical infrastructure. Navigant evaluated economic projections assuming 0% and 50% of residential and commercial buildings would require electrical infrastructure upgrades. Further discussed in Section 2.4.2, the team analyzes the effects of different electric infrastructure upgrade cost projections, including upgrade requirements for 0% and 50% of residential and commercial buildings.

---

[12] Appliance costs from Gilbert Kitching of KPF Group in 2016. SoCalGas provided KPF Group research to Navigant for use in this report.

[13] Navigant reviewed these costs relative to other data sources, including the Database for Energy Efficiency Resources (DEER), and noted the equipment costs appear higher for each type of equipment (gas and electric) relative to what was observed from the DEER sources.

[14] Electrician subcontractor cost for HPWH was removed to avoid double counting upgrade cost.

[15] Details on the CPUC Energy Efficiency Potential and Goals Studies are available at: http://www.cpuc.ca.gov/General.aspx?id=2013

[16] EIA. 2016. “Updated Buildings Sector Appliance and Equipment Costs and Efficiency.” Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/

[17] TRC Solutions. 2016. “Palo Alto Electrification Final Report.” City of Palo Alto. Available at: https://www.cityofpaloalto.org/civicax/filebank/documents/55069

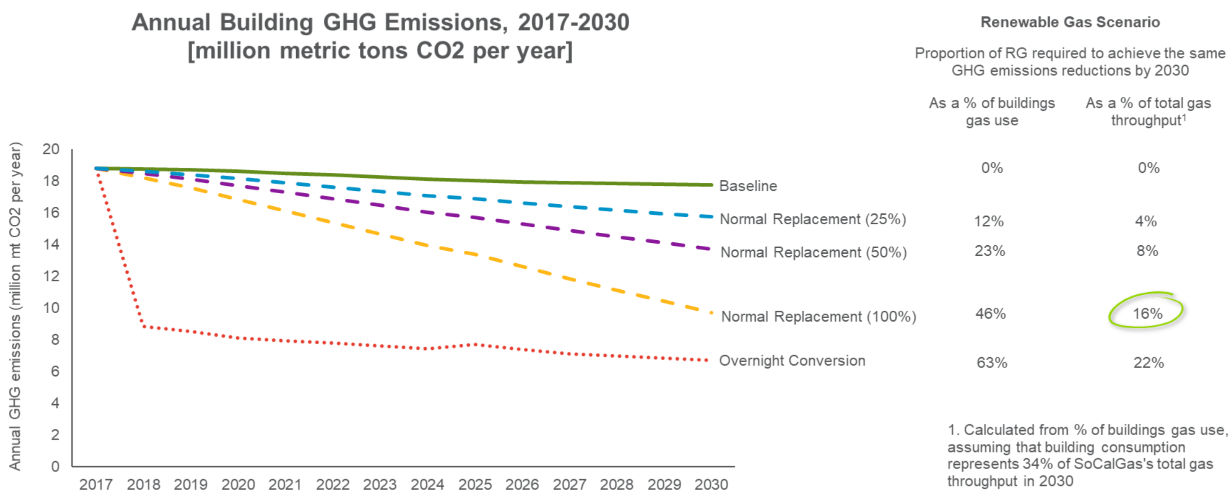
Further discussed below, Navigant conducted sensitivity analyses for gas and electric appliance costs, the cost for possible electrical infrastructure upgrades, and energy rates for RG and electricity.

Summary of Key Results

RG Requirements and GHG Emissions Reductions

Figure ES-1 illustrates the results from the analysis of RG requirements. Under the Normal Replacement 100% scenario, the same GHG emissions reductions can be achieved by gas appliances if 46% of building gas use comes from RG by 2030.[18] This equates to 16% of total SoCalGas throughput coming from RG by 2030 (i.e., approximately 140 BCF/year based on an estimated total SoCalGas throughput of 867 BCF/year in 2030).[19]

Figure ES-1. Annual GHG Emissions Reductions and Required RG Percentage Under Different Electrification Scenarios



Source: Navigant analysis

As shown in Table ES-2, if there was a lower conversion rate, a lower volume of RG would be required to maintain GHG emissions equivalency. Normal Replacement 50% would require 23% RG as a percentage of buildings gas use (8% of total system throughput). Normal Replacement 25% would require 12% RG as a percentage of buildings gas use (4% of total system throughput).

[18] The total for core gas (residential, core commercial, core industrial, natural gas vehicles) is approximately the same volume as buildings (residential, core commercial, non-core commercial).

[19] 2016 California Gas Report and supporting materials are available at: https://www.socalgas.com/regulatory/cgr.shtml

Table ES-2. RG Requirements in 2030 to Maintain GHG Parity with Electrification Scenarios

Scenario	Conversion %	Required RG % of SoCalGas Buildings Gas Use (2030)	Required RG % of Total SoCalGas Gas Throughput (2030)	Required Annual RG Volume (BCF/year, 2030)
Overnight Conversion	100% of Total Market	63%	22%	188
Normal Replacement	100% ROB	46%	16%	137
	50% ROB	23%	8%	69
	25% ROB	12%	4%	36

2016 California Gas report estimates total SoCalGas throughput of 867 BCF/year in 2030.

Source: Navigant analysis

Table ES-3 summarizes the specific GHG emissions reductions from electrification for specific building segments and end uses. Most appliances achieve GHG emissions reductions through electrification in 2018, and the advantage increases in 2030 as the RPS targets reduce grid electricity emissions further. Electric technologies that use electric resistance heating (e.g., commercial boilers) have smaller reductions relative to those with heat pump heating (e.g., residential space and water heating). Commercial electric cooking equipment (e.g., fryers, convection ovens) have higher unit efficiency relative to gas models (e.g., fryers: 75%-85% for electric vs. 35%-60% for gas; convection ovens: 65%-70% for electric vs. 30%-45% for gas). Clothes dryers using electric resistance heating increase GHG emissions in 2018 relative to gas models, but the comparison narrows by 2030 due to higher RPS introductions.

For additional context, the buildings sector accounted for approximately 11% of California's total 2015 GHG emissions of 440.4 million metric tons of CO_2e, with residential and commercial buildings accounting for 6% and 5%, respectively.[20] These estimates represent GHG emissions from whole building energy consumption, whereas the values for Table ES-3 represent specific building end uses.

[20] California Air Resources Board, *California Greenhouse Gas Emission Inventory - 2017 Edition*. June 2017. https://www.arb.ca.gov/cc/inventory/data/data.htm

Table ES-3. GHG Emissions Reductions from Electrification by Building Segment/End Use

Building Segment	Appliance/ End Use	Gas Technology (Installed Base)	Electric Replacement (Efficiency)	GHG Emissions Reductions from Electrification	
				2018	2030
Residential	Space Heating	Gas Furnace	Electric Heat Pump (COP 3)	69%	74%
	Water Heating	Gas Water Heater	Electric Heat Pump Water Heater (EF 2)	63%	70%
	Clothes Dryer	Gas Clothes Dryer	Electric Clothes Dryer (Baseline)	-7%*	13%
Commercial	Space Heating	Gas Boiler	Electric Boiler (99%)	7%	29%
	Space Heating	Gas Furnace (RTU)	Electric Heat Pump (RTU, COP 3)	62%	71%
	Water Heating	Gas Water Heater Boiler	Electric Water Heater (99%)	6%	26%
	Water Heating	Small Gas Water Heater (>50 gal)	Electric Heat Pump Water Heater (COP 4)	69%	74%
	Cooking (Convection Oven)	Gas Convection Oven	Electric Convection Oven (FSTC Baseline)	44%	58%
	Cooking (Fryer)	Gas Fryer	Electric Fryer (FSTC Baseline)	56%	68%
	Clothes Dryer	Gas Clothes Dryer	Electric Clothes Dryer (Baseline)	-1%*	20%

*Negative reductions values refer to a net increase in emissions (i.e., conversion from natural gas to electric appliances would result in a net increase in emissions in a given year).

Source: Navigant analysis

GHG Emissions Reduction Strategies

After developing the RG volume estimates to maintain GHG emissions reductions with the Normal Replacement 100% scenario, Navigant projected the potential cost for RG and electrification strategies under different assumptions.[21] The various RG and electrification projections include impacts of in-state and out-of-state RG supply resources, appliance costs, possible electrical infrastructure upgrade requirements, incremental energy efficiency, and electricity rate impacts.

Table ES-4 summarizes the major RG and electrification projections analyzed in this section.

[21] The Normal Replacement 100% scenario represents the most aggressive RG scenario. The results and findings for the less aggressive electrification scenarios (Normal Replacement 50% and 25%) are summarized in Section 4.4.

Table ES-4. GHG Emissions Reduction Projections with RG and Electrification

Projection	Appliance Type/ Efficiency	RG Source	Electrification	Electricity Rates	Electrification Costs
Baseline (IEPR Gas & Elec Rates)	Baseline Efficiency	N/A	N/A	IEPR	N/A
Renewable Gas (In-State Supply)	Baseline Efficiency	In-State	N/A	IEPR	N/A
Renewable Gas (In-State) + Energy Efficiency	High Efficiency	In-State	N/A	IEPR	N/A
Renewable Gas (Out-of-State Supply)	Baseline Efficiency	Out-of-State	N/A	IEPR	N/A
Renewable Gas (Mixed In-State / Out-of-State)	Baseline Efficiency	25% In-State / 75% Out-of-State	N/A	IEPR	N/A
Electrification (ROB, IEPR Rates, incl. Upgrades)	Baseline Efficiency	N/A	100% of gas appliances replaced with electric models at end of life	IEPR	Yes
Electrification (ROB, High Rates, incl. Upgrades)	Baseline Efficiency	N/A	100% of gas appliances replaced with electric models at end of life	High	Yes
Electrification (ROB, IEPR Rates, w/o Upgrades)	Baseline Efficiency	N/A	100% of gas appliances replaced with electric models at end of life	IEPR	No
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	Baseline Efficiency	N/A	100% of gas appliances replaced with electric models at end of life	IEPR	No

Section 2.4 provides details on utility and appliance cost assumptions.

Source: Navigant analysis

Cumulative Appliance Cost Impacts

Cumulative appliance costs represent the purchase, installation, and electric infrastructure upgrade costs for all appliances installed in SoCalGas territory over the 2018-2030 period. The appliance costs for each projection are influenced by fuel type, appliance efficiency, purchase cost, installation cost, and the need for electric infrastructure upgrades.

- Compared to the baseline and RG projections, electrification scenarios have an appliance cost premium of $3 billion-$27 billion (6%-60%) depending on whether electrical infrastructure costs are included. Residential HPWHs have the most significant appliance and upgrade cost difference and show a notable cost increase ($3 billion, 6%) in the lowest cost assumptions.
- The appliance cost for electrification projections is largely determined by the residential water heater cost assumptions. The installed cost for electric HPWHs is higher than for baseline gas

storage water heaters (up to $4,313 vs. $1,448) and may require electrical infrastructure upgrades (up to $4,671) for existing homes ($2,336 per home average assuming 50% of homes require upgrades). For the Low Cost HPWH scenario, electrification carries a $550 installed cost premium for existing homes.

- Because the RG projection uses baseline gas appliances and does not require infrastructure upgrades within the building, the RG projection has the same appliance cost as the baseline projection.

Consumer Annual Utility Cost Impacts

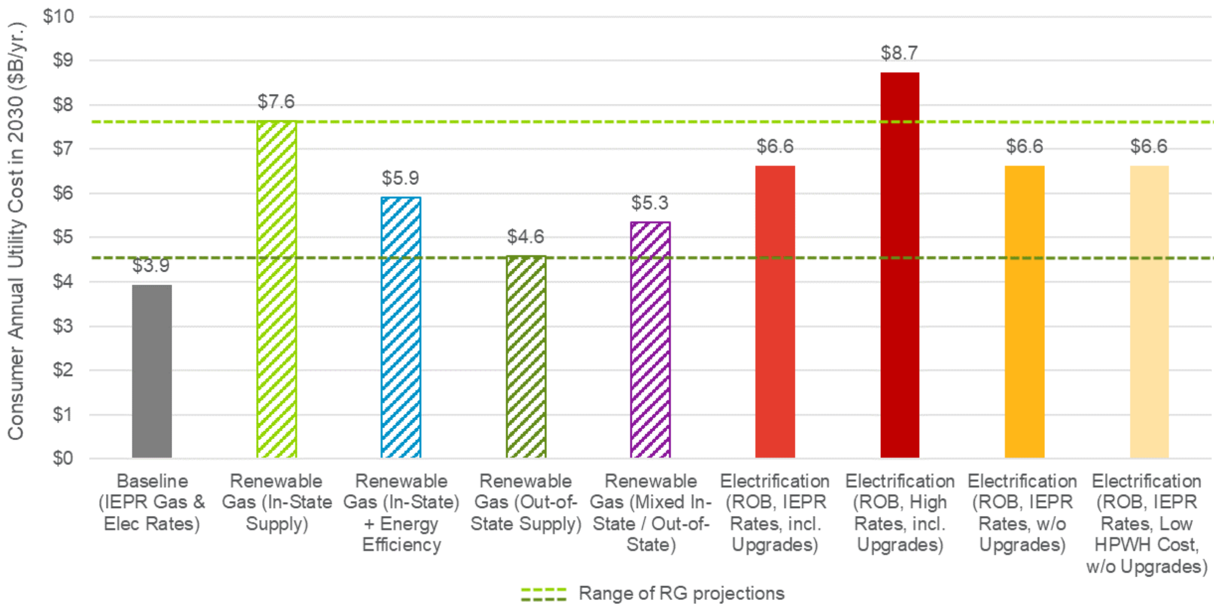
Consumer utility costs in each projection represent the annual operating cost for all residential and commercial appliances in SoCalGas territory in each year over the analysis period (2018-2030), including new and existing gas and electric appliances. Figure ES-2 summarizes consumer annual utility costs in 2030. The analysis compares consumer annual utility costs in 2030 because it is the first year where all projections provide the same GHG emissions reductions. These costs represent the consumer utility cost to building owners in each year and do not represent the direct cost to utilities for any necessary grid infrastructure improvements. These infrastructure costs are at least partially represented by the high electricity rate[22] and RG projections, which may implicitly include the utility's grid infrastructure upgrade costs.

The following list summarizes the key findings and trends for consumer utility costs:

- Each GHG emissions reduction strategy increases consumer annual utility costs in future years. In 2030, consumer annual utility costs would increase by $0.7 billion/year-$4.8 billion/year over the baseline projection for the range of RG and electrification projections.
- Electric end-use loads with electric heat pump technologies (e.g., residential space heating and water heating) show modest energy cost increases, whereas electric technologies using electric resistance elements (e.g., residential clothes dryers, commercial boilers, commercial cooking) show larger energy cost increases and overall impact despite their lower installed appliance stock.
- The RG projection using a mixed supply from in-state (25%) and out-of-state (75%) RG resources ($5.3 billion/year) and the out-of-state RG projection ($4.6 billion/year) would have lower consumer annual utility costs than electrification projections ($6.6 billion/year) using IEPR electricity rates. The RG projection using in-state RG ($7.6 billion/year) has a higher consumer annual utility cost than the electrification scenario ($6.6 billion/year) using IEPR electricity rates.
- The in-state RG + Energy Efficiency projection has lower consumer annual utility costs than each electrification scenario ($5.9 billion/year vs. $6.6 billion/year-$8.7 billion/year) due to the lower gas consumption of the higher efficiency appliances and the decreased RG requirement. Higher efficiency electric technologies would reduce operating costs for the electrification projections while increasing first costs, but that is not within the scope of this analysis.

[22] Navigant analyzed a higher electricity rate projection to bookend the IEPR rate projection. This high uncertainty projection is meant to capture an upper-case scenario for future electricity rates based on other rate projections in the region.

Figure ES-2. Consumer Annual Utility Cost in 2030 for RG and Electrification Projections (New and Existing Appliances)



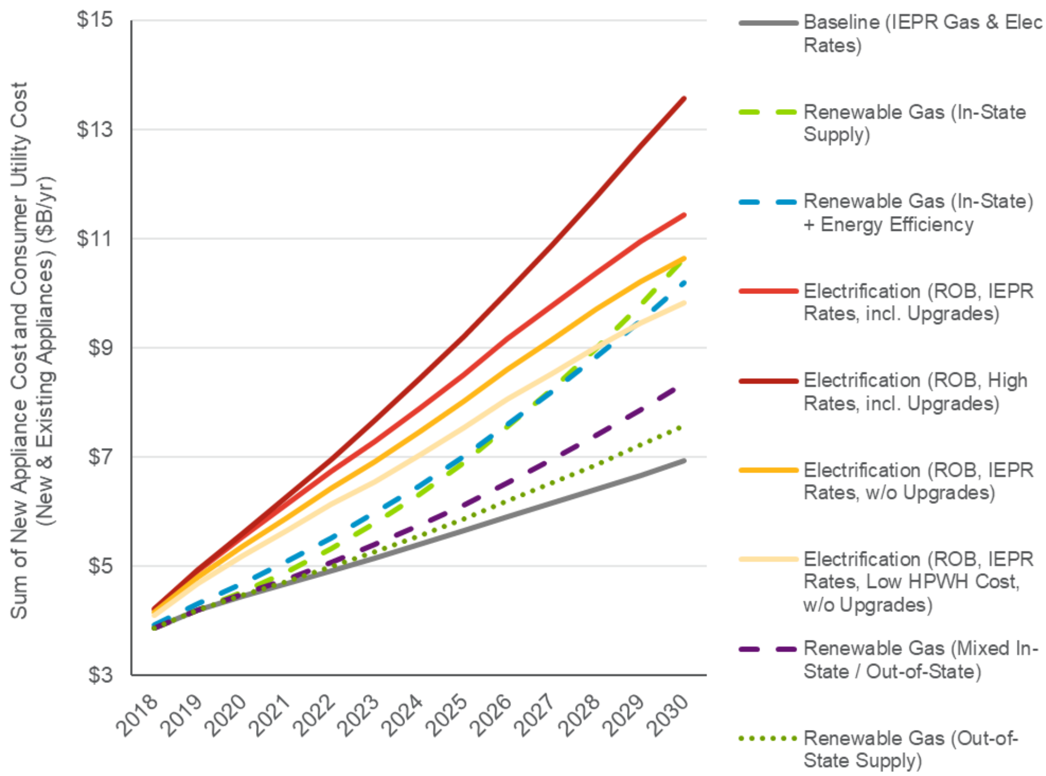
Represents consumer energy consumption costs for all appliances (new and existing).

Source: Navigant analysis

Combined Annual Cost Impacts

Figure ES-3 summarizes the combined annual cost for each projection, including consumer annual utility cost for new and existing appliances and annualized appliance and upgrade costs in each year from 2018 to 2030. This represents the average annual costs that a building owner would experience. This is because they would incur the appliance purchase and upgrade cost once over the appliance's lifetime but experience consumer utility bills on a recurring basis. In 2030, the RG projection using in-state RG has comparable combined annual cost ($10.6 billion/year) to the range of electrification projections ($9.8 billion/year-$13.6 billion/year). RG from out-of-state resources has substantially lower combined annual cost than each of the other RG and electrification projections.

Figure ES-3. Combined Annual Cost for RG and Electrification Scenarios (New and Existing Appliances, Annualized Over 15 Years)



Represents sum of costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed from 2018 to 2030.

Source: Navigant analysis

Table ES-5 summarizes the cumulative values for consumer utility cost, annualized appliance and upgrade cost, and combined annual cost over the analysis period (2018-2030). When appliance and upgrade costs are annualized over 15 years, consumer utility costs have the largest influence on cumulative combined annual cost. Each RG projection has lower cumulative combined annual cost ($73 billion-$87 billion) than electrification projections ($92 billion-$112 billion) over the analysis period (2018-2030). This comparison is mostly due to consumer utility cost differences, particularly for early years when RG prices are lower on the supply curve. When considered as net present value (NPV) with a 3% discount rate, the cumulative combined annual cost for RG projections range from $60 billion-$71 billion and electrification projections range from $75 billion-$91 billion.

Table ES-5. Cumulative Consumer Utility, Appliance, and Combined Annual Cost 2018-2030 for RG and Electrification Projections (New and Existing Appliances, Annualized Over 15 Years)

Projection	Cumulative Consumer Utility Cost 2018-2030 ($ Billions)	Cumulative Appliance Cost 2018-2030 – Annualized 15 Years ($ Billions)	Cumulative Combined Annual Cost 2018-2030 ($ Billions)
Baseline (IEPR Gas & Elec Rates)	$50	$21	$70
Renewable Gas (In-State Supply)	$66	$21	$87
Renewable Gas (In-State) + Energy Efficiency	$58	$29	$87
Renewable Gas (Out-of-State Supply)	$52	$21	$73
Renewable Gas (Mixed In-State / Out-of-State	$56	$21	$77
Electrification (ROB, IEPR Rates, incl. Upgrades)	$70	$33	$103
Electrification (ROB, High Rates, incl. Upgrades)	$79	$33	$112
Electrification (ROB, IEPR Rates, w/o Upgrades)	$70	$28	$97
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$70	$22	$92

Represents cumulative sum of costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed from 2018 to 2030. Numbers may not add to total due to rounding.

Source: Navigant analysis.

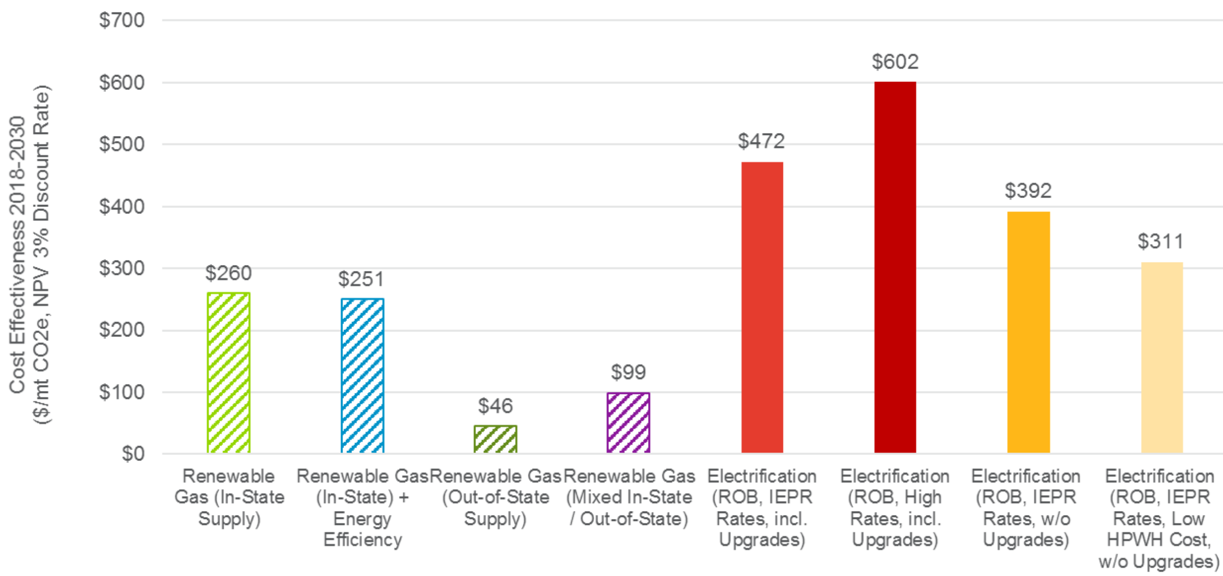
Cost-Effectiveness of GHG Emissions Reductions

Figure ES-4 summarizes the cost-effectiveness of each GHG emissions reduction strategy ($/mt CO_2e) to maintain the GHG emissions reductions with the Normal Replacement 100% scenario in 2030. These figures represent the cumulative combined annual cost for GHG emissions reduction over the 2018-2030 period, including consumer annual utility cost for new and existing appliance and annualized appliance and upgrade costs for those installed since 2018. These values represent NPV assuming a 3% discount rate. The RG and electrification projection each provides the same GHG emissions reductions in 2030, with some variation in earlier years due to analysis assumptions such as RG introduction timeline, grid emissions factors, growth rates, and other factors. The following list summarizes the key findings and trends for cost-effectiveness, assuming the RG supply will be available at the costs assumed in this study:

- Using the RG cost assumptions provided for this analysis, the range of RG projections ($46/mt CO_2e-$260/mt CO_2e) are lower than the range of electrification projections ($311/mt CO_2e-$602/mt CO_2e). When annualized, the cost difference between the electrification projections is largely determined by the consumer annual utility cost rather than the cost of appliance purchase and infrastructure upgrades.

- The in-state RG + Energy Efficiency projection has a lower cost ($251/mt CO_2e) than the in-state RG projection ($260/mt CO_2e) by using the cost-effective incremental energy efficiency to decrease the amount of higher priced RG. The RG projection using out-of-state RG has a substantially lower cost ($46/mt CO_2e) than the other RG and electrification projections due to no incremental appliance cost and a minimal consumer utility cost increase.

Figure ES-4. Cost-Effectiveness of GHG Emissions Reduction Strategies: 2018-2030 (Cumulative Cost and GHG Emissions Reductions with the Normal Replacement 100% Scenario, NPV 3% Discount Rate)



Incremental costs include sum of energy consumption costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) in 2030. Costs represent NPV with 3% discount rate.

Source: Navigant analysis

Conclusions

This study analyzed the potential GHG emissions reductions from building electrification, estimated the amount of RG needed to match GHG emissions reductions under different scenarios, projected the combined annual cost for consumer utility and appliance costs under different assumptions, and compared the cost-effectiveness of each GHG emissions reduction strategy. When examining these results, it is important to note that the current study focuses on residential and commercial buildings only and does not consider RG supply constraints, additional RG program needs, or any direct cost to electric utilities for any necessary grid infrastructure improvements.

Based on RG supply availability at the costs assumed in this study, the research indicates that RG delivered to residential and commercial buildings could reach similar GHG emissions reduction targets in 2030 as appliance electrification. When comparing the cost-effectiveness of different GHG emissions reduction strategies, RG scenarios have comparable or lower costs to electrification scenarios when considering the range of possible RG and electricity rate projections, and uncertainties around appliance purchase, installation, and upgrade cost estimates.

The study concludes that RG is worth further consideration as part of the low-carbon buildings strategy, including in-state RG resources, out-of-state RG resources, and incremental energy efficiency. Given the uncertainties in assumptions for RG and electrification projections, further research is necessary to determine the best pathways to achieve California's ambitious GHG goals.

Recommendations

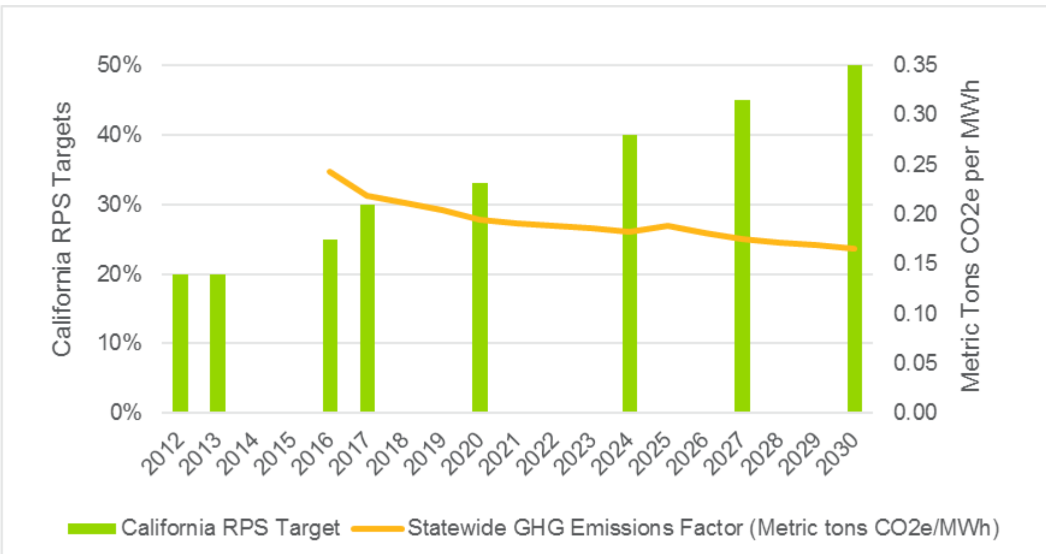
Navigant recommends SoCalGas and other stakeholders pursue the following activities to further investigate the potential for RG as a part of California's low-carbon future.

1. Include and further explore RG as an option to meet GHG emissions targets for buildings in 2030 and beyond, including developing a common set of assumptions with respect to RG resource and infrastructure availability and costs, and advancing RG policies.
2. Conduct further research to estimate how appliance electrification could affect electric utilities and consumers, particularly related to a common set of assumptions for appliance installation costs, and upgrade costs for building and grid infrastructure.
3. Evaluate opportunities to foster greater RG supply within California and with regional stakeholders.

1. INTRODUCTION AND OVERVIEW

California's electricity Renewable Portfolio Standard (RPS) targets of 33% by 2020 and 50% by 2030 will substantially decrease greenhouse gas (GHG) emissions for the electricity sector and reduce the GHG emissions for residential and commercial buildings. Figure 1-1 summarizes the impact that the RPS will have on the GHG emissions for utility-delivered electricity. To meet the GHG emissions targets, various stakeholders have proposed full electrification of building energy loads to achieve greater GHG emissions reductions at higher RPS levels. For example, the National Resources Defense Council (NRDC) and partners presented materials in February 2018 to promote building electrification through legislation,[23] the Los Angeles City Council adopted a resolution in February 2018 to compel LA's Building and Safety Department and the Department of Water and Power (LADWP) to study pathways toward building electrification,[24] and Southern California Edison (SCE) released a November 2017 white paper titled *The Clean Power and Electrification Pathway*.[25] These stakeholders propose that replacing natural gas appliances with electric appliances will result in greater GHG reductions, especially once the RPS hits 50% and greater.

Figure 1-1. California RPS Targets and Average Electricity GHG Emissions Factor



Source: RPS Targets from 2017 California Energy Commission (CEC) "Tracking Progress" report, GHG emissions factors from Navigant analysis described in Section 2.2

---

[23] Golden and Delforge. 2018. "The Next Step in the Clean Energy Transition – Decarbonizing Heating Energy in Buildings." NRDC. Available at: http://www.lgsec.org/wp-content/uploads/2018/02/NRDC-Sierre-Club-LGSEC-Decarbonizing-Heating-Energy-in-Buildings-Feb-12-2018-v2.pdf

[24] Snoonian Glenn. 2018. "L.A. Takes Big Step to Curb Greenhouse Gas Emissions from Buildings." Architectural Record. Available at: https://www.architecturalrecord.com/articles/13253-la-takes-big-step-to-curb-greenhouse-gas-emissions-from-buildings

[25] SCE. 2017. *The Clean Power and Electrification Pathway*. Available at: https://www.edison.com/content/dam/eix/documents/our-perspective/g17-pathway-to-2030-white-paper.pdf

California does not have a similar RPS target for natural gas (i.e., a renewable gas standard). Additionally, the GHG emissions resulting from the direct use of natural gas within buildings will not decrease without substantial increases in energy efficiency throughout the building stock and the introduction of renewable gas (RG). In recent years, Southern California Gas Company (SoCalGas) has explored RG pilots and interconnection programs to help major commercial and industrial customers reduce their GHG emissions and explored the possibility of greater use throughout California.[26]

SoCalGas wanted to understand the amount of RG that would be required so the use of gas appliances in buildings would have the same GHG reductions as converting all appliances to electricity. SoCalGas engaged Navigant Consulting, Inc. (Navigant) to conduct a study to understand the amount of RG required to meet GHG emissions reduction targets for buildings over the period 2018-2030. It is important to note that the current scope focuses on residential and commercial buildings only and does not consider RG supply constraints, additional RG program needs, or any direct cost to electric utilities for any necessary grid infrastructure improvements.

[26] SoCalGas Renewable Natural Gas Tool Kit, Fall 2016 Renewable Natural Gas Workshop presentations, and other materials available at: https://www.socalgas.com/smart-energy/renewable-gas

2. EVALUATION APPROACH AND METHODOLOGY

Navigant developed a model to evaluate the potential GHG emissions reductions from appliance electrification in SoCalGas territory and estimate RG needs under different scenarios over the period 2018-2030. The following steps describe the evaluation approach and methodology:

- Develop a business-as-usual baseline case for residential and commercial building stock for future years.
  - Focus on 10 most impactful appliance/building type combinations and project impacts over the residential and commercial customer base.
  - Develop GHG emissions timeline for natural gas and electricity based on hourly consumption patterns of baseline case and RPS timeline.
- Determine the GHG emissions reductions from converting natural gas to electricity in different scenarios: Overnight Conversion and Normal Replacement—100%, 50% and 25% replace on burnout (ROB).
- Estimate the amount of RG required to maintain GHG emissions no worse than electric appliances in different scenarios.
- Estimate the consumer annual utility costs for gas and electric appliances in each scenario, including rate projections for conventional gas, RG from in-state and out-of-state resources, and electricity rate projections.
- Estimate the cost for new gas and electric appliances in each scenario, including purchase, installation, and electrical infrastructure upgrade costs.
- Compare the GHG emissions reductions for each scenario relative to their incremental combined annual cost (consumer utility and appliance costs).

This section describes the key attributes of the modeling methodology, data sources, and assumptions for the business-as-usual baseline case and each analyzed scenario. Specific details are provided in the appendices.

2.1 GHG Emissions Methodology

2.1.1 Business-as-Usual Baseline

Navigant developed a baseline characterization for the residential and commercial building stock and appliance characteristics within SoCalGas territory. The evaluation team used the results of the *2017 California Public Utilities Commission (CPUC) Energy Efficiency Potential and Goals* study[27] as a starting point for its analysis and adjusted as necessary using information from the *2016 California Gas Report and SoCalGas Workpapers*.[28] The *CPUC Potential and Goals* study characterizes the installed base of

[27] Details on the CPUC Energy Efficiency Potential and Goals Studies are available at: http://www.cpuc.ca.gov/General.aspx?id=2013

[28] 2016 California Gas Report and supporting materials are available at: https://www.socalgas.com/regulatory/cgr.shtml

natural gas and electric energy efficiency options and forecasts energy efficiency savings in California's investor-owned utilities (IOUs) through 2030. The analysis also projects incremental energy savings potential from both natural gas energy efficiency and building envelope retrofit programs above existing IOU energy efficiency program savings.

The business-as-usual baseline calculates GHG emissions from 10 natural gas residential and commercial end uses across the entire SoCalGas service territory. Table 2-1 summarizes the building segment and end-use selections. Navigant focused the analysis on 10 natural gas technologies that have significant customer consumption, potential for electrification, and incremental gas energy efficiency options. For this analysis, the evaluation team selected an electric heat pump water heater (HPWH) as the baseline residential electric option rather than an electric resistance model. The electrification discussion in California generally assumes that the HPWH would be used.

Table 2-1. Residential and Commercial Gas End Uses Selected for Analysis

Building Segment	Appliance/ End Use	Baseline Consumption in SoCalGas Territory (Million Therms per Year)	Gas Technology (Installed Base)	Electric Replacement (Efficiency)
Residential	Space Heating	1,518	Gas Furnace	Electric Heat Pump (COP 3)[29]
	Water Heating	946	Gas Water Heater	Electric Heat Pump Water Heater (EF 2)
	Clothes Dryer	193	Gas Clothes Dryer	Electric Clothes Dryer (Baseline)
Commercial	Space Heating	386	Gas Boiler	Electric Boiler (99%)
	Space Heating	209	Gas Furnace (RTU)	Electric Heat Pump (RTU, COP 3)
	Water Heating	132	Gas Water Heater Boiler	Electric Water Heater (99%)
	Water Heating	19	Small Gas Water Heater (>50 gal)	Electric Heat Pump Water Heater (COP 4)
	Cooking (Convection Oven)	26	Gas Convection Oven	Electric Convection Oven (FSTC Baseline)
	Cooking (Fryer)	20	Gas Fryer	Electric Fryer (FSTC Baseline)
	Clothes Dryer	2	Gas Clothes Dryer	Electric Clothes Dryer (Baseline)

Note: RTU = Rooftop Unit; COP = Coefficient of Performance; EF = Energy Factor; FSTC = Food Service Technology Center
Source: Navigant analysis

Navigant calculated equivalent consumption values for both natural gas and electric technologies based on the heating load or other duty load. For space and water heating technologies, this process involved a

[29] Conversion from nominal HSPF to localized HSPF from US Energy Information Administration (EIA) Heating Fuel Comparison Calculator for Los Angeles, available at: www.ememc.com/wp-content/uploads/2014/07/Copyofheatcalc.xls

conversion of natural gas consumption to heating load for electricity consumption using the efficiencies for natural gas and electric technologies. For clothes dryers, the evaluation team used baseline consumption estimated from federal appliance standards.[30] For cooking products, the team used baseline consumption estimates from Food Service Technology Center (FSTC) calculators assuming the same cooking load (e.g., pounds of food per day).[31]

To estimate GHG emissions and select high impact gas measures, Navigant calculated the GHG emissions for the 10 end uses based on the current mix of gas- versus electricity-fueled appliances, along with their respective hourly load profile and GHG emissions factor from the E3 Pathways model (Section 2.2). The 2017 figure was projected to 2030 on an annual basis using appliance-level energy savings estimates, population growth estimates, and GHG emissions factor projections in line with the RPS targets.

The evaluation team used the business-as-usual baseline to analyze GHG emissions impacts and RG requirements in each electrification scenario. The business-as-usual baseline captures the following attributes:

- Electricity supply impacts assuming actual 50% RPS generation in 2030 (rather than banked credits) and the effects of electric vehicle (EV) adoption, behind-the-meter solar PV systems, battery storage, demand response, etc.
- Anticipated energy efficiency impacts from appliance standards, building codes, and utility energy efficiency programs from the latest Potential and Goals study.
- No new electrification of buildings (i.e., maintains the same ratio of natural gas and electric appliances).
- No RG introduction into natural gas supply through 2030.

2.1.2 Electrification Scenarios

Navigant developed several electrification strategies for the analysis: an **Overnight Conversion** scenario and several **Normal Replacement** scenarios:

- The **Overnight Conversion** scenario represents theoretical technical potential GHG emissions reductions from complete appliance electrification. This scenario assumes an overnight conversion of the entire installed base of 10 major natural gas appliances in all buildings from natural gas to electricity (i.e., every gas appliance is replaced with an electric one regardless of condition, age, or customer preference). This scenario summarizes the long-term potential GHG emissions reductions from electrification policies assuming a maximum RPS of 50% by 2030.
- The **Normal Replacement** scenarios represent projections for possible electrification initiatives in California:
    - **Normal Replacement 100%:** 100% of annual gas appliance retirements are replaced with electric appliances. In an average year, approximately 6.6% of natural gas

[30] Baseline energy consumption information for gas and electric dryers for new federal appliance standards estimated from November 2011 ENERGY STAR *Market & Industry Scoping Report on Residential Clothes Dryers*. Available at: https://www.energystar.gov/sites/default/files/asset/document/ENERGY_STAR_Scoping_Report_Residential_Clothes_Dryers.pdf

[31] Life-Cycle & Energy Cost Calculators for various kitchen appliances are available on the FSTC website at https://fishnick.com/saveenergy/tools/calculators/

appliances are replaced by electric appliances at the end of their 15-year effective useful life (EUL). By 2030, 87% of the installed base would be electric assuming 2018 as a start year.

- **Normal Replacement 50%:** 50% of annual gas appliance retirements are replaced with electric appliances. In an average year, approximately 3.3% of natural gas appliances are replaced by electric options at the end of their 15-year EUL. By 2030, 43% of the installed base would be electric assuming 2018 as a start year.
- **Normal Replacement 25%:** 25% of annual gas appliance retirements are replaced with electric appliances. In an average year, approximately 1.6% of natural gas appliances are replaced by electric options at the end of their 15-year EUL. By 2030, 22% of the installed base would be electric assuming 2018 as a start year.

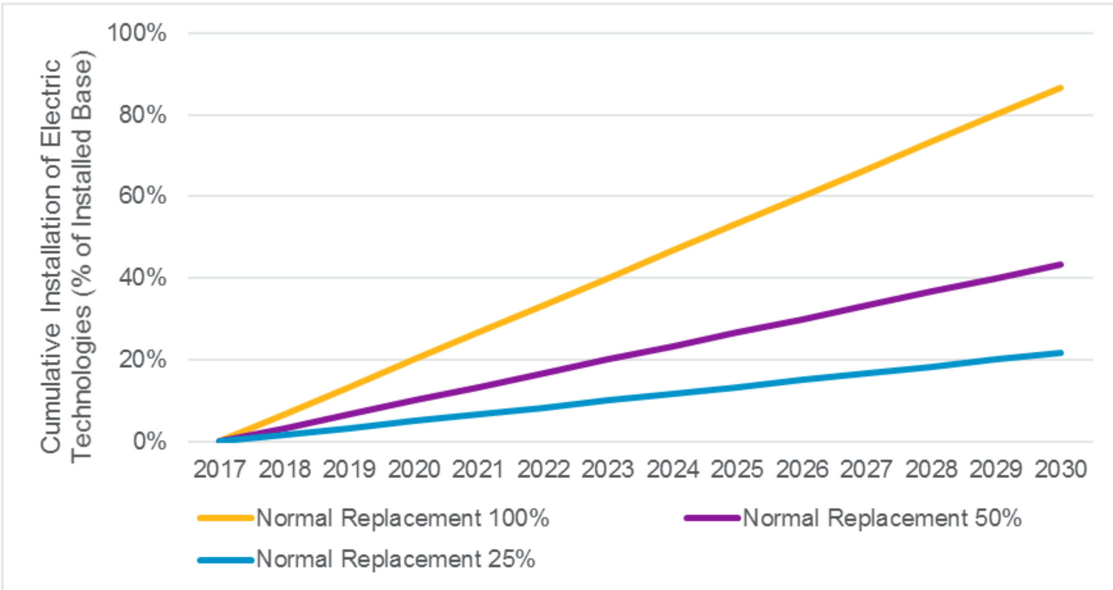
Navigant examined how the installed base in residential and commercial buildings changes over time, assuming gas-fueled appliances are replaced with electricity-fueled appliances at the end of their useful life. Appliances have an EUL from initial purchase until replacement, and their replacement rate in mature markets can be approximated as the inverse of the EUL. For example, an appliance with an EUL of 15 years would expect to have 7% of its installed based replaced every year. When a gas appliance fails at the end of its useful life and requires replacement, customers have the choice between a natural gas and an electric appliance.[32]

The Normal Replacement scenario represents the impacts of increased incentives for electric technologies, building code updates that limit the installation of natural gas equipment during new construction or major renovation, or appliance standards updates that substantially limit the sale of natural gas products. The evaluation team modeled three Normal Replacement scenarios (100%, 50%, and 25% of annual ROB) to understand the effect that these activities may have. For example, increased incentives for electric technologies would represent the Normal Replacement 25% scenario, whereas restrictions on the sale of natural gas appliances would represent the Normal Replacement 100% scenario.

Figure 2-1 demonstrates the relationship between turnover of the installed base in the Normal Replacement scenarios assuming a 15-year EUL (i.e., every 15 years the appliance needs replacement, meaning that 7% of the installed base is replaced annually).

[32] Appliance electrification often carries an additional installation cost to upgrade the electrical panel and circuitry. These electrification upgrade costs are described in Section 2.4.2.

Figure 2-1. Cumulative Installation of Electric Technologies Assuming Normal Replacement and 15-Year EUL (% of Installed Base)



Source: Navigant analysis

For each electrification scenario, Navigant modeled the number of natural gas appliances that would be replaced in each year by electric appliances and calculated their electricity consumption and GHG emissions based on the hourly load profile and hourly electricity emissions factor in each year. The team then determined GHG emissions reductions in each electrification scenario by calculating the difference in emissions from the baseline scenario. This value represents the GHG emissions reductions target that must be achieved by the RG options. Discussed in Section 2.2, Navigant introduced high efficiency gas appliances through a similar process for applicable scenarios. The team analyzed incremental energy efficiency measures above existing IOU energy efficiency program savings.

2.1.3 Renewable Gas Scenarios

After determining the GHG emissions reductions target from each electrification scenario, Navigant estimated the amount of RG needed to achieve the same GHG emissions reduction in 2030. The team assumed that RG has a GHG emissions factor of 0.0 mt per therm.[33] Table 2-2 summarizes the relative size of residential and commercial consumption relative to SoCalGas overall throughput. Navigant presents the results as a percentage of both the total consumption by residential and commercial buildings and as the percentage of total SoCalGas gas throughput in 2030. Buildings make up approximately 34% of SoCalGas total gas throughput in 2030.[34] The percentage of total SoCalGas gas throughput assumes all of the RG supply is allocated to residential and commercial buildings and no other RG initiatives (i.e., if buildings require 5% RG of total SoCalGas gas throughput, any RG initiatives for electric generation, industrial, and other customers would be in addition to the 5% RG for buildings).

[33] Navigant understands that some RG resources can have non-zero emissions factors, both negative (i.e., net removal of CO_2 from the atmosphere) and positive values depending on the source of the RG.

[34] The total for core gas (residential, core commercial, core industrial, natural gas vehicles) is approximately the same volume as buildings (residential, core commercial, non-core commercial).

Navigant also assumes that RG supply meets pipeline quality standards and does not pose issues for use by appliances designed for conventional gas.

Table 2-2. Average Daily Gas Consumption by Customer Segment: 2030

Customer Segment	Annual SoCalGas Consumption by Segment		Percentage of Total SoCalGas Gas Throughput (2030)
	MMCF/Day (2030)	BCF/Year (2030)	
Total Gas Throughput	**2,374**	**867**	**100%**
Residential	603	220	25%
Commercial (Core)	175	64	7%
Commercial (Non-Core)	40	16	2%
Total Residential and Commercial	**818**	**299**	**34%***

Note: MMCF = Million Cubic Feet; BCF = Billion Cubic Feet

* Remaining 66% of total SoCalGas throughput for power generation, non-core industrial, vehicles, and other customers.

Source: 2016 California Gas Report Supplement, Projected Average Year[35]

2.2 Gas Energy Efficiency Scenarios

Navigant developed two gas energy efficiency scenarios assuming no additional electrification: a **Natural Gas Energy Efficiency**[36] scenario and a **Renewable Gas Energy Efficiency** scenario. Each energy efficiency scenario provides incremental energy savings on top of the energy efficiency estimates in the Potential and Goals study. The team modeled this by looking at the anticipated 2030 saturation of energy efficiency technologies in the Potential and Goals study (Mid model) and considering the remaining potential in these energy efficiency scenarios to serve as an incremental potential. For example, if the Potential and Goals study projected 50% market adoption of ENERGY STAR gas fryers by 2030, the remaining 50% would be modeled as incremental energy efficiency savings. This represents the technical potential for energy efficiency to support a sensitivity analysis and is not meant to represent a likely scenario.

- The **Natural Gas Energy Efficiency** scenario assumes that no appliance electrification happens and that gas-fueled appliances are replaced by energy efficient versions following the same replacement rate as described in the Normal Replacement scenarios (100%, 50%, 25%, see Section 2.1.2). This scenario represents an alternative to electrification scenarios, whereby GHG emissions reductions can be achieved with no fuel switching, although the resulting GHG reductions are small relative to electrification.
- The **Renewable Gas Energy Efficiency** scenario assumes that no appliance electrification happens and that gas-fueled appliances are replaced by energy efficient versions following the same replacement rate as described in the Normal Replacement scenario (100%, 50%, 25% see Section 2.1.2). The difference from the Natural Gas Energy Efficiency scenario lies in the fuel

[35] 2016 California Gas Report Supplement and supporting materials are available at: https://www.socalgas.com/regulatory/cgr.shtml

[36] This scenario does not achieve the targeted GHG reductions goals and is provided only as a reference case to identify the incremental GHG reductions that could be achieved through only energy efficiency. Navigant excludes this scenario in most tables and figures.

used. In the previous scenario, appliances are fueled by standard natural gas. In this scenario, appliances are fueled by a blend of natural gas and RG. The assumed blend composition is less than an RG-only scenario, as energy efficiency decreases the amount of RG required to reach the same GHG emissions reductions target. This scenario represents a combination of the Renewable Gas and the Natural Gas Energy Efficiency scenarios to achieve similar GHG emissions reductions as for electrification.

This analysis does not consider higher efficiency electric technologies, which would show a similar effect to natural gas energy efficiency scenarios at higher initial cost. Electrification scenarios with incremental energy efficiency would reduce operating costs compared to electrification scenarios without additional energy efficiency.

In addition to higher efficiency natural gas appliances, Navigant also reviewed the potential energy, cost, and GHG emissions reductions from a residential building envelope upgrade program targeting older homes. Upgrading the building envelope would reduce natural gas and electricity consumption for space heating and space cooling, while also improving occupant comfort and other non-energy benefits. These upgrades include improving insulation for attics, ceilings, roofs, walls, floors, and ducts and installing high performance double-pane windows. This analysis uses data from the 2017 Potential and Goals study to project the incremental energy savings above those already projected for IOU programs as part of CPUC's goals to double energy efficiency. Navigant also evaluated the payback of each envelope upgrade to understand which measures would provide reasonable cost-effectiveness of 15, 20, and 30 years. Section 3.3 summarizes the results of this analysis.

2.3 Economic Evaluation Methodology

Navigant analyzed the economics of each GHG emissions reduction strategy by modeling the consumer utility cost, appliance cost, and combined annual cost (the sum of the consumer utility and appliance costs).

- **Consumer utility costs** in each scenario represent the annual energy costs for the 10 residential and commercial appliances in each year, including new and existing gas and electric appliances in all scenarios. These values represent the energy costs to building owners in each year and are calculated by multiplying the energy consumption for each appliance by the applicable utility rate in each year for each scenario. For example, in the electrification scenarios, the consumer utility costs reflect changes in the assumed appliance mix over time as gas appliances are replaced with electric models. Further discussed in Section 2.4.3, Navigant analyzed the effects of different utility rate projections for renewable gas (in-state and out-of-state supply) and electricity (Integrated Energy Policy Report, or IEPR, and high estimates).
- **Appliance costs** in each scenario represent the purchase, installation, and electric infrastructure upgrade costs for all appliances installed in each year. This analysis assumes that an existing building has natural gas appliances; therefore, many building owners must upgrade at least part of their electrical infrastructure to accommodate electric appliances. The electrification upgrade costs are only counted once—when a gas appliance is converted to an electric appliance. Further discussed in Section 2.4.2, Navigant analyzed the impacts of different electric infrastructure upgrade cost projections, including upgrade requirements for 0% and 50% of residential and commercial buildings. The team also annualized the appliance and upgrade cost over a 15-year period to allow for better comparison of energy efficiency and to represent the average annual costs that a building owner would experience. When considering cumulative appliance costs over

the 2018-2030 period, the annualized values occur in each year over the 15-year period after the appliance was installed.[37]

- Navigant analyzed the combined annual cost (the sum of the consumer utility and appliance costs) in terms of net present value (NPV) to account for the time value of money. The team applied a discount rate of 3% and 9% to present the range experienced by California stakeholders. The CEC's Life-Cycle Cost Methodology for energy efficiency measures uses a 3% real (inflation adjusted) discount rate,[38] whereas 9% represents the weighted average rate of return or return on equity for California IOUs.[39]

2.4 Key Assumptions for Analysis

2.4.1 Electricity Emissions Factors

Navigant developed hourly and annual electricity emissions factor and hourly load shapes for electric technologies using the E3 Pathways model.[40] The Pathways model is a long horizon energy model used by California stakeholders to assess the cost and GHG emissions impacts of California's energy demand and supply choices. Appendix C provides additional details on the E3 Pathways model.

The emissions factor (mt of CO_2 per kWh) for electricity supply varies throughout the day, season, and year depending on the available renewable and non-renewable generation sources in California. This is especially true at higher RPS percentages in 2030 when zero emissions resources cover most of the state's electricity supply needs at certain hours of the year. When calculating the GHG emissions for appliances, Navigant disaggregated the annual consumption value to each hour of the year using appliance load shapes from the E3 Pathways model and multiplied these values by the hourly emissions factor for electricity in each year.

Table 2-4 provides the calculated GHG emissions factors for SoCalGas territory for 2016-2030. Navigant adjusted the hourly emissions factors from the E3 model to align with 2016 annual estimates by SCE and the US Environmental Protection Agency's (EPA's) eGrid for electricity delivered to customers. Table 2-3 summarizes the historic emissions factors for delivered electricity statewide, Pacific Gas and Electric (PG&E) territory, and SCE territory. The extracted data from the E3 model represents emissions for hourly electricity supply statewide and does not include downstream effects that effect the emissions of delivered electricity and gas (e.g., transmission and distribution losses) or differences in Northern versus Southern California grid. Navigant scaled the 2018-2030 hourly emissions factors to the historical SCE values to better reflect the emissions for delivered electricity in SoCalGas territory, while maintaining the

---

[37] For example, the cumulative appliance cost value for 2020 would include three annualized payments for appliances installed in 2018, two payments in 2019 for appliances installed in 2018, and one payment in 2020 for appliances installed in 2018.

[38] Architectural Energy Corporation. 2011. "Life-Cycle Cost Methodology." Prepared for CEC. January 14, 2011. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/general_cec_documents/2011-01-14_LCC_Methodology_2013.pdf

[39] CPUC. 2018. "California Electric and Gas Utility Cost Report." CPUC Energy Division. April 2018. Available at: http://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/About_Us/Organization/Divisions/Office_of_Governmental_Affairs/Legislation/2018/California%20Electric%20And%20Gas%20Utility%20Cost%20Report.pdf

[40] California PATHWAYS Model Framework and Methods: https://www.arb.ca.gov/cc/scopingplan/california_pathways_model_framework_jan2017.pdf

hourly distribution of renewable versus non-renewable resources and RPS targets. IOU-owned generation has lower GHG emissions than out-of-state sources but only covers a portion of the electricity delivered to customers.

Table 2-3. Historical Electricity Emissions Factors (GHG Emissions per MWh)

Electricity Territory	2012	2013	2014	2015	2016	Source
Statewide (mt CO_2/MWh)	0.29	-	-	-	0.24	EPA eGrid 2012 (2014), 2016 (2018)[41]
PG&E (mt CO_2/MWh)	-	0.20	0.20	0.19	-	PG&E annual report[42]
SCE (mt CO_2/MWh)	-	0.37	0.26	0.23	0.24	SCE annual reports[43]

Note: 2,205 lbs. per metric ton, 1,000 kWh per MWh

Sources: Various, as detailed in table

Table 2-4. California RPS Targets and GHG Emissions Factor for RG Analysis

Year	California RPS Targets and GHG Emissions Factor for RG Analysis	
	RPS Target (%)	Emissions Factor (mt CO_2 per MWh)
2016	25%	0.24
2017	30%	0.22
2018		0.21
2019		0.20
2020	33%	0.20
2021		0.19
2022		0.19
2023		0.19
2024	40%	0.18
2025		0.19
2026		0.18
2027	45%	0.18
2028		0.17
2029		0.17
2030	50%	0.16

Source: RPS Targets from 2017 CEC "Tracking Progress" report, GHG Emissions factors from Navigant analysis

[41] EPA. 2016. "Emissions & Generation Resource Integrated Database (eGRID)." at: https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

[42] PG&E. 2017. "Corporate Responsibility and Sustainability Report 2017." Available at: http://www.pgecorp.com/corp_responsibility/reports/2017/en02_climate_change.html

[43] SCE. 2017. "2016 Corporate Responsibility & Sustainability Report." Available at: https://www.edison.com/content/dam/eix/documents/investors/corporate_responsibility/2016-eix-corporate-responsibility-and-sustainability-report.pdf

2.4.2 Appliance and Electrical Infrastructure Costs

This section summarizes the appliance and electrical infrastructure costs for natural gas and electric appliances, including high efficiency options where applicable. Appliance costs represent purchase and installation costs for existing buildings. Residential appliance cost ($ per home) estimates were based on 2016 data compiled by KPF Group based on construction invoice and budget estimates from Southern California builders and contractors.[44] The estimated costs assume the combined purchase, installation, and upgrade costs including contractor overhead, profit, permit fees, and other factors that homeowners would experience with professional installation.[45, 46] Commercial appliance cost ($ per 1,000 SF) estimates are from the CPUC Potential and Goals study.[47] In many cases, the CPUC Potential and Goals study did not contain cost information for an electric equivalent technology, and the gas appliance costs were scaled using other available resources that provide costs for both gas and electric technologies (e.g., EIA appliance cost database).[48]

Table 2-5 summarizes installed costs for residential and commercial gas appliances.

Table 2-5. Residential and Commercial Gas Appliance Cost Estimates

Building Segment	Gas Technology (Installed Base)	Installed Cost	Source/Notes
Residential (per home)	Gas Furnace (80% AFUE, SEER 14 AC)	$8,177	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016
	Gas Water Heater (50 gal)	$1,448	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016
	Gas Clothes Dryer	$565	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016
Commercial (per 1,000 SF)	Gas Boiler (81% AFUE)	$632	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost
	Gas Furnace (RTU)	$148	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost
	Gas Water Heater Boiler	$21	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost
	Small Gas Water Heater (>50 gal)	$7.6	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost
	Gas Convection Oven	$81	Estimate based on Work Paper PGECOFST101 (August 2016), per 1,000 SF, total installed cost
	Gas Fryer	$77	Estimate based on Workpaper PGECOFST102 (June 2016), per 1,000 SF, total installed cost
	Gas Clothes Dryer	$27	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost

Note: AFUE = Annual Fuel Utilization Efficiency; SEER = Seasonal Energy Efficiency Ratio
Source: Navigant analysis

44 Appliance costs from Gilbert Kitching of KPF Group in 2016. SoCalGas provided KPF Group research to Navigant for use in this report.

45 Navigant reviewed these costs relative to other data sources, including the Database for Energy Efficiency Resources (DEER). The equipment costs appear higher for each type of equipment relative to what was observed from the DEER sources. Comparison for the KPF Group estimates and other resources is provided in Appendix A.5.

46 Electrician subcontractor cost for HPWH was removed to avoid double counting upgrade cost.

47 Details on the CPUC Energy Efficiency Potential and Goals Studies are available at: http://www.cpuc.ca.gov/General.aspx?id=2013

48 EIA. 2016. “Updated Buildings Sector Appliance and Equipment Costs and Efficiency.” Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/

Table 2-6 summarizes installed costs for high efficiency gas appliances. These appliances were analyzed as incremental values to the energy efficiency already included in the Potential and Goals study. The team did not analyze advanced gas technologies such as gas heat pumps for space heating or micro combined heat and power (mCHP) systems.

Table 2-6. Gas Energy Efficiency Measures Selected for Analysis

Building Segment	Gas Technology (Installed Base)	Installed Cost	Source/Notes
Residential (per home)	Gas Furnace (92% AFUE, SEER 14 AC)	$10,213	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016
	Condensing Tankless Water Heater	$4,497	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016[49]
	ENERGY STAR Gas Clothes Dryer	$615	Based on DEER Workpaper, has $50 incremental cost
Commercial (per 1,000 SF)[50]	Condensing Boiler (94% AFUE)	$893	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost
	N/A	N/A	Condensing RTUs are emerging in cold climates and may not be cost-effective for California
	Condensing Boiler (94% AFUE)	$29	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost
	Small Gas Water Heater (>50 gal)	$9.2	Estimate based on Potential and Goals data for tankless, 150 kBtuh and 0.82 EF, per 1,000 SF, total installed cost
	ENERGY STAR Gas Convection Oven	$105	Estimate based on Work Paper PGECOFST101 (August 2016), per 1,000 SF, total installed cost
	Gas Fryer Gas Fryer	$100	Estimate based on Workpaper PGECOFST102 (June 2016), per 1,000 SF, total installed cost
	ENERGY STAR Gas Clothes Dryer	$28	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost

Source: Navigant analysis

Table 2-7 summarizes installed costs for residential and commercial electric appliances. Most electric appliances have similar costs to the natural gas counterpart, with the exception of residential HPWHs. As discussed later in this section, Navigant conducted a sensitivity analysis with lower cost HPWH products to account for potential technology and cost improvements in the 2020-2030 timeframe.

[49] Gas tankless water heaters typically require an upgraded supply line, which can substantially increase installation costs. The installed cost data for this measure includes estimates for piping upgrade and installation, but costs can vary greatly.

[50] The source data for high efficiency gas appliances is unclear whether commercial condensing boilers include new venting as part of their installation costs.

Table 2-7. Residential and Commercial Electric Appliance Cost Estimates

Building Segment	Electric Replacement (Efficiency)	Installed Cost	Source/Notes
Residential (per home)	Electric Heat Pump (SEER 14, HSPF 8.2, COP 3)[51]	$8,152	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016
	Electric Heat Pump Water Heater (EF 2)	$4,313	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016
	Electric Clothes Dryer (Baseline)	$509	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016
Commercial (per 1,000 SF)	Electric Boiler (99%)	$379	Estimated 40% lower installed cost from EIA Updated Buildings Sector Appliance and Equipment Costs and Efficiencies. Nov 2016 - scaled to match output of electric boiler
	Electric Heat Pump (RTU, COP 3)	$148	Assume same cost as commercial RTU with gas furnace – TRC report for City of Palo Alto[52] suggests 20% incremental cost, EIA 2016 cost estimates suggest 20% lower cost
	Electric Water Heater (99%)	$12	Estimated 40% lower installed cost from EIA Updated Buildings Sector Appliance and Equipment Costs and Efficiencies. Nov 2016 - scaled to match output of electric boiler
	Electric Heat Pump Water Heater (COP 4)	$8.7	TRC report for Palo Alto estimates 15% incremental cost premium for commercial heat pump models over gas models
	Electric Convection Oven (FSTC Baseline)	$77	Estimate based on Work Paper PGECOFST101 (August 2016), per 1,000 SF, total installed cost
	Electric Fryer (FSTC Baseline)	$93	Estimate based on Workpaper PGECOFST102 (June 2016), per 1,000 SF, total installed cost
	Electric Clothes Dryer (Baseline)	$24	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost

Note: HSPF = Heating Seasonal Performance Factor
Source: Navigant analysis

Table 2-8 provides the estimated costs for electrical infrastructure upgrades for existing residential and commercial buildings to switch to electric appliances. This analysis assumes that an existing building has natural gas appliances; therefore, building owners may need to upgrade at least part of their electrical infrastructure to accommodate electric appliances. Navigant analyzed the impacts of different electric infrastructure upgrade cost projections, including upgrade requirements for 0% and 50% of residential and commercial buildings. Limited information exists on the average electrical upgrade costs for existing buildings, and anecdotal estimates range widely based on the type of electrical appliance (e.g., electric HPWH, solar PV system, EV charger), age of building, contractor prices, etc. Recently constructed or new buildings will likely have lower infrastructure upgrade costs than most existing buildings, or none at all. In addition, future changes to Title 24 codes to accommodate EVs and other technologies may eliminate incremental costs for electrical infrastructure. As discussed later in this section, the team conducted a

[51] Conversion from nominal HSPF to localized HSPF from EIA Heating Fuel Comparison Calculator for Los Angeles, available at: www.ememc.com/wp-content/uploads/2014/07/Copyofheatcalc.xls

[52] TRC Solutions. 2016. "Palo Alto Electrification Final Report." City of Palo Alto. Available at: https://www.cityofpaloalto.org/civicax/filebank/documents/55069

sensitivity analysis for electric appliances with and without electrical upgrade costs to account for these issues.

- **Residential:** Limited information exists on the electrical upgrade requirements and costs for existing homes. An existing home may require an electrical infrastructure upgrade to accommodate an electric HPWH at an estimated cost of up to $4,671. The upgrades include a higher capacity electrical panel (100 amp-200 amp, estimated $3,181), a branch circuit to the HPWH (15 amp-30 amp, estimated $640), and a utility service connection fee (estimated $850).[53] In addition, the analysis assumes that baseline buildings have air conditioning, so the electrical infrastructure for an electric heat pump for space heating is available. Some existing homes (particularly newer homes and those with a swimming pool or solar PV) may have sufficient electrical infrastructure and may only require minimal electrical upgrade costs. Navigant evaluated economic projections assuming 0% ($0) and 50% ($2,336 = 50% x $4,671) of homes would require electrical infrastructure upgrades.
- **Commercial:** Limited information is available on the electrical upgrade requirements and costs for existing commercial buildings. A 2016 report by TRC for the City of Palo Alto provides estimates for several commercial buildings; the report estimates that most commercial buildings have electrical panel capacity to accommodate electric appliances and the panel only requires higher capacity branch circuits to meet the electric loads. For small office buildings, the study estimated the electrical infrastructure upgrade cost of approximately 10% of the appliance's installed cost ($4,399 for a branch circuit upgrade to accommodate five rooftop heat pumps at a total average cost of $48,276 [$7,563- to $11,500 per unit]).[54] Navigant evaluated economic projections assuming 0% (0% upgrade cost addition) and 50% (5% upgrade cost addition = 50% x 10%) of commercial buildings would require electrical infrastructure upgrades.

Table 2-8. Electrical Infrastructure Upgrade Cost

Building Segment	Appliance	Electrical Infrastructure Upgrade Cost	Source/Notes
Residential	Water Heating Only	$0-$2,336	• The upgrades include a higher capacity electrical panel (100 amp-200 amp, estimated $3,181), branch circuit to the HPWH (15 amp-30 amp, estimated $640), and utility service connection fee (estimated $850). • Navigant evaluated economic projections assuming 0% ($0) and 50% ($2,336 = 50% x $4,671) of homes would require electrical infrastructure upgrades.
Commercial	All Appliances	0%-5% of equipment cost	• Estimate of 10% upgrade cost including branch circuit upgrades, assumes existing electrical panel is sized for increased load. • Navigant evaluated economic projections assuming 0% (0% upgrade cost addition) and 50% (5% upgrade cost addition = 50% x 10%) of commercial buildings would require electrical infrastructure upgrades.

Source: Navigant analysis based on estimates by TRC[55]

[53] TRC Solutions, *Palo Alto Electrification Final Report*, City of Palo Alto, 2016. Available at: https://www.cityofpaloalto.org/civicax/filebank/documents/55069

[54] TRC Solutions. 2016.

[55] TRC Solutions. 2016.

The economic analysis in Section 4 analyzes the cost of appliance electrification through several scenarios, including adjustments for both appliance and electrical infrastructure upgrade costs.

- **Electrification with Upgrade Costs:** Installed cost for electric appliances with electrical infrastructure upgrade costs. This scenario assumes that 50% of residential and commercial buildings require electrical infrastructure upgrades and, therefore, represents the highest appliance cost scenario.
- **Electrification without Upgrade Costs:** Installed cost for electric appliances without electrical infrastructure upgrade costs. This scenario assumes that 0% of residential and commercial buildings require electrical infrastructure upgrades and, therefore, represents the impact of appliance purchase and installation cost only.
- **Electrification with Low HPWH Cost:** Installed cost for electric appliances assuming low HPWH purchase and installation cost and no infrastructure upgrade cost. Residential HPWHs are an emerging technology with potential technology and cost improvements over the 2020-2030 timeframe. To account for this, Navigant conducted a sensitivity analysis assuming a lower cost HPWH product and upgrade requirements based on estimates in a study by the University of California (UC) Berkeley and Lawrence Berkeley National Laboratory (Berkeley Lab) researchers.[56] The researchers estimate a $1,900 total installed cost for a HPWH ($1,400 plus $500 installation, $1,900 total) to replace an existing gas storage water heater ($850 plus $500 installation, $1,350 total), representing an incremental cost of $550 over the gas storage water heater estimate. The Low HPWH Cost ($550 incremental cost) is lower than the estimates from KPF Group, and therefore, represents the lowest appliance cost scenario in this analysis. Appendix A.5 also includes a comparison of residential water heater cost estimates.

For new construction, there may be infrastructure costs savings for builders and gas utilities because gas line extensions and gas meters would not be required; however, these elements were not analyzed as part of this effort. Navigant understands that builders pay a line extension allowance to gas utilities, and this allowance is returned to the builder over time after the occupants move into the home and establish their utility accounts. This process ensures that ratepayers are not burdened if there is a builder default on the development before home sale and occupancy.

2.4.3 Projected Utility Rates

Figure 2-2 summarizes the conventional, renewable, and blended gas rates for this analysis.[57]

- Projected conventional gas rates for SoCalGas territory are based on CEC projections for the 2017 IEPR (February 2018 workshop).[58]

[56] Raghavan et al. 2017. “Scenarios to Decarbonize Residential Water Heating in California.” *Energy Policy, 109*. 441-451. Available at: https://rael.berkeley.edu/publication/scenarios-to-decarbonize-residential-water-heating-in-california/

[57] Navigant has not independently validated the utility cost estimates from the IEPR nor the RG supply costs.

[58] CEC. 2018. “Feb 21 2018 Workshop for Final 2017 IEPR Adoption, Mid-Mid Forecast.” Available at: http://www.energy.ca.gov/2017_energypolicy/documents/2018-02-21_business_meeting/2018-02-21_middemandcase_forecst.php

- Projected rates for in-state and out-of-state RG are based on procurement cost projections from a 2017 ICF report,[59] with an assumed transmission and distribution rate of $0.54 per therm. The RG rates follow a supply curve, where the price for RG increases with increased demand due to the need for more expensive RG supply resources as demand for RG increases. In-state RG supply ranges from approximately $1.5 per therm (0 BCF/year-200 BCF/year) in 2018, increasing to approximately $3.5 by 2030. Out-of-state RG ranges from $1.0 per therm (0 BCF/year-2,000 BCF/year) in 2018, increasing to $1.5 per therm by 2030.
- In addition to the in-state and out-of-state RG projections, Navigant also developed a projection showing a blend of in-state/out-of-state RG based on a May 2018 ICF memo.[60] In 2030, ICF estimates an approximately 100 BCF in-state RG supply and 300 BCF out-of-state RG delivery to California, for a total RG supply of 400 BCF. This assumes national RG production of 500 BCF-1,000 BCF in 2030, with approximately 40% of national RG production supplied to California; this is a decrease from the state's 65%-75% share today. Navigant developed the mixed in-state/out-of-state RG projection assuming 25% in-state RG and 75% out-of-state RG over the analysis period. This mixed RG supply example would have a supply cost range of $1.1 per therm in 2018, increasing to $2.0 per therm by 2030.[61]

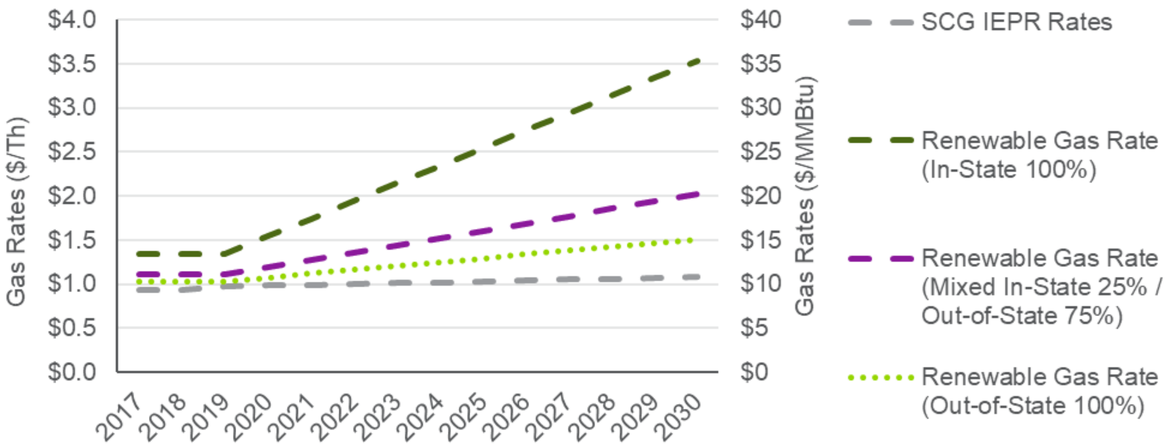
The price that residential and commercial customers would pay to receive gas with the necessary RG percentage to meet the GHG emissions goals is a blended gas rate consisting of the applicable percentages of RG supply and conventional gas. For example, if customers required 10% RG to meet the GHG emissions target, the blended gas rate would be 90% conventional gas and 10% RG. Figure 2-2 summarizes the in-state RG rate, out-of-state RG rate, and mixed in-state/out-of-state RG rate for the Normal Replacement 100% scenario, where RG accounts for 46% of buildings' gas consumption in 2030 (i.e., 46% RG, 54% conventional gas). This assumes that all of the RG costs are carried by residential and commercial customers since these segments will claim the GHG emissions reductions.

[59] Sheehy and Rosenfeld. 2017. "Design Principles for a Renewable Gas Standard." 2017. Available at: https://www.icf.com/resources/white-papers/2017/design-principles-for-renewable-gas. Resource assumes levelized cost of energy for RG infrastructure and supply.

[60] Memo from Philip Sheehy of ICF to SoCalGas. "Potential RNG Supply to California." May 2018. Provided by SoCalGas for this analysis.

[61] Navigant has not independently validated the RG supply costs and resources.

Figure 2-2. Annual Gas Rates for Analysis (Conventional Gas, RG, Blended Gas Rates)



This figure summarizes the in-state RG rate, out-of-state RG rate, and mixed in-state/out-of-state RG rate for the 100% Normal Replacement scenario, where RG accounts for 46% of buildings' gas consumption in 2030 (i.e., 46% RG, 54% conventional gas) and draws upon 2017 IEPR and ICF reports. One therm equals 0.10 MMBtu.

Source: Navigant analysis

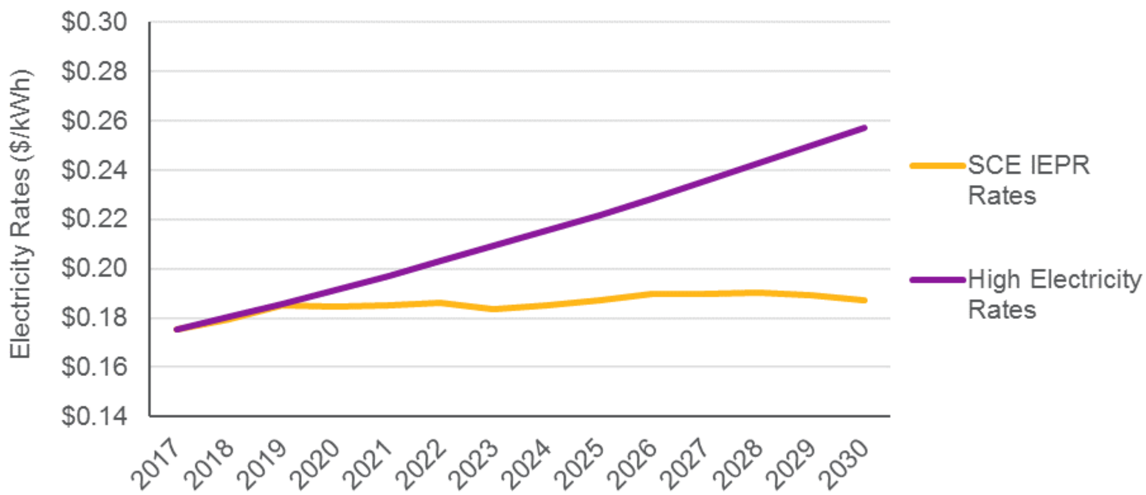
Figure 2-3 summarizes the baseline and high electricity rates used for this analysis. Projected average annual electricity rates for SCE territory are based on CEC projections for the 2017 IEPR (February 2018 workshop, mid demand forecast).[62] To reflect possible distribution, transmission, and generation needs to accommodate increased building loads, Navigant also ran a high electricity rate projection to bookend the IEPR rate projection. The evaluation team applied an annual growth rate of 3% to the SCE rates based on projections within LADWP's 2016 Final Integrated Resource Plan (IRP)[63] that represent the stacked impacts of increased RPS, energy storage, local solar, system reliability, and electrification impacts and other factors that may be unique to LADWP.[64] This high uncertainty projection is meant to capture an upper-case scenario for future electricity rates based on other rate projections in the region (further discussed below).

[62] CEC. 2018. "Feb 21 2018 Workshop for Final 2017 IEPR Adoption, Mid-Mid Forecast." Available at: http://www.energy.ca.gov/2017_energypolicy/documents/2018-02-21_business_meeting/2018-02-21_middemandcase_forecst.php

[63] LADWP. 2016. "2016 Final Power Integrated Resource Plan." Available at: https://www.ladwp.com/ladwp/faces/wcnav_externalId/a-p-doc?_adf.ctrl-state=iirytk0lc_4&_afrLoop=35208544433395

[64] Navigant estimated an annual growth rate of 3% to fit the LADWP IRP curve over the 2017-2036 period ($0.15/kWh in 2017 to $0.26/kWh in 2036).

Figure 2-3. Annual Electricity Rates for Analysis



High electricity rates based on 3% annual increase for IEPR SCE values.
Source: Navigant analysis

For the high electricity rate projections, Navigant used a 3% annual growth estimate for an upper bound projection based on the LADWP IRP and other regional estimates. The SCE General Rate Case for 2018[65] projects increased rates of 2.7% in 2018, 4.2% in 2019, and 5.2% in 2020 as part of the distribution infrastructure upgrade planning.[66] A recent UC Berkeley/Berkeley Lab analysis on residential water heating electrification uses electricity growth rates of 2%-5% for future projections (2% in base and 5% as upper bound).[67] There is high uncertainty in projecting future electricity rates, and the 3% annual growth rate provides sensitivity over the IEPR values of an approximately 1% annual growth rate.

Discussed in Section 5.3, additional research is necessary to understand the effects that appliance electrification, RG, and other GHG emissions strategies could have in future years for natural gas and electricity rates, including time-of-use or multi-tiered rate structures, customer consumption patterns, grid infrastructure needs, stranded assets, and other issues.

[65] Edison International. 2016. "2018 SCE General Rate Case Overview." September 1, 2016. Available at: https://www.edison.com/content/dam/eix/documents/investors/sec-filings-financials/2018-SCE-general-rate-case-overview.pdf

[66] The SCE General Rate Case only cover the years 2018-2020 and does not project across the full 2018-2030 range. Historically, there are instances of large increases in several years, followed by several years of low or zero annual rate increases.

[67] Raghavan et al. 2017. "Scenarios to Decarbonize Residential Water Heating in California." *Energy Policy, 109*. 441-451. Available at: https://rael.berkeley.edu/publication/scenarios-to-decarbonize-residential-water-heating-in-california/

3. RG REQUIREMENTS ANALYSIS RESULTS

3.1 RG Requirements in 2030 Under Each Scenario

This section summarizes key technical results of the study, focusing on the RG requirements in 2030 under both the **Overnight Conversion** and **Normal Replacement** scenarios. Appendix D and Appendix E contains the full results of the analysis.

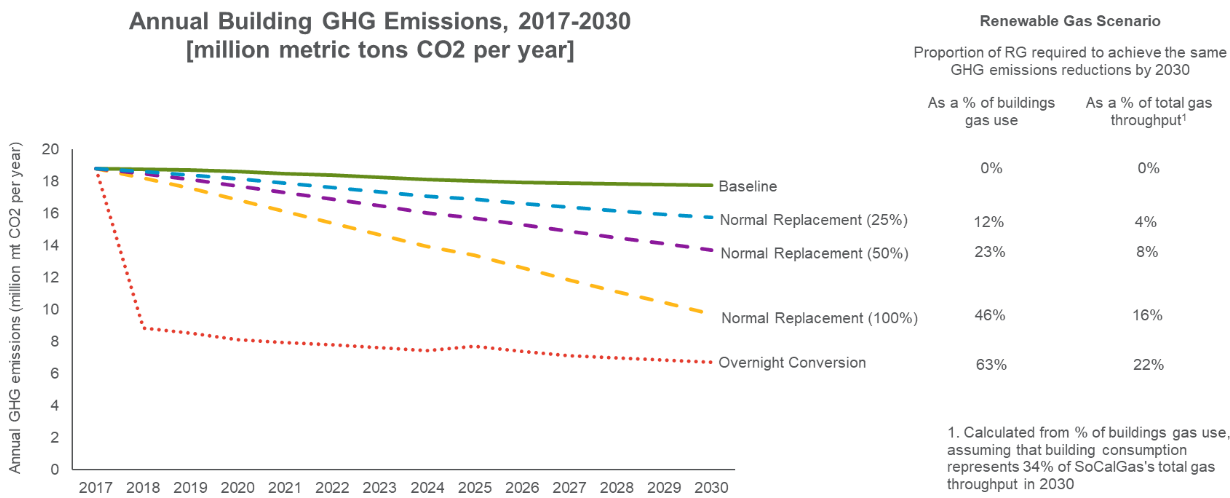
- **Overnight Conversion:** Conversion of 100% of natural gas appliances in SoCalGas customer homes, assuming early replacement regardless of condition, age, or customer preference.
- **Normal Replacement:** Conversion of natural gas appliances at end of life replacement and new purchase, assuming that 100%, 50%, and 25% of SoCalGas customers currently with natural gas appliances purchase an electric model over a natural gas model. Because major gas appliances have EULs of 10-20 years, only a small portion of the installed base is replaced every year and, therefore, subject to electrification in the Normal Replacement scenario. This represents potential electrification initiatives that rely on customer incentives, building code updates, and other programs.

3.1.1 RG Requirements by 2030

Figure 3-1 and Table 3-1 summarize the required RG percentages to maintain GHG emissions parity with 100% electrification of residential and commercial loads under several scenarios. The RG amounts are expressed as a percentage of annual SoCalGas residential and commercial consumption and total SoCalGas annual throughput for all sectors. The percentage of total gas throughput assumes that all GHG credit from RG supply goes toward residential and commercial customers, with industrial, generation, transportation, and other segments not claiming any RG benefits. Residential and commercial consumption represent approximately 34% of total SoCalGas gas throughput in 2030 (i.e., approximately 299 BCF/year based on an estimated total SoCalGas throughput of 867 BCF/year in 2030).[68] The remaining 66% of SoCalGas throughput is electric power generation and non-core industrial customers.

[68] 2016 California Gas Report Supplement and supporting materials are available at: https://www.socalgas.com/regulatory/cgr.shtml

Figure 3-1. Annual GHG Emissions Reductions and Required RG Percentage Under Different Electrification Scenarios



Source: Navigant analysis

Under each scenario, SoCalGas would need to supply a significant percentage of RG to residential and commercial customers to maintain parity with electrification.

- For the **Overnight Conversion** scenario, RG would need to satisfy 63% of total residential and commercial gas use, or roughly 22% of total system throughput.
- For **Normal Replacement** scenarios, the amount of RG required in 2030 is less than the Overnight Conversion scenario and depends on the aggressiveness of electrification:
  - **Normal Replacement 100%:** If 100% of appliances sold after 2020 were electric, RG would need to satisfy 46% of total residential and commercial gas use, or roughly 16% of total system throughput.
  - **Normal Replacement 50%:** If 50% of appliances sold after 2020 were electric, RG would need to satisfy 23% of total residential and commercial gas use, or roughly 8% of total system throughput.
  - **Normal Replacement 25%:** If 25% of appliances sold after 2020 were electric, RG would need to satisfy 12% of total residential and commercial gas use, or roughly 4% of total system throughput.

Table 3-1. RG Requirements in 2030 to Maintain GHG Parity with Electrification Scenarios

Scenario	Conversion %	Required RG % of SoCalGas Buildings Gas Use (2030)	Required RG % of Total SoCalGas Gas Throughput (2030)	Required Annual RG Volume (BCF/year, 2030)
Overnight Conversion	100% of Total Market	63%	22%	188
Normal Replacement	100% ROB	46%	16%	137
	50% ROB	23%	8%	69
	25% ROB	12%	4%	36

2016 California Gas report estimates total SoCalGas throughput of 867 BCF/year in 2030.

Source: Navigant analysis.

3.1.2 RG Timeline in Each Scenario and RG Introduction in 2020

For each scenario described above, Navigant assumed a target 2030 RG percentage to match the electricity GHG emissions and calculated an introduction schedule assuming a linear increase in RG percentage every year starting in 2020. Assuming a linear increase in supply, SoCalGas would need to introduce the following RG percentages in 2020 to meet the 2030 RG targets and maintain parity with electrification scenarios.

- For the **Overnight Conversion** scenario, SoCalGas would need to introduce 6% of total residential and commercial gas use, or roughly 2% of total system throughput in 2020 to meet the 2030 RG targets.
- For **Normal Replacement** scenarios, the amount of RG required in 2030 is less than the Overnight Conversion scenario and depends on the aggressiveness of electrification:
  - If 100% of appliances sold after 2020 were electric, SoCalGas would need to introduce 4% of total residential and commercial gas use, or roughly 1% of total system throughput in 2020 to meet the 2030 RG targets.
  - If 50% of appliances sold after 2020 were electric, SoCalGas would need to introduce 2% of total residential and commercial gas use, or roughly 1% of total system throughput in 2020 to meet the 2030 RG targets.
  - If 25% of appliances sold after 2020 were electric, SoCalGas would need to introduce 1% of total residential and commercial gas use, or roughly 0.4% of total system throughput in 2020 to meet the 2030 RG targets.

3.1.3 GHG Emissions Reductions

Table 3-2 summarizes the GHG emissions reductions from each electrification scenario and the RG introduction volumes to match these reductions. By design, electrification and RG scenarios achieve the same GHG emissions reductions in 2030. Required RG percentages for buildings are higher than GHG emissions reductions due to the baseline including both gas and electric appliances.

Table 3-2. 2030 GHG Emissions Reductions with Different Electrification and RG Scenarios

Scenario	Conversion %	2030 GHG Emissions Reductions (% of 2030 Buildings Baseline)	Required RG % of SoCalGas Buildings Gas Use	Required RG % of Total SoCalGas Gas Throughput
Overnight Conversion	100% of Total Market	62%	63%	22%
Normal Replacement	100% ROB	45%	46%	16%
	50% ROB	23%	23%	8%
	25% ROB	11%	12%	4%

GHG emissions reductions are the same in both the electrification and RG scenarios in 2030. Required RG percentage of buildings is slightly higher than GHG emissions reductions due to the baseline including both gas and electric appliances.

Source: Navigant analysis

3.2 Impacts for Specific Building Segments and End Uses

3.2.1 GHG Emissions Impacts for Specific Residential and Commercial Segments and End Uses

Table 3-3 summarizes the specific GHG emissions reductions from electrification for specific building segments and end uses. Most appliances achieve GHG emissions reductions through electrification in 2018, and the advantage increases in 2030 as the RPS targets reduce grid electricity emissions further. Electric technologies that use electric resistance heating (e.g., commercial boilers) have smaller reductions relative to those with heat pump heating (e.g., residential space and water heating). Commercial electric cooking equipment (e.g., fryers, convection ovens) has higher unit efficiency relative to gas models (e.g., fryers: 75%-85% for electric vs. 35%-60% for gas; convection ovens: 65%-70% for electric vs. 30%-45% for gas). Clothes dryers using electric resistance heating increase GHG emissions in 2018 relative to gas models, but the comparison narrows by 2030 due to higher RPS introductions.

For additional context, the buildings sector accounted for approximately 11% of California's total 2015 GHG emissions of 440.4 million metric tons of CO_2e, with residential and commercial buildings accounting for 6% and 5%, respectively.[69] These estimates represent GHG emissions from whole building energy consumption, whereas the values for Table 3-3 represent specific building end uses.

[69] California Air Resources Board, *California Greenhouse Gas Emission Inventory - 2017 Edition*. June 2017. https://www.arb.ca.gov/cc/inventory/data/data.htm

Table 3-3. GHG Emissions Reductions from Electrification by Building Segment/End Use

Building Segment	Appliance / End Use	Gas Technology (Installed Base)	Electric Replacement (Efficiency)	GHG Emissions Reductions from Electrification	
				2018	2030
Residential	Space Heating	Gas Furnace	Electric Heat Pump (COP 3)	69%	74%
	Water Heating	Gas Water Heater	Electric Heat Pump Water Heater (EF 2)	63%	70%
	Clothes Dryer	Gas Clothes Dryer	Electric Clothes Dryer (Baseline)	-7%*	13%
Commercial	Space Heating	Gas Boiler	Electric Boiler (99%)	7%	29%
	Space Heating	Gas Furnace (RTU)	Electric Heat Pump (RTU, COP 3)	62%	71%
	Water Heating	Gas Water Heater Boiler	Electric Water Heater (99%)	6%	26%
	Water Heating	Small Gas Water Heater (>50 gal)	Electric Heat Pump Water Heater (COP 4)	69%	74%
	Cooking (Convection Oven)	Gas Convection Oven	Electric Convection Oven (FSTC Baseline)	44%	58%
	Cooking (Fryer)	Gas Fryer	Electric Fryer (FSTC Baseline)	56%	68%
	Clothes Dryer	Gas Clothes Dryer	Electric Clothes Dryer (Baseline)	-1%*	20%

* Negative reductions values refer to a net increase in emissions (i.e., conversion from natural gas to electric appliances would result in a net increase in emissions in a given year).

Source: Navigant analysis

3.2.2 Sensitivity for Advanced Heat Pump Technologies

Navigant also analyzed the impact that higher efficiency residential electric heat pump technologies may have on RG requirements. This assumes residential space heating heat pump coefficients of performance (COPs) increase from 3 to 4, and residential HPWH COPs increase from 2 to 3. Table 3-4 summarizes the RG requirements assuming adoption of more advanced residential electric technologies starting in 2020. The RG requirements increase slightly to account for the greater GHG emissions reductions from higher efficiency equipment, but the magnitude of change is largely captured by the original conversion to electric heat pump technology.

Table 3-4. RG Requirements in 2030 to Maintain GHG Parity with Electrification Scenarios (Assuming Advanced Residential Heat Pump Technology)

Scenario	Conversion %	Required RG % of Buildings Gas Use		Required RG % of Total SoCalGas Gas Throughput	
		Current Technologies	Advanced Residential Heat Pump Technologies	Current Technologies	Advanced Residential Heat Pump Technologies
Overnight Conversion	100% of Total Market	63%	69%	21.7%	23.8%
Normal Replacement	100% ROB	46%	50%	15.9%	17.2%
	50% ROB	23%	25%	7.9%	8.6%
	25% ROB	12%	13%	4.1%	4.5%

Assumes residential space heating heat pump COPs increase from 3 to 4, and residential HPWH COPs increase from 2 to 3.
Source: Navigant analysis

3.3 Impacts of Residential Building Envelope Upgrade Program

Navigant analyzed the technical potential for a residential building envelope upgrade program by using data from the 2017 Potential and Goals study on the saturation of baseline technologies today and in 2030. These upgrades include improving insulation for attics, ceilings, roofs, walls, floors, and ducts as well as installing high performance double-pane windows. This study projects the amount of cost-effective energy savings that could be achieved from IOU energy efficiency programs and the naturally occurring energy savings from window replacements at end of life. The incremental energy savings that could be achieved from a building envelope upgrade program would be above those already projected for IOU programs as part of CPUC's goals to double energy efficiency. Navigant also evaluated the payback of each envelope upgrade to understand which measures would provide reasonable cost-effectiveness of 15, 20, and 30 years given that the savings for certain building envelope measures can be low in mild climates.

Table 3-5 summarizes the potential energy and cost savings, and GHG emissions reductions from a potential building envelope upgrade program for measures that provide a simple payback of less than 15 years. The building envelope program provides cost-effective GHG emissions reductions, but these savings are on a much smaller scale than the RG, appliance energy efficiency, or electrification projections. Building envelope measures have smaller energy savings potential for individual homes than many appliance energy efficiency measures. Approximately 25%-50% of homes in SoCalGas territory could benefit from one or more building envelope improvements, but many of these are projected to be upgraded through current IOU energy efficiency programs or through natural replacements. For example, the Potential and Goals study projects 48% of homes have single-pane, inefficient windows, but only 10% of homes would still have inefficient single-pane windows in 2030 due to natural replacement and other IOU energy efficiency programs. In this example, the incremental building envelope program could only capture the remaining 10% of the market with inefficient windows.

Table 3-5. GHG Emissions Reductions, Consumer Utility Cost Savings, and Simple Payback for Incremental Residential Building Envelope Upgrade Program in 2030

Program Attributes/ Metrics	GHG Emissions Reductions (Million mt CO_2 per Year)	Estimated Upgrade Costs ($ Millions)	Consumer Annual Utility Cost Savings in 2030 ($ Millions)	Simple Payback (Years)
Incremental Building Envelope Upgrade Savings in 2030	0.19	$921	$70	13

An incremental building envelope upgrade program includes savings above those already projected for IOU programs and provides a simple payback of less than 15 years. Analysis includes 2030 utility cost, GHG emissions factors, building envelope characteristics, and other attributes for the SoCalGas territory.

Source: Navigant analysis

4. RG ECONOMIC ANALYSIS RESULTS

This section describes the economic analysis for the baseline, electrification, and RG projections, assuming that each projection must meet the 2030 GHG emissions reductions target of the Normal Replacement 100% electrification scenario. This target represents the most challenging RG scenario due to the supply curve reaching up to $4 per therm for in-state supply at higher RG percentages (Figure 2-2). The results and findings would scale for less aggressive electrification scenarios (Normal Replacement 50%, 25%), with the exception of the RG scenarios, which would have lower costs due to the lower RG supply prices. Section 4.4 discusses the costs for RG strategies to meet the Normal Replacement 50% and 25% electrification scenarios, with full results in Appendix G.

Table 4-1 summarizes the major RG and electrification projections analyzed in this section.

Table 4-1. GHG Emissions Reduction Projections with RG and Electrification

Projection	Appliance Type/ Efficiency	RG Source	Electrification	Electricity Rates	Electrification Costs
Baseline (IEPR Gas & Elec Rates)	Baseline Efficiency	N/A	N/A	IEPR	N/A
Renewable Gas (In-State Supply)	Baseline Efficiency	In-State	N/A	IEPR	N/A
Renewable Gas (In-State) + Energy Efficiency	High Efficiency	In-State	N/A	IEPR	N/A
Renewable Gas (Out-of-State Supply)	Baseline Efficiency	Out-of-State	N/A	IEPR	N/A
Renewable Gas (Mixed In-State / Out-of-State)	Baseline Efficiency	25% In-State / 75% Out-of-State	N/A	IEPR	N/A
Electrification (ROB, IEPR Rates, incl. Upgrades)	Baseline Efficiency	N/A	100% of gas appliances replaced with electric models at end of life	IEPR	Yes
Electrification (ROB, High Rates, incl. Upgrades)	Baseline Efficiency	N/A	100% of gas appliances replaced with electric models at end of life	High	Yes
Electrification (ROB, IEPR Rates, w/o Upgrades)	Baseline Efficiency	N/A	100% of gas appliances replaced with electric models at end of life	IEPR	No
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	Baseline Efficiency	N/A	100% of gas appliances replaced with electric models at end of life	IEPR	No

Section 2.4 provides details on utility and appliance cost assumptions.

Source: Navigant analysis.

4.1 Consumer Utility Cost Results

Consumer utility costs in each projection represent the annual operating cost for all residential and commercial appliances in each year over the analysis period (2018-2030), including new and existing gas and electric appliances. These values represent the consumer utility costs to building owners in each year and are calculated by multiplying the energy consumption for each appliance by the applicable utility rate in each year for each projection. For example, in the electrification projections, the consumer utility costs reflect changes in the assumed appliance mix over time as gas appliances are replaced with electric models. As discussed in Section 2.4.3, Navigant analyzed the impacts of different utility rate projections for renewable gas and electricity. These costs represent the consumer utility cost to building owners in each year and do not represent the direct cost to utilities for any necessary grid infrastructure improvements. These infrastructure costs are at least partially represented by the high electricity rate[70] and RG projections, which may implicitly include the utility's grid infrastructure upgrade costs.

Figure 4-1 summarizes the consumer annual utility cost projections in each year from 2018 to 2030 for new and existing appliances in each projection. Figure 4-2 and Table 4-2 summarize consumer annual utility costs in 2030. The consumer utility costs for each projection are influenced by fuel type, appliance efficiency, and utility rate. The analysis compares consumer annual utility costs in 2030 because it is the first year where all projections provide the same GHG emissions reductions. Cumulative utility cost values over the 2018-2030 analysis period are discussed in Section 4.3.

The following list summarizes the key findings and trends for consumer utility costs in 2030:

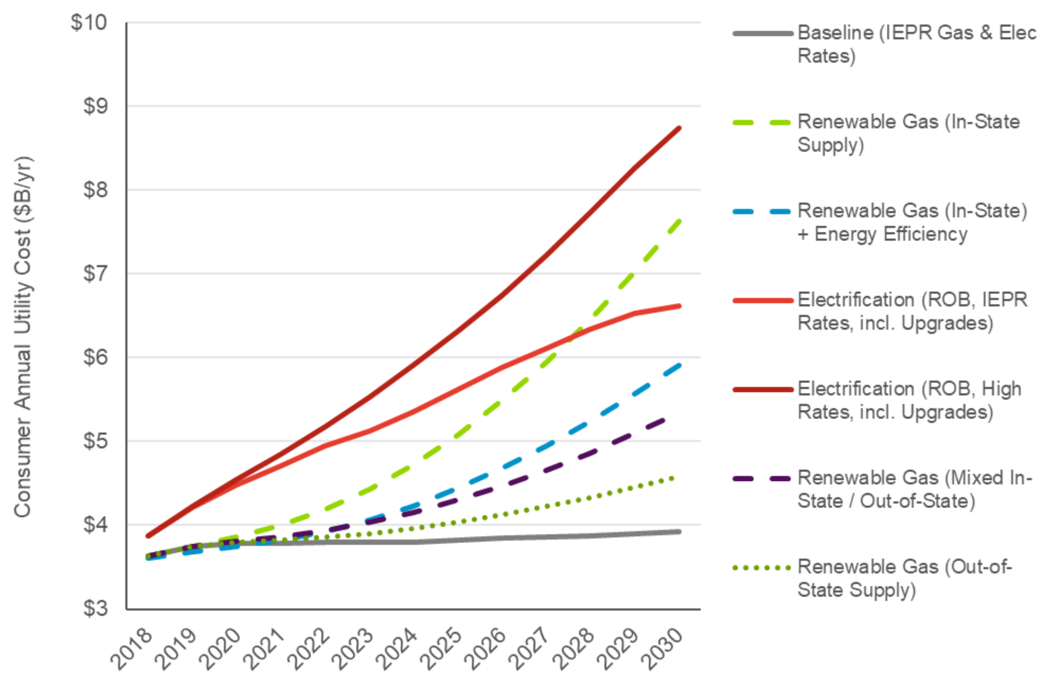
- Each GHG emissions reduction strategy substantially increases consumer annual utility costs, with the exception of the out-of-state RG projections. The in-state RG and in-state RG + Energy Efficiency projections increase consumer annual utility costs by 94% and 50% in 2030, respectively; the electrification projections increase consumer annual utility costs by 69%-123% in 2030. An RG projection with mixed in-state (25%) and out-of-state (75%) RG resources would increase consumer annual utility costs by 36% in 2030.
- Electric end-use loads with electric heat pump technologies (e.g., residential space heating and water heating) show modest energy cost increases, whereas electric technologies using electric resistance elements (e.g., residential clothes dryers, commercial boilers, commercial cooking) show larger energy cost increases and overall impact despite their lower installed appliance stock.
- The RG projection using in-state RG ($7.6 billion/year) has higher consumer annual utility costs than the electrification projection ($6.6 billion/year) using the IEPR electricity rates. The RG projection with mixed in-state (25%) and out-of-state (75%) RG resources would have a lower consumer annual utility cost ($5.3 billion/year).
- The combined in-state RG + Energy Efficiency projection has lower consumer annual utility costs than each electrification projection ($5.9 billion/year vs. $6.6 billion/year-$8.7 billion/year) due to the lower gas consumption of the higher efficiency gas appliances and the decreased RG requirement. This has a two-fold effect on consumer annual utility cost: this projection uses a lower amount of high cost RG (i.e., RG percentage of 39% vs. 46% of buildings' gas use), and

[70] Navigant analyzed a higher electricity rate projection to bookend the IEPR rate projection. This high uncertainty projection is meant to capture an upper-case scenario for future electricity rates based on other rate projections in the region.

the RG has a lower price from the supply curve (Figure 2-2). Accelerated electric energy efficiency may reduce this gap.

- RG from out-of-state resources has substantially lower consumer annual utility costs than each of the other RG and electrification projections. As shown in Figure 2-2, in-state RG supply ranges from approximately $1.5 per therm (0 BCF/year-200 BCF/year) in 2018 to approximately $3.5 by 2030; out-of-state RG ranges from $1.0 per therm (0 BCF/year-2,000 BCF/year) in 2018, increasing to $1.5 per therm by 2030.[71] In-state RG may be prioritized over out-of-state supply resources to support the economic and environmental goals of the state's agricultural industry, but out-of-state RG resources may have lower costs. For example, a mixed RG supply from in-state (25%) and out-of-state (75%) resources would have a supply cost range of $2.0 per therm by 2030.

Figure 4-1. Consumer Annual Utility Cost for RG and Electrification Projections (New and Existing Appliances)

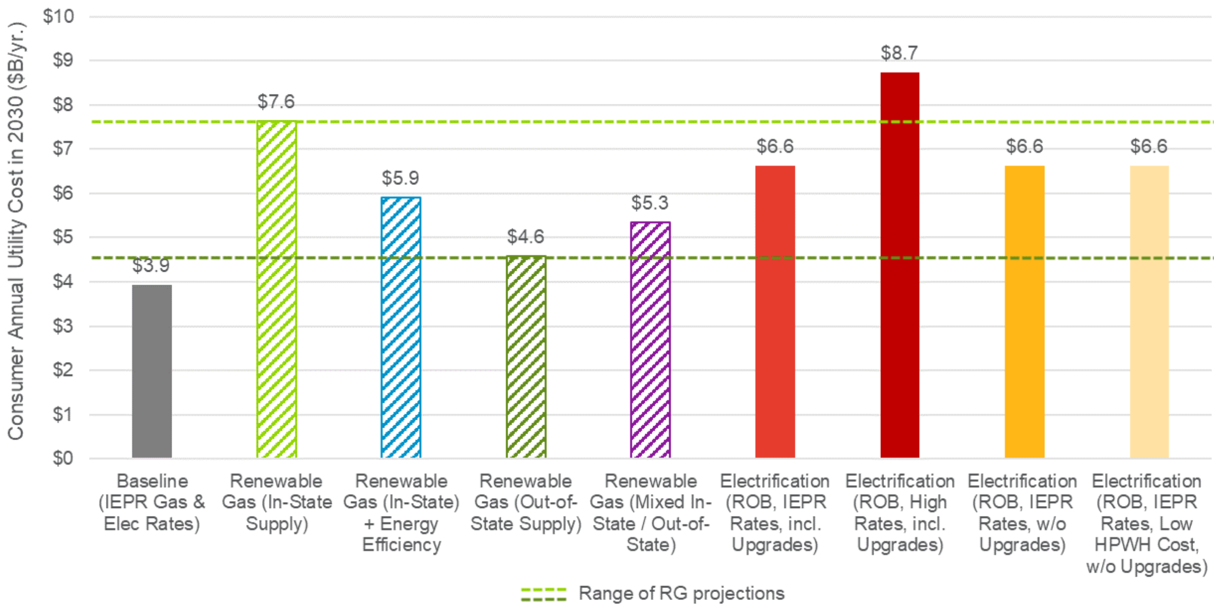


Represents energy consumption costs for all appliances (new and existing). The Low HPWH cost projection—titled Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)—has the same consumer utility cost as the Electrification IEPR Rates projection. Appliance and upgrade costs do not affect consumer utility costs.

Source: Navigant analysis

[71] Sheehy and Rosenfeld. 2017. "Design Principles for a Renewable Gas Standard." 2017. Available at: https://www.icf.com/resources/white-papers/2017/design-principles-for-renewable-gas

Figure 4-2. Consumer Annual Utility Cost in 2030 for RG and Electrification Projections (New and Existing Appliances)



Represents energy consumption costs for all appliances (new and existing).
Source: Navigant analysis

Table 4-2. Consumer Annual Utility Cost in 2030 for RG and Electrification Projections (New and Existing Appliances)

Projection	Consumer Annual Utility Cost in 2030 ($ Billions/Year)	Consumer Utility Cost Increase ($ Billions/Year)	Increase Over Baseline
Baseline (IEPR Gas & Elec Rates)	$3.9	N/A	N/A
Renewable Gas (In-State Supply)	$7.6	$3.7	94%
Renewable Gas (In-State) + Energy Efficiency	$5.9	$2.0	50%
Renewable Gas (Out-of-State Supply)	$4.6	$0.7	17%
Renewable Gas (Mixed In-State / Out-of-State)	$5.3	$1.4	36%
Electrification (ROB, IEPR Rates, incl. Upgrades)	$6.6	$2.7	69%
Electrification (ROB, High Rates, incl. Upgrades)	$8.7	$4.8	123%
Electrification (ROB, IEPR Rates, w/o Upgrades)	$6.6	$2.7	69%
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$6.6	$2.7	69%

Represents energy consumption costs for all appliances (new and existing).
Source: Navigant analysis

4.2 Appliance Cost Results

Table 4-3 summarizes the cumulative appliance costs in each projection from installations over the entire analysis period (2018-2030). These values represent the purchase, installation, and electric infrastructure upgrade costs for all appliances installed over the 2018-2030 period. The appliance costs for each projection are influenced by fuel type, appliance efficiency, purchase cost, installation cost, and the need for electric infrastructure upgrades. Compared to the baseline and RG projections, electrification projections have an appliance cost premium of $3 billion-$27 billion (6%-60%) depending on whether electrical infrastructure costs are included. Residential HPWHs have the most significant appliance and upgrade cost difference and show a notable cost increase ($3 billion, 6%) in the lowest cost assumptions. Because the RG projection uses baseline gas appliances and does not require infrastructure upgrades within the building, the RG projection has the same appliance cost as the baseline projection. Similarly, the in-state RG + Energy Efficiency projection has higher appliance costs than other RG projections by assuming higher efficiency gas appliances.

Table 4-3. Cumulative Appliance Cost for RG and Electrification Projections (2018-2030, Unadjusted)

Projection	Cumulative Appliance Cost 2018-2030 – Unadjusted ($ Billions)	Incremental Appliance Cost ($ Billions)	Increase Over Baseline
Baseline (IEPR Gas & Elec Rates)	$45	N/A	N/A
Renewable Gas (In-State Supply)	$45	$0	0%
Renewable Gas (In-State) + Energy Efficiency	$64	$19	43%
Renewable Gas (Out-of-State Supply)	$45	$0	0%
Renewable Gas (Mixed In-State/ Out-of-State)	$45	$0	0%
Electrification (ROB, IEPR Rates, incl. Upgrades)	$72	$27	60%
Electrification (ROB, High Rates, incl. Upgrades)	$72	$27	60%
Electrification (ROB, IEPR Rates, w/o Upgrades)	$60	$15	34%
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$48	$3	6%

Represents appliance purchase, installation, and electric infrastructure upgrade costs for appliances installed from 2018 to 2030.
Source: Navigant analysis

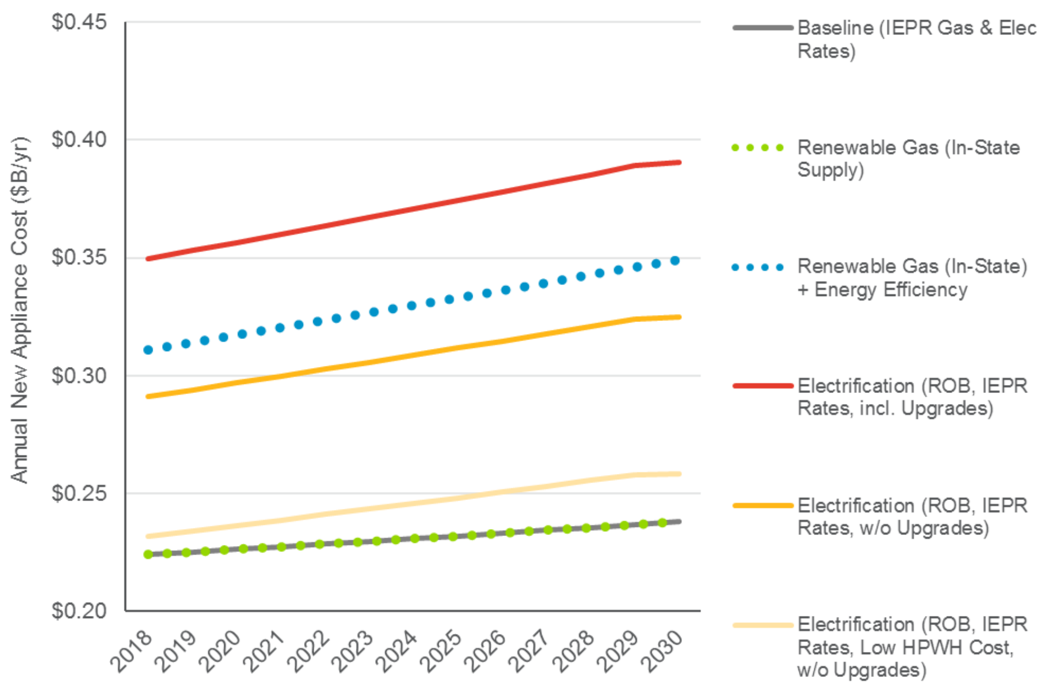
Figure 4-3 and Table 4-4 summarize the annual appliance costs for each projection, assuming that the purchase, installation, and infrastructure upgrade costs, if any, are spread over the 15-year life of many appliances.[72] Further discussed in Section 4.3, annualizing the appliance and upgrade cost allows for better comparison of energy efficiency and represents the average annual costs that a building owner

[72] Applicable one-type costs are spread over a 15-year period without considering adjustments for finance, NPV, or other factors.

would experience. When considering cumulative appliance and upgrade costs, the annualized values occur in each year over the 15-year period after the appliance was installed, such that the 2030 value includes the annualized cost for all appliances installed from 2018 to 2030. The following list summarizes the key findings and trends for annual appliance costs:

- Projections using baseline natural gas appliances have lower appliance costs than electrification projections collectively. Many electric appliances have lower appliance costs than gas appliances, including residential space heating, commercial boilers, commercial ovens, and clothes dryers.
- The appliance cost for electrification projections is largely determined by residential water heater cost assumptions. Electric HPWHs have a higher cost than baseline gas storage water heaters ($4,313 vs. $1,448) and may require electrical infrastructure upgrades ($4,671) for existing homes ($2,336 per home average assuming 50% of homes require upgrades). For the Low Cost HPWH projection, there is a $550 installed cost premium for residential electrification. Section 2.4.2 provides additional details on appliance cost.
- As discussed above, the RG projection uses baseline gas appliances and does not require infrastructure upgrades within the building.
- The electrification projections show an inflection point in appliance cost in 2030 due to the assumed conversion rates and appliance lifetimes. For an appliance with a 12-year lifetime (e.g., clothes dryer, fryer), installations in 2018 would require replacement in 2030. If these appliances required infrastructure upgrades during initial installation in 2018, they would not require similar upgrades in 2030. The change reflects these buildings having already upgraded their electrical infrastructure during initial electric appliance installation.

Figure 4-3. Annual Appliance Cost for RG and Electrification Projections (New Appliances in Each Year, Annualized Over 15 Years)



Represents appliance purchase, installation, and electric infrastructure upgrade costs in each individual year (2018-2030), with appliance and upgrade costs annualized over 15 years. This figure does not represent cumulative annualized costs (e.g., 2020 annualized payment for 2018 installation). RG figures overlap with conventional gas options because they have the same appliance costs.

Source: Navigant analysis

Table 4-4. Annual and Cumulative Appliance Cost for RG and Electrification Projections (Unadjusted and Annualized Over 15 Years)

Projection	Annual Appliance Cost in 2030 – Unadjusted ($ Billions/Year)	Cumulative Appliance Cost 2018-2030 – Unadjusted ($ Billions)	Annual Appliance Cost in 2030 – Annualized 15 Years ($ Billions/Year)	Cumulative Appliance Cost 2018-2030 – Annualized 15 Years ($ Billions)
Baseline (IEPR Gas & Elec Rates)	$3.6	$45	$0.2	$21
Renewable Gas (In-State Supply)	$3.6	$45	$0.2	$21
Renewable Gas (In-State) + Energy Efficiency	$5.2	$64	$0.3	$29
Renewable Gas (Out-of-State Supply)	$3.6	$45	$0.2	$21
Renewable Gas (Mixed In-State / Out-of-State)	$3.6	$45	$0.2	$21
Electrification (ROB, IEPR Rates, incl. Upgrades)	$5.9	$72	$0.4	$33
Electrification (ROB, High Rates, incl. Upgrades)	$5.9	$72	$0.4	$33
Electrification (ROB, IEPR Rates, w/o Upgrades)	$4.9	$60	$0.3	$28
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$3.9	$48	$0.3	$22

Represents appliance purchase, installation, and electric infrastructure upgrade costs for appliances installed in 2030, as well as all appliances installed from 2018 to 2030. The table presents unadjusted cost values and cost values annualized over 15 years.

Source: Navigant analysis

4.3 Combined Annual Cost Results

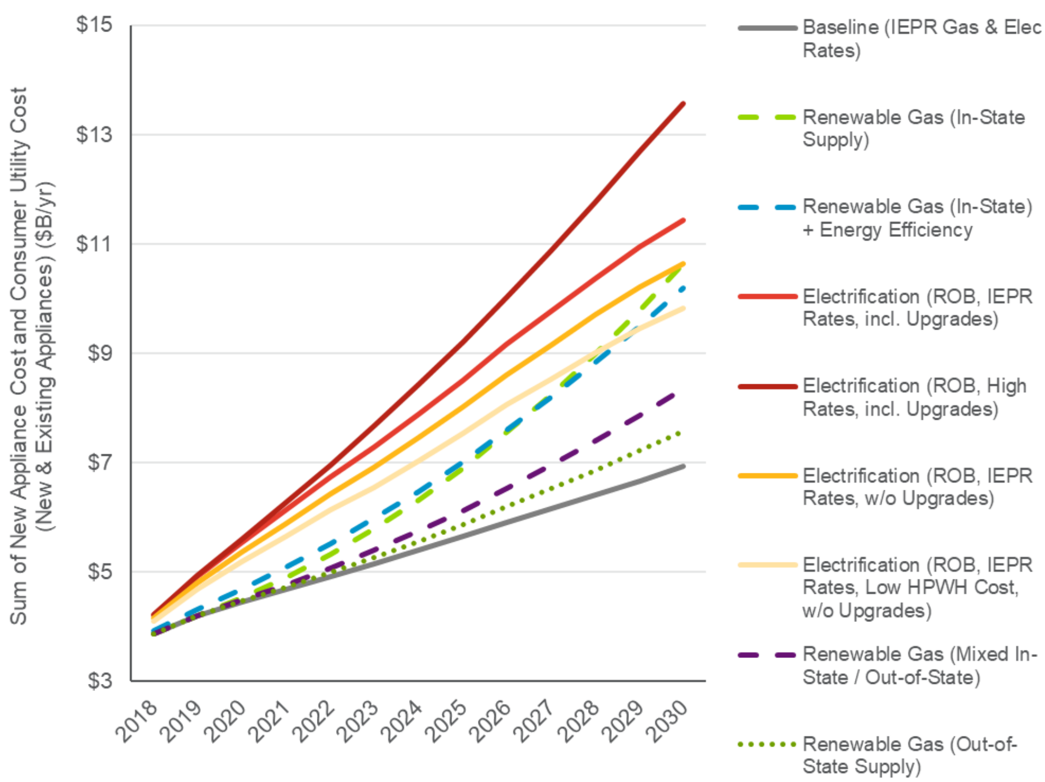
Figure 4-4 summarizes the combined annual cost for each projection, including consumer annual utility cost for new and existing appliances and annualized appliance and upgrade costs in each year from 2018 to 2030. Table 4-5 summarizes the combined annual cost in 2030. When appliance and upgrade costs are annualized over 15 years, consumer utility costs have the largest influence on combined annual cost. This represents the average annual costs that a building owner would experience; this is because they would incur the appliance purchase and upgrade cost once over the appliance's lifetime, but experience utility bills every year. Appendix G provides detailed results for each projection. The following list summarizes the key findings and trends for combined annual cost:

- The RG projection using in-state RG has comparable combined annual cost ($10.6 billion/year) to the range of electrification projections ($9.8 billion/year-$13.6 billion/year) in 2030.
- The combined in-state RG + Energy Efficiency projection ($10.2 billion/year) has lower combined annual cost than the in-state RG projection due to the lower gas consumption of the higher efficiency appliances and the decreased RG requirement. When annualized, the consumer utility cost savings of high efficiency appliances using in-state RG supply overcome the higher

purchase cost. Described previously in this section, incremental energy efficiency to reduce the required amount of in-state RG has a substantial impact on consumer annual utility cost.

- RG from out-of-state resources has substantially lower combined annual cost than each of the other RG and electrification projections. This projection assumes baseline gas appliances and low RG rates, and the low RG rates have only a modest increase on the blended gas rate. As shown in Figure 2-2 in Section 2, the in-state RG supply ranges from approximately $1.5 per therm (0 BCF/year-200 BCF/year) in 2018 to approximately $3.5 by 2030; out-of-state RG ranges from $1.0 per therm (0 BCF/year-2,000 BCF/year) in 2018, increasing to $1.5 per therm by 2030. A mixed RG supply from in-state (25%) and out-of-state (75%) resources would have a supply cost range of $2.0 per therm by 2030.

Figure 4-4. Combined Annual Cost for RG and Electrification Projections (New and Existing Appliances, Annualized Over 15 Years)



Represents sum of costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed from 2018 to 2030.

Source: Navigant analysis

Table 4-5. Combined Annual Cost in 2030 for RG and Electrification Projections (New and Existing Appliances, Annualized Over 15 Years)

Projection	Combined Annual Cost in 2030 ($ Billions/Year)	Incremental Combined Annual Cost in 2030 ($ Billions/Year)	Increase Over Baseline
Baseline (IEPR Gas & Elec Rates)	$6.9	N/A	N/A
Renewable Gas (In-State Supply)	$10.6	$3.7	53%
Renewable Gas (In-State) + Energy Efficiency	$10.2	$3.3	47%
Renewable Gas (Out-of-State Supply)	$7.6	$0.7	9%
Renewable Gas (Mixed In-State / Out-of-State)	$8.3	$1.4	20%
Electrification (ROB, IEPR Rates, incl. Upgrades)	$11.4	$4.5	65%
Electrification (ROB, High Rates, incl. Upgrades)	$13.6	$6.6	96%
Electrification (ROB, IEPR Rates, w/o Upgrades)	$10.6	$3.7	53%
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$9.8	$2.9	42%

Represents sum of costs in 2030 for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed from 2018 to 2030.

Source: Navigant analysis

Table 4-6 summarizes the cumulative values for consumer utility cost, annualized appliance and upgrade cost, and combined annual cost over the analysis period (2018-2030). When appliance and upgrade costs are annualized over 15 years, consumer utility costs have the largest influence on combined annual cost. The following list summarizes the key findings and trends for cumulative consumer utility, appliance, and combined annual cost values:

- Each RG projection has lower cumulative combined annual cost ($73 billion-$87 billion) than electrification projections ($92 billion-$112 billion) over the 2018-2030 analysis period. This comparison is mostly due to consumer utility cost differences, particularly for electrification projections without electrical infrastructure upgrades.
- The consumer utility cost for an RG scenario is directly related to the cost of the required RG supply and the required RG percentage of buildings' gas use. As shown in Figure 4-1, the consumer utility costs for RG projections increase over time as greater volumes of more expensive RG supply are required. The in-state RG projection shows the largest sensitivity to this supply curve, whereas the out-of-state RG projection is less sensitive.
- In addition, the cumulative consumer utility and annual cost values for RG projections are lower than electrification projections, as the lower cost RG supply in early years counteracts the higher RG supply costs in 2030.

Table 4-6. Cumulative Consumer Utility, Appliance, and Combined Annual Cost 2018-2030 for RG and Electrification Projections (New and Existing Appliances, Annualized Over 15 Years)

Projection	Cumulative Consumer Utility Cost 2018-2030 ($ Billions)	Cumulative Appliance Cost 2018-2030 – Annualized 15 Years ($ Billions)	Cumulative Combined Annual Cost 2018-2030 ($ Billions)
Baseline (IEPR Gas & Elec Rates)	$50	$21	$70
Renewable Gas (In-State Supply)	$66	$21	$87
Renewable Gas (In-State) + Energy Efficiency	$58	$29	$87
Renewable Gas (Out-of-State Supply)	$52	$21	$73
Renewable Gas (Mixed In-State / Out-of-State)	$56	$21	$77
Electrification (ROB, IEPR Rates, incl. Upgrades)	$70	$33	$103
Electrification (ROB, High Rates, incl. Upgrades)	$79	$33	$112
Electrification (ROB, IEPR Rates, w/o Upgrades)	$70	$28	$97
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$70	$22	$92

Represents cumulative sum of costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed from 2018 to 2030. Numbers may not add to total due to rounding.

Source: Navigant analysis

Table 4-7 summarizes the cumulative combined annual cost over the entire analysis period (2018-2030) and compares the NPV using discount rates of 0%, 3%, and 9%. The CEC's Life-Cycle Cost Methodology for energy efficiency measures uses a 3% real (inflation adjusted) discount rate,[73] whereas 9% represents the weighted average rate of return or return on equity for California IOUs.[74] The NPV results using a 3% discount rate are used in the cost-effectiveness comparison in the following section.

[73] Architectural Energy Corporation. 2011. "Life-Cycle Cost Methodology." Prepared for CEC. January 14, 2011. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/general_cec_documents/2011-01-14_LCC_Methodology_2013.pdf

[74] CPUC. 2018. "California Electric and Gas Utility Cost Report." CPUC Energy Division. April 2018. Available at: http://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/About_Us/Organization/Divisions/Office_of_Governmental_Affairs/Legislation/2018/California%20Electric%20And%20Gas%20Utility%20Cost%20Report.pdf

Table 4-7. Cumulative Combined Annual Cost 2018-2030 for RG and Electrification Projections (New and Existing Appliances, Annualized Over 15 Years) ($ Billions)

Projection	Cumulative Combined Annual Cost 2018-2030 ($ Billions)		
	NPV, 0% Discount Rate	NPV, 3% Discount Rate	NPV, 9% Discount Rate
Baseline (IEPR Gas & Elec Rates)	$70	$58	$42
Renewable Gas (In-State Supply)	$87	$71	$49
Renewable Gas (In-State) + Energy Efficiency	$87	$71	$50
Renewable Gas (Out-of-State Supply)	$73	$60	$43
Renewable Gas (Mixed In-State / Out-of-State)	$77	$63	$45
Electrification (ROB, IEPR Rates, incl. Upgrades)	$103	$84	$59
Electrification (ROB, High Rates, incl. Upgrades)	$112	$91	$63
Electrification (ROB, IEPR Rates, w/o Upgrades)	$97	$80	$56
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$92	$75	$53

Represents cumulative sum of costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed from 2018 to 2030.

Source: Navigant analysis

4.4 Cost-Effectiveness for GHG Emissions Reductions

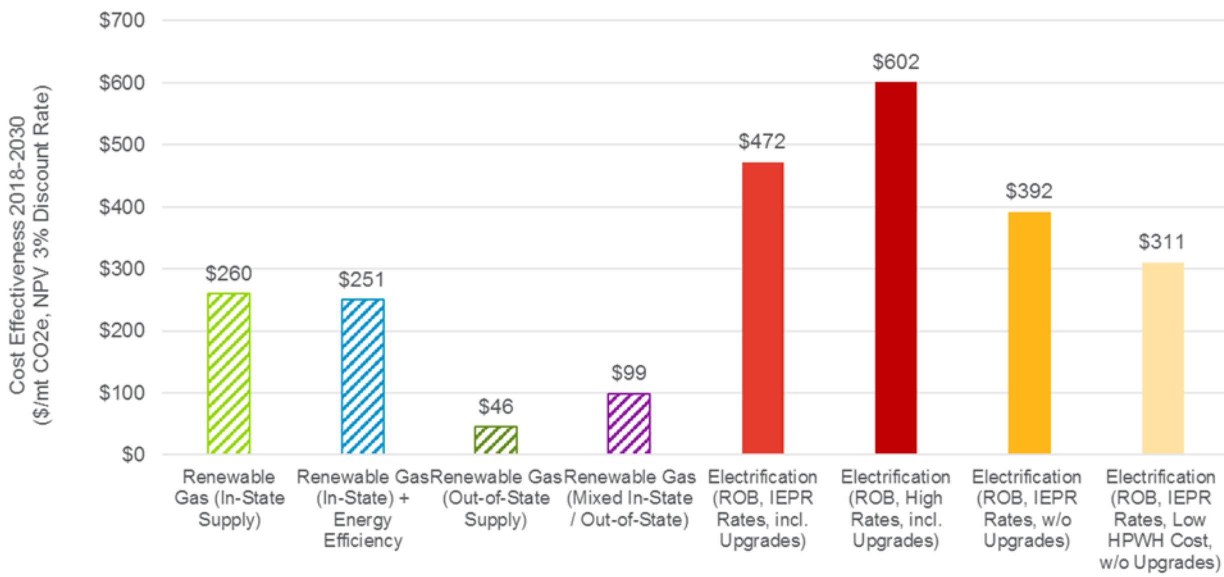
Figure 4-5 and Table 4-8 summarize the cost-effectiveness of each GHG emissions reduction strategy ($/mt CO_2e) to maintain the GHG emissions reductions with the Normal Replacement 100% scenario in 2030. These figures represent the cumulative combined annual cost for GHG emissions reduction over the 2018-2030 period, including consumer annual utility cost for new and existing appliances and annualized appliance and upgrade costs for those installed since the 2018 start year. These values represent NPV assuming a 3% discount rate. Each of the RG and electrification projections provides the same GHG emissions reductions in 2030, with some variation in earlier years due to analysis assumptions such as RG introduction timeline, grid emissions factors, growth rates, etc. The key difference in the cost-effectiveness comparison is due to the consumer annual utility costs— annual appliance costs have a lesser impact. The following list summarizes the key findings and trends for cost-effectiveness:

- Using the RG cost assumptions provided for this analysis, the range of RG projections ($46/mt CO_2e-$260/mt CO_2e) are lower than the range of electrification projections ($311/mt CO_2e-$602/mt CO_2e). When annualized, the cost difference between the electrification projections is largely determined by the consumer annual utility cost rather than the cost of appliance purchase and infrastructure upgrades.
- The in-state RG + Energy Efficiency projection has a lower cost ($251/mt CO_2e) than the in-state RG projection by using cost-effective incremental energy efficiency to decrease the amount of higher priced RG. The RG projection using out-of-state RG has a substantially lower

cost ($46/mt CO_2e) than the other RG and electrification projections due to no incremental appliance cost and a minimal consumer utility cost increase.

- These findings suggest that RG is worth considering as part of the low-carbon buildings strategy, including in-state resources, out-of-state resources, and incremental energy efficiency. Given the uncertainties in assumptions for RG and electrification projections, future research is necessary to determine an optimized pathway (Section 5.3). Other considerations related to risk assessment, public policy, and customer preferences will be important in developing the path to achieve California's ambitious GHG goals.

Figure 4-5. Cost-Effectiveness of GHG Emissions Reduction Strategies: 2018-2030 (Cumulative Cost and GHG Emissions Reductions with the Normal Replacement 100% Scenario, NPV 3% Discount Rate)



Incremental costs include the sum of energy consumption costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed from 2018 to 2030. Costs represent NPV with 3% discount rate.

Source: Navigant analysis.

Table 4-8. Cost-Effectiveness of GHG Emissions Reduction Strategies: 2018-2030 (Cumulative Incremental Cost and GHG Emissions Reductions with the Normal Replacement 100% Scenario, NPV 3% Discount Rate)

Projection	Cumulative Combined Annual Cost 2018-2030 ($ Billions)	Cumulative Incremental Cost 2018-2030 ($ Billions)	Cumulative GHG Emissions Reductions (Million mt CO_2e)	Cost-Effectiveness ($/mt CO_2e)
Renewable Gas (In-State Supply)	$71	$13	49	$260
Renewable Gas (In-State) + Energy Efficiency	$71	$13	52	$251
Renewable Gas (Out-of-State Supply)	$60	$2	49	$46
Renewable Gas (Mixed In-State / Out-of-State)	$63	$5	49	$99
Electrification (ROB, IEPR Rates, incl. Upgrades)	$84	$26	55	$472
Electrification (ROB, High Rates, incl. Upgrades)	$91	$33	55	$602
Electrification (ROB, IEPR Rates, w/o Upgrades)	$80	$21	55	$392
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$75	$17	55	$311

Incremental costs include the sum of energy consumption costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed from 2018 to 2030. Costs represent NPV with 3% discount rate.

Source: Navigant analysis

The preceding discussion in this section describes the cost-effectiveness of GHG emissions reduction strategies, assuming that each strategy must meet the 2030 GHG emissions reductions target of the Normal Replacement 100% electrification scenario. This target represents the most challenging RG scenario due to the supply curve reaching $3-$4 per therm for in-state supply at higher RG percentages (Figure 2-2). The results and findings would scale for less aggressive electrification scenarios (Normal Replacement 50% and 25%), except for the RG scenarios, which would have lower costs due to the lower RG supply prices. Appendix G provides the results for the Normal Replacement 50% and 25% scenarios.

Table 4-9 summarizes the cost-effectiveness of the RG strategy using in-state RG supply to match 2030 GHG emissions targets of the Normal Replacement 50% and 25% electrification scenarios. As stated previously, the cost for an RG scenario is directly related to the cost of the required RG supply and the required RG percentage of buildings' gas use. For available in-state supply of 200 BCF/year, the cost for in-state RG rises from $1.5 per therm to $3.5 per therm based on the volume of RG required.[75] By using lower volumes of cheaper RG supply, RG strategies would have a lower cost ($/mt CO_2e) for the 50% and 25% Normal Replacement electrification scenarios. The following examples show the impact for in-

[75] Sheehy and Rosenfeld. 2017. "Design Principles for a Renewable Gas Standard." ICF. Available at: https://www.icf.com/resources/white-papers/2017/design-principles-for-renewable-gas

state RG supply; lower cost out-of-state RG or a mixed RG supply of in-state and out-of-state resources would experience a similar cost reduction.

- To meet the GHG emissions target of the Normal Replacement 100% electrification scenario, in-state RG has a supply price of $3.5/therm and 46% RG supply is needed for buildings' gas use in 2030. The cost-effectiveness of cumulative combined annual cost and GHG emissions reductions is $260/mt CO_2e.
- To meet the GHG emissions target of the Normal Replacement 50% electrification scenario, in-state RG has a supply price of $2.4/therm and 23% RG supply is needed for buildings' gas use in 2030. The cost-effectiveness of cumulative combined annual cost and GHG emissions reductions is $152/mt CO_2e.
- To meet the GHG emissions target of the Normal Replacement 25% electrification scenario, in-state RG has a supply price of $1.9/therm and 12% RG supply is needed for buildings' gas use in 2030. The cost-effectiveness of cumulative combined annual cost and GHG emissions reductions is $100/mt CO_2e.

Table 4-9. Cost-Effectiveness of RG Strategy (In-State Supply) to Match 2030 GHG Emissions Targets of 50% and 25% Normal Replacement Electrification Scenarios (NPV 3% Discount Rate)

Electrification Scenario	Required RG % of SoCalGas Buildings Gas Use (2030)	Required Annual RG Volume (BCF/Year, 2030)	In-State RG Supply Price at Required 2030 Volume ($/therm)	GHG Emissions Reductions (Million mt CO_2e)	Cost-Effectiveness ($/mt CO_2e per Year)
Normal Replacement 100%	46%	137	$3.5	49	$260
Normal Replacement 50%	23%	69	$2.4	24	$152
Normal Replacement 25%	12%	36	$1.9	13	$100

2016 California Gas report estimates total SoCalGas throughput of 867 BCF/year in 2030. Costs represent NPV with 3% discount rate.
Source: Navigant analysis

5. KEY FINDINGS AND AREAS FOR FUTURE RESEARCH

5.1 Summary of Technical Analysis

Navigant's approach involved developing a spreadsheet model to evaluate the potential GHG emissions reductions from appliance electrification and to estimate RG needs under different scenarios. The evaluation team analyzed several electrification strategies: Overnight Conversion scenario (100% of installed base is converted to electric appliances) and Normal Replacement scenarios (100%, 50%, and 25% of annual appliance ROB to electric). This section summarizes the key findings from the technical analysis.

- **RG Requirements by 2030:** Under each scenario, SoCalGas would need to supply a significant percentage of the RG to residential and commercial customers to maintain parity with electrification.
    - For the **Overnight Conversion** scenario, RG would need to satisfy 63% of total residential and commercial gas use, or roughly 22% of total system throughput.[76]
    - For the **Normal Replacement** scenarios, the amount of RG required in 2030 is less than the Overnight Conversion scenario and depends on the aggressiveness of electrification:
        - If 100% of appliances sold after 2020 were electric, RG would need to satisfy 46% of total residential and commercial gas use, or roughly 16% of total system throughput.
        - If 50% of appliances sold after 2020 were electric, RG would need to satisfy 23% of total residential and commercial gas use, or roughly 8% of total system throughput.
        - If 25% of appliances sold after 2020 were electric, RG would need to satisfy 12% of total residential and commercial gas use, or roughly 4% of total system throughput.
- **GHG Emissions Impacts by End Use:** Most appliances achieve GHG emissions reductions through electrification in 2018, and the advantage increases in 2030 as the RPS targets reduce grid electricity emissions further.
    - Electric technologies that use electric resistance heating (e.g., commercial boilers) have smaller reductions relative to those with heat pump heating (e.g., residential space and water heating). GHG emissions reductions for heat pump heating technologies range from approximately 60% to 75% in 2030.
    - Commercial electric cooking equipment (e.g., fryers, convection ovens) have higher unit efficiency relative to gas models (e.g., fryers: 75%-85% for electric vs. 35%-60% for gas; convection ovens: 65%-70% for electric vs. 30%-45% for gas).
    - For additional context, the buildings sector accounted for approximately 11% of California's total 2015 GHG emissions of 440.4 million metric tons of CO_2e, with

[76] 2016 California Gas report estimates total SoCalGas throughput of 867 BCF/year in 2030.

residential and commercial buildings accounting for 6% and 5%, respectively.[77] These estimates represent GHG emissions from whole building energy consumption rather than the specific building end uses discussed in this report.

5.2 Summary Economic Analysis

Navigant analyzed the consumer annual utility and appliance cost effects of several GHG emissions reduction projections, including incremental energy efficiency, appliance electrification, and RG under different sets of assumptions. Each projection was designed to meet the 2030 GHG emissions reductions target of the Normal Replacement 100% electrification scenario.

- **Consumer Annual Utility Cost:** Each GHG emissions reduction strategy substantially increases consumer annual utility costs in future years. In 2030, consumer annual utility costs would increase by $0.7 billion/year-$4.8 billion/year over the baseline projection for the range of RG and electrification projections.
    - Electric end-use loads with electric heat pump technologies (e.g., residential space heating and water heating) show modest energy cost increases, whereas electric technologies using electric resistance elements (e.g., residential clothes dryers, commercial boilers, commercial cooking) show larger energy cost increases and overall impact despite their lower installed appliance stock.
    - The RG projection using in-state RG ($7.6 billion/year) has a higher consumer annual utility cost than the electrification projection ($6.6 billion/year) using IEPR electricity rates in 2030. The RG projection with mixed in-state (25%) and out-of-state (75%) RG resources would have a lower consumer annual utility cost ($5.3 billion/year) in 2030.
    - The combined in-state RG + Energy Efficiency projection has lower consumer annual utility costs than each electrification projection ($5.9 billion/year vs. $6.6 billion/year-$8.7 billion/year) due to the lower gas consumption of the higher efficiency appliances and the decreased RG requirement. Energy efficiency for electric technologies would reduce operating costs for the electrification projections but is not within the scope of this analysis.
- **Appliance Cost:** Because the RG projection uses baseline gas appliances and does not require infrastructure upgrades within the building, the RG projection has no incremental appliance cost.
    - Compared to the RG projection, electrification projections have an appliance cost premium over gas appliance projections ($3 billion-$27 billion or 6%-60% higher cumulative appliance cost from 2018 to 2030) depending on whether electrical infrastructure costs are included.
    - The appliance cost for electrification projections is largely determined by the residential water heater cost assumptions and electrical infrastructure upgrade costs. Electric HPWHs have a higher cost than baseline gas storage water heaters ($4,313 vs. $1,448 total installed costs) and may require electrical infrastructure upgrades ($4,671) for existing homes ($2,336 per home average assuming 50% of homes require upgrades).

[77] California Air Resources Board, *California Greenhouse Gas Emission Inventory - 2017 Edition*. June 2017. https://www.arb.ca.gov/cc/inventory/data/data.htm

- For the Low Cost HPWH projection, electric HPWHs carry a $550 installed cost premium over baseline gas storage water heaters per residential home. The Low Cost HPWH projection carries an incremental $3 billion cumulative appliance cost over gas appliance projections.

- **Combined Annual Cost:** When appliance and electrical infrastructure upgrade costs are annualized over 15 years, consumer utility costs have the largest influence on combined annual cost.
  - **2030 Only:** The RG projection using in-state RG has a comparable combined annual cost ($10.6 billion/year) to the range of electrification projections ($9.8 billion/year-$13.6 billion/year) in 2030. RG from out-of-state resources has substantially lower combined annual cost than each of the other RG and electrification projections.
  - **Cumulative 2018-2030:** Each RG projection has lower cumulative combined annual cost ($73 billion-$87 billion) than the electrification projections ($92 billion-$112 billion) over the 2018-2030 analysis period. This comparison is mostly due to consumer utility cost differences, particularly for early years when RG prices are lower on the supply curve.
    - When considered as NPV with a 3% discount rate, the cumulative combined annual cost for RG projections range from $60 billion-$71 billion and electrification projections range from $75 billion-$91 billion.
- **Cost-Effectiveness for GHG Emissions Reductions:** Each of the RG and electrification projections provides the same GHG emissions reductions in 2030. The key difference in the cost-effectiveness comparison is due to the consumer annual utility costs, with annual appliance costs having a lesser impact. These values represent cumulative combined annual cost and GHG emissions reductions for 2018-2030 and NPV assuming a 3% discount rate.
  - Using the RG cost assumptions provided for this analysis, the range of RG projections ($46/mt CO_2e-$260/mt CO_2e) are lower than the range of electrification projections ($311/mt CO_2e-$602/mt CO_2e).
  - The in-state RG + Energy Efficiency projection has a lower cost ($251/mt CO_2e) than the in-state RG projection ($260/mt CO_2e) by using the cost-effective incremental energy efficiency to decrease the amount of higher priced RG. The RG projection using out-of-state RG has a substantially lower cost ($46/mt CO_2e) than the other RG and electrification projections due to no incremental appliance cost and a minimal consumer utility cost increase.
  - Matching the 2030 GHG emissions reductions target of the Normal Replacement 100% electrification scenario represents the most challenging RG scenario due to the supply curve reaching $3-$4 per therm for in-state RG supply at higher RG percentages. The cost for an RG scenario is directly related to the cost of the required RG supply and the required RG percentage of buildings' gas use. By using lower volumes of cheaper RG supply, RG strategies would have lower cost for the Normal Replacement 25% and 50% electrification scenarios.

5.3 Areas of Future Research

Navigant conducted this analysis to understand the costs and benefits of different GHG emissions reduction strategies for the residential and commercial building markets. This analysis relies on numerous assumptions about California's building stock, appliance costs, utility rates, and other parameters that have limited available information on their effects, particularly in 2030. The following list summarizes some factors that may be explored in future research:

- **RG Supply Availability and Constraints:** This analysis assumes that sufficient RG is available to meet the requirements in the California building market and reflects current supply and cost estimates from a 2017 ICF study.[78] Stakeholders should further explore the feasibility of ramping up in-state RG production to meet the 2030 requirements and encouraging regional and national development for longer-term supply. In addition, future research should evaluate the potential for power-to-gas and hydrogen supplies to supplement RG resources from landfills, wastewater treatment plans, agricultural residues, animal products, and other sources.
- **Competing RG Uses:** California and other states currently use available RG supply for medium and heavy transportation and distributed electricity production. This analysis assumes sufficient RG supply is available for pipeline introduction to satisfy building gas loads but does not explore the cost-effectiveness of competing RG uses. Stakeholders should further analyze the costs and benefits of RG for different end uses and understand how to leverage the available in-state and out-of-state RG supply with greatest cost-effectiveness.
- **Electrical Upgrade Costs:** Limited information is available on the average electrical upgrade costs for existing residential and commercial buildings; anecdotal estimates range widely based on the type of electrical appliance (e.g., electric HPWH, solar PV system, EV charger), age of building, contractor prices, etc. This analysis leverages research performed by TRC for the City of Palo Alto[79] on electrical upgrade costs in California. Stakeholders should conduct additional research to quantify the cost to upgrade electrical infrastructure in existing California buildings and the proportion of buildings requiring different upgrade levels.
- **Customer Preferences:** Stakeholders should study the effects that appliance electrification initiatives would have on customer preferences, satisfaction, resale values, and other attributes to the California buildings market.
- **Electricity Grid Impacts:** Future research should examine the impacts that appliance electrification initiatives could have on local and statewide electricity grid and electric rates.
- **Gas Infrastructure Costs:** This analysis did not consider the possible cost savings in new construction from not putting in gas lines, meters, and running gas pipes within the building. Future research should evaluate the possible gas infrastructure cost savings for new construction.
- **Analysis Timeframe:** This analysis investigates the impacts of RG and appliance electrification in 2030 when the California RPS target reaches 50% but does not explore the impacts at higher

[78] Sheehy and Rosenfeld. 2017. "Design Principles for a Renewable Gas Standard." ICF. Available at: https://www.icf.com/resources/white-papers/2017/design-principles-for-renewable-gas

[79] TRC Solutions. 2016. "Palo Alto Electrification Final Report." City of Palo Alto. Available at: https://www.cityofpaloalto.org/civicax/filebank/documents/55069

RPS levels in future years. Stakeholders should explore the impacts of various building GHG emissions strategies beyond 2030.

- **Increased Space Cooling in Existing Homes:** Stakeholders should study the potential effects that electric heat pump adoption could have on increased space cooling consumption in homes that did not previously use air conditioners.
- **Utility Rates:** Additional research is necessary to understand the impacts that appliance electrification could have in future years for natural gas and electricity rates, including rate structures, stranded assets, and other issues.
- **Higher Utility Rates Reducing Consumption:** In both RG and appliance electrification scenarios, California consumers would see increased consumer utility bills. Researchers have identified the price elasticity of natural gas[80] and electricity[81] in California, such that consumers will consume less natural gas and electricity when prices are higher. Stakeholders should study the effects that higher utility rates to achieve GHG emissions reductions would have on building consumption and utility rate impacts.
- **Installation, Operation, and Maintenance Requirements:** Additional research is necessary to analyze the differences in installation, operation, and maintenance requirements between gas and electric appliances.

[80] Auffhammer and Rubin. 2018. "Natural Gas Price Elasticities and Optimal Cost Recovery Under Consumer Heterogeneity: Evidence from 300 Million Natural Gas Bills." Energy Institute at Haas, University of California, Berkeley. Available at: https://ei.haas.berkeley.edu/research/papers/WP287.pdf

[81] CEC. 2017. "Residential TOU Load Impacts CED 2017 Revised." Available at: http://docketpublic.energy.ca.gov/PublicDocuments/17-IEPR-03/TN221972_20171214T140010_Residential_TOU_Load_Impacts_CED_2017_Revised.pptx

6. CONCLUSIONS

This study analyzed the potential GHG emissions reductions from building electrification in the residential and commercial sectors, estimated the amount of RG needed to match GHG emissions reductions under different scenarios, projected the combined annual cost for consumer utility and appliance costs under several assumptions, and compared the cost-effectiveness of each GHG emissions reduction strategy.

Based on RG supply availability at the costs assumed in this study, RG delivered to residential and commercial buildings could reach similar GHG emissions reduction targets in 2030 as appliance electrification. When comparing the cost-effectiveness of different GHG emissions reduction strategies, RG scenarios have comparable or lower costs to electrification scenarios when considering the range of RG supply and electricity rate projections, and uncertainties around appliance purchase, installation, and upgrade cost estimates. When examining these results, it is important to note that the current study focuses on residential and commercial buildings only and does not consider RG supply constraints, additional RG program needs, or any direct cost to electric utilities for any necessary grid infrastructure improvements other than the high electricity rate scenario.

The study concludes that RG is worth further consideration as part of the low-carbon buildings strategy, including in-state RG resources, out-of-state RG resources, and incremental energy efficiency. Further research identified in this study such as risks, public policy, and customer preferences will be important in developing paths to achieve California’s ambitious GHG goals.

7. RECOMMENDATIONS

Navigant recommends SoCalGas and other stakeholders pursue the following activities to further investigate the potential for RG as a part of California's low-carbon future.

1. **Include and further explore RG as an option to meet GHG emissions targets for buildings in 2030 and beyond, including developing a common set of assumptions with respect to RG resource and infrastructure availability and cost, and advancing RG policies**

   This analysis demonstrates the potential for RG to provide cost-effective GHG emissions reductions for residential and commercial buildings. California should study RG as a viable option to achieve its GHG emissions targets, including assessing supply and resource costs, infrastructure needs, the supply chains, and the need for a statewide RG standard. RG could follow a similar trajectory as renewable electricity. An RG standard would build on the successes of California's Low Carbon Fuel Standard for transportation fuels, but extend it to deliver RG supplies into the gas pipeline network for direct use by buildings. This strategy not only serves the 2030 targets but will continue as a strategy for the state's GHG emissions targets to 2050 and beyond.

2. **Conduct further research to estimate how appliance electrification could affect electric utilities and consumers, particularly related to a common set of assumptions for appliance installation costs, and upgrade costs for building and grid infrastructure**

   This analysis concludes that RG may be able to provide a similar level of GHG emissions reductions as appliance electrification at similar costs and is worthy of additional study as a GHG emissions reduction strategy. Nevertheless, these conclusions rely on numerous assumptions on the electric rate impacts and building infrastructure needs to accommodate large-scale conversions to electric appliances in the buildings sector, as well as their associated installation costs. Limited reliable information is available on the cost to upgrade the electrical infrastructure of residential and commercial buildings in California, as well as how many California buildings require the upgrades. These upgrades would be similar to those for EVs, solar PV systems, and other advanced electric technologies that are increasingly installed across the state and may reduce barriers to greater appliance electrification. Large increases in building electricity consumption may require electric utilities to upgrade their own infrastructure and procure sufficient renewable and non-renewable supply resources. Navigant analyzed different projections of appliance cost, building upgrades, and utility rates to understand how these factors could affect the comparison between RG and electrification strategies, but further research is necessary to better quantify these impacts for California. SoCalGas and other stakeholders should encourage greater research into the cost and market need to upgrade both building and utility infrastructure to accommodate large-scale appliance electrification and estimate the effects on electric utility rates and rate structures throughout the state, including time-of-use or multi-tiered rates. This will require coordination with CEC, CPUC, and the California electric utilities to quantify the costs fairly and inform statewide decisions.

3. **Evaluate opportunities to foster greater RG supply within California and with regional stakeholders.**

   This analysis shows that RG from both in-state and out-of-state resources can play a significant role in achieving the GHG emissions reductions targets for California buildings. In-state RG may be prioritized over out-of-state RG supply resources to support the economic and environmental goals of the state's agricultural industry even if out-of-state RG resources may have lower costs. Nevertheless, out-of-state RG resources will be necessary to achieve larger GHG emissions reductions beyond 2030, particularly as RG demands in California increase for transportation and electrical generation uses. Cost projections for out-of-state RG resources are lower than in-state resources, such that there is significant incentive for California stakeholders to encourage greater development both regionally and nationally. SoCalGas should continue to work with local, regional, and national stakeholders to promote the development of RG resources, particularly for introduction into gas pipelines. These activities include collaboration with agricultural organizations and groups such as The Coalition for Renewable Natural Gas[82] (SoCalGas/Sempra is a member) and continued technology development for feedstocks, conversion, upgrading, injection, and other key processes.

[82] Details available at *The Coalition for Renewable Natural Gas* website: http://www.rngcoalition.com/

APPENDIX A. ASSUMPTIONS FOR GAS AND ELECTRIC APPLIANCES

Appendix A provides a summary of the key data sources and assumptions for calculating baseline energy consumption and market sizing for natural gas and electric appliances, including:

- Section A.1. Key Data Sources for Energy Consumption and Market Sizing
- Section A.2. Residential Appliance Assumptions
- Section A.3. Commercial Appliance Assumptions
- Section A.4. Electrical Infrastructure Upgrade Assumptions

A.1 Key Data Sources for Energy Consumption and Market Sizing

Natural gas consumption values were provided by the *2017 CPUC Potential and Goals* study[83] and the *2016 California Gas Report and SoCalGas Workpapers*.[84] Section A.2 and A.3 summarize the baseline data for residential and commercial appliances. Navigant calculated equivalent consumption values for both natural gas and electric technologies based on the heating load or other duty load. For space and water heating technologies, this process involved a conversion of natural gas consumption to heating load to electricity consumption using the efficiencies for natural gas and electric technologies. For clothes dryers, we used baseline consumption estimated from federal appliance standards.[85] For cooking products, we used baseline consumption estimates from FSTC calculators assuming the same cooking load (e.g., lbs. of food per day).[86]

Data inputs from the potential study are organized in the Measure Input Characterization System (MICS) database, which lists every researched technology from the study and its consumption, costs, market data across California's sixteen climate zones and four IOUs.[87] From this database, Navigant extracted all gas technologies contained in SoCalGas' service territory by customer segment and climate zone, and the following attributes of each technology:

- Technology Name
- Technology Climate Zone
- Sector and customer segment
- Efficiency Level (below-code, code, and above-code)

[83] Details on the CPUC Energy Efficiency Potential and Goals Studies are available at: http://www.cpuc.ca.gov/General.aspx?id=2013

[84] 2016 California Gas Report and supporting materials are available at: https://www.socalgas.com/regulatory/cgr.shtml

[85] Baseline energy consumption information for gas and electric dryers for new federal appliance standards estimated from November 2011 ENERGY STAR Market & Industry Scoping Report on Residential Clothes Dryers. Available at: https://www.energystar.gov/sites/default/files/asset/document/ENERGY_STAR_Scoping_Report_Residential_Clothes_Dryers.pdf

[86] Life-Cycle & Energy Cost Calculators for various kitchen appliances are available on the Food Service Technology Center website. Available at https://fishnick.com/saveenergy/tools/calculators/

[87] Details on the 2018 CPUC Energy Efficiency Potential and Goals Studies are available at: http://www.cpuc.ca.gov/General.aspx?id=6442452619

- End Use (years)
- Lifetime (years)
  - Gas consumption (therms/year)
  - Density (penetration of technology in building segment)
  - Applicability Factor (technical applicability of technology, numerical from 0 to 100%)
  - Saturation (the fraction of the end use stock that is represented by the technology within its technology group)
  - Stock (number of households or 1,000 SF)

$$Segment\ consumption = Gas\ consumption * density * applicability\ factor * saturation * stock$$

The main source for consumption data in the potential study was the CPUC's *2016 Database of Energy Efficient Resources (DEER)*.[88] Other sources used included the *California Lighting and Appliance Saturation Study (CLASS)*, the *California Residential Appliance Saturation Study (RASS)*, and the *2017 California Integrated Energy Policy Report (IEPR)*.

Table A-1 describes the sector, customer segments, and number of units derived from the CPUC Potential and Goals study.

Table A-1. Technology Customer Segment

Sector	Customer Segment	Units
Residential	Single-family, Multi-family	Households
Commercial	College, Grocery, Health, Lodging, Large Office, Small Office, Other, Refrigerated Warehouse, Restaurant, Retail, School, Warehouse	1,000 SF

Source: 2017 CPUC Potential and Goals study

Table A-2 lists all climate zones within SoCalGas service territory.

[88] Details on CPUC's 2016 Database of Energy Efficient Resources (DEER) are available at: http://www.deeresources.com/

Table A-2. CPUC Climate Zones

Climate Zone	CPUC Reference City (City in SoCalGas Territory)
Climate Zone 4	Sunnyvale (Paso Robles)
Climate Zone 5	Santa Maria
Climate Zone 6	Los Angeles
Climate Zone 7	San Diego (San Clemente area)
Climate Zone 8	El Toro
Climate Zone 9	Pasadena
Climate Zone 10	Riverside
Climate Zone 13	Fresno
Climate Zone 14	China Lake (Victorville)
Climate Zone 15	El Centro
Climate Zone 16	Mount Shasta (Palmdale)

Source: 2017 CPUC Potential and Goals study

A.2 Residential Appliance Assumptions

Table A-3. Selected Residential Gas Appliances and Unit Energy Consumption

Appliances/ End Use	Gas Technology (Installed Base)	Electric Replacement (Efficiency)	Annual Gas Consumption (Th per Year)	Heating Load (Th per Year.)	Annual Electricity Consumption (kWh per Year)	Source
Space Heating	Gas Furnace (80%)	Electric Heat Pump (COP 3)*	270	216	2,110	2016 Gas Report
Water Heating	Gas Water Heater (0.6 EF)	Electric Heat Pump Water Heater (EF 2)	170	102	1,494	2016 Gas Report
Clothes Dryer	Gas Clothes Dryer (Baseline)	Electric Clothes Dryer (Baseline)	35	N/A	939	2016 Gas Report

Navigant calculated equivalent consumption values for both natural gas and electric technologies based on the heating load or other duty load, and 29.3 kWh per therm conversion factor. For space and water heating technologies, this process involved a conversion of natural gas consumption to heating load to electricity consumption using the efficiencies for natural gas and electric technologies. For clothes dryers, we used baseline consumption estimated from federal appliance standards.

*Electric heat pump, 8.2 nominal HSPF, 10.4 adjusted HSPF for Los Angeles, conversion to 3.0 COP (HSPF / 3.412 = COP, EIA Space Heating Comparison Calculator)[89]

Sources: Various, described in table

[89] Conversion from nominal HSPF to localized HSPF from EIA Heating Fuel Comparison Calculator for Los Angeles, available at: www.ememc.com/wp-content/uploads/2014/07/Copyofheatcalc.xls

Table A-4. Residential Baseline Consumption in SoCalGas Territory

Building Segment/ End Use	Baseline Consumption in SoCalGas Territory (Million Therms /Year)	Size of Building Segment (Households)	Effective Useful Life	Natural Gas Appliance %	Source
Space Heating	1,518	5,737,640	20	98%	CPUC Potential and Goals Study
Water Heating	946	5,737,640	15	97%	CPUC Potential and Goals Study
Clothes Dryer	193	6,145,776	12	90%	CPUC Potential and Goals Study

Sources: Various, described in table

Residential appliance costs ($ per home) estimates were based on 2016 data compiled by KPF Group based on construction invoice and budget estimates from southern California builders and contractors.[90]

The estimated costs assume the combined purchase, installation, and upgrade costs, including contractor overhead, profit, permit fees, and other factors that homeowners would experience with professional installation.[91] The line-item labor and materials estimates include 30% gross margin for existing homes and 15% for new homes, and installation labor hour estimates of 7 hours for electric HPWH and 3 hours for baseline gas water heater. Navigant reviewed these costs relative to other data sources, including the Database for Energy Efficiency Resources (DEER). The equipment costs appear higher for each type of equipment relative to what was observed from the DEER sources.

Table A-5. Residential Baseline End Use Costs and Sources

Appliance/ End Use	Installed Cost per home ($)	Source
Gas Furnace (80%)	$8,177	KPF Group Appliance Data for existing home
Gas Water Heater (0.6 EF)	$1,448	KPF Group Appliance Data for existing home
Gas Clothes Dryer (Baseline)	$565	KPF Group Appliance Data for existing home

Sources: Various, described in table

Table A-6 summarizes installed costs for high efficiency gas appliances and their assumed 2030 saturation for the business-as-usual baseline. These appliances were analyzed as incremental values to the energy efficiency already included in the Potential and Goals study. We modeled this by looking at the anticipated 2030 saturation of the energy efficiency technologies in the Potential and Goals study (Mid

[90] Appliance costs from Gilbert Kitching of KPF Group in 2016. SoCalGas provided KPF Group research to Navigant for use in this report.

[91] Cost data based on line-item labor and materials estimates for southern California, including hourly estimates for labor, and time and material estimates for venting, ducting, piping, and other installation tasks.

model), and considering the remaining potential in these energy efficiency scenarios to serve as an incremental potential. This represents the technical potential for energy efficiency to support sensitivity analysis, and is not meant to represent a likely scenario.

Table A-6. Residential Gas Energy Efficiency Measures

Gas Technology (Installed Base)	Installed Cost	Assumed 2030 Saturation in Baseline Scenario	Source / Notes
Gas Furnace (92% AFUE, SEER 14 AC)	$10,213	20%	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016
Condensing Tankless Water Heater	$4,497	30%	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016[92]
ENERGY STAR Gas Clothes Dryer	$615	33%	Based on DEER Workpaper has $50 incremental cost

Source: Navigant analysis

Table A-7 summarizes installed costs for residential electric appliances. The majority of electric appliances have similar costs to the natural gas counterpart, with the exception of residential heat pump water heaters (HPWHs). As discussed in Section 2.4.2, we conducted a sensitivity analysis with lower cost HPWH products to account for potential technology and cost improvements from 2020-2030 timeframe.

Table A-7. Residential Electric End Uses Selected for Analysis

Electric Replacement (Efficiency)	Installed Cost	Source / Notes
Electric Heat Pump (SEER 14, heating seasonal performance factor (HSPF) 8.2, COP 3)[93]	$8,152	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016
Electric Heat Pump Water Heater (EF 2)	$4,313	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016
Electric Clothes Dryer (Baseline)	$509	Based on KPF Group Appliance Data for existing home, fully installed cost in 2016

Source: Navigant analysis

92 Gas tankless water heaters typically require an upgraded supply line, which can substantially increase installation costs. The installed cost data for this measure includes estimates for piping upgrade and installation, but costs can vary greatly.

93 Conversion from nominal HSPF to localized HSPF from EIA Heating Fuel Comparison Calculator for Los Angeles, available at: www.ememc.com/wp-content/uploads/2014/07/Copyofheatcalc.xls

A.3 Commercial Appliance Assumptions

Table A-8. Selected Commercial Gas Appliances and Unit Energy Consumption

Appliance/ End Use	Gas Technology (Installed Base)	Electric Replacement (Efficiency)	Annual Gas Consumption (Th/Year per 1,000 SF)	Heating Load (Th/Year)	Annual Electricity Consumption (kWh/Year per 1,000 SF)	Source
Space Heating	Gas Boiler (80%)	Electric Boiler (99%)	174	139	4117	CPUC Potential and Goals Study
Space Heating	Gas Furnace (RTU, 81%)	Electric Heat Pump (RTU, COP 3)	72	59	572	CPUC Potential and Goals Study
Water Heating	Gas Water Heater Boiler (80%)	Electric Water Heater (99%)	43	34	1021	CPUC Potential and Goals Study
Water Heating	Small Gas Water Heater (>50 gal, 0.6 EF)	Electric Heat Pump Water Heater (COP 4)	7	4	29	CPUC Potential and Goals Study
Cooking (Convection Oven)	Gas Convection Oven (FSTC Baseline)	Electric Convection Oven (FSTC Baseline)	16	N/A	191	FSTC Calculator
Cooking (Fryer)	Gas Fryer (FSTC Baseline)	Electric Fryer (FSTC Baseline)	32	N/A	352	FSTC Calculator
Clothes Dryer	Gas Clothes Dryer (Baseline)	Electric Clothes Dryer (Baseline)	4	N/A	104	CPUC Potential and Goals Study

Navigant calculated equivalent consumption values for both natural gas and electric technologies based on the heating load or other duty load, and 29.3 kWh per therm conversion factor. For space and water heating technologies, this process involved a conversion of natural gas consumption to heating load to electricity consumption using the efficiencies for natural gas and electric technologies. For clothes dryers, we used baseline consumption estimated from federal appliance standards. For cooking products, we used baseline consumption estimates from FSTC calculators assuming the same cooking load (e.g., lbs. of food per day). *Electric commercial air-source heat pump, 10.3 EER, 3.0 COP

Sources: Various, described in table

Table A-9. Commercial Baseline Consumption in SoCalGas Territory

Appliance / End Use	Baseline Consumption in SoCalGas Territory (Million Therms / Year)	Size of Building Segment (1,000 SF)	Effective Useful Life	Natural Gas Appliance %	Source
Gas Boiler (80%)	386	2,220,357	20	100%	CPUC Potential and Goals Study
Gas Furnace (RTU, 81%)	209	3,850,467	20	75%	CPUC Potential and Goals Study
Gas Water Heater Boiler (80%)	132	3,065,866	20	100%	CPUC Potential and Goals Study
Small Gas Water Heater (>50 gal, 0.6 EF)	19	3,850,467	15	75%	CPUC Potential and Goals Study
Gas Convection Oven (FSTC Baseline)	26	2,374,028	12	66%	CPUC Potential and Goals Study
Gas Fryer (FSTC Baseline)	20	694,036	12	90%	CPUC Potential and Goals Study
Gas Clothes Dryer (Baseline)	2	1,055,522	12	60%	CPUC Potential and Goals Study

Sources: Various, described in table

Table A-10. Commercial Baseline End Use Costs and Sources

Appliance/ End Use	Installed Cost per 1,000 SF ($)	Source
Gas Boiler (80%)	$632	CPUC Potential and Goals Study
Gas Furnace (RTU, 81%)	$148	CPUC Potential and Goals Study
Gas Water Heater Boiler (80%)	$21	CPUC Potential and Goals Study
Small Gas Water Heater (>50 gal, 0.6 EF)	$7.6	CPUC Potential and Goals Study
Gas Convection Oven (FSTC Baseline)	$81	CPUC Potential and Goals Study
Gas Fryer (FSTC Baseline)	$77	CPUC Potential and Goals Study
Gas Clothes Dryer (Baseline)	$27	CPUC Potential and Goals Study

Sources: Various, described in table.

Table A-11 summarizes installed costs for high efficiency gas appliances, and their assumed 2030 saturation in the Baseline Scenario. These appliances were analyzed as incremental values to the energy efficiency already included in the Potential and Goals study. We modeled this by looking at the anticipated 2030 saturation of the energy efficiency technologies in the Potential and Goals study (Mid model), and considering the remaining potential in these energy efficiency scenarios to serve as an incremental potential. This represents the technical potential for energy efficiency to support sensitivity analysis and does not reflect realistic market adoption.

Table A-11. Commercial Gas Energy Efficiency Measures

Appliance/ End Use	Gas Technology (Installed Base)	Installed Cost	Assumed 2030 Saturation in Baseline Scenario	Source / Notes
Space Heating	Condensing Boiler (94% AFUE)[94]	$893	3%	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost
Space Heating	Commercial Furnace (N/A)	N/A	0%	Condensing RTUs are emerging in cold climates and likely not cost-effective for CA
Water Heating	Condensing Boiler (94% AFUE)	$29	33%	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost
Water Heating	Small Gas Water Heater (>50 gal)	$9.2	16%	Estimate based on Potential and Goals data for tankless, 150kBtuh and 0.82EF, per 1,000 SF, total installed cost
Cooking (Convection Oven)	ENERGY STAR Gas Convection Oven	$105	61%	Estimate based on Work Paper PGECOFST101 (August 2016), per 1,000 SF, total installed cost
Cooking (Fryer)	Gas Fryer Gas Fryer	$100	59%	Estimate based on Workpaper PGECOFST102 (June 2016), per 1,000 SF, total installed cost
Clothes Dryer	ENERGY STAR Gas Clothes Dryer	$28	45%	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost

Source: Navigant analysis

Table A-12 summarizes installed costs for residential and commercial electric appliances.

[94] The source data for high efficiency gas appliances is unclear whether commercial condensing boilers include new venting as part of their installation costs.

Table A-12. Commercial Electric End Uses Selected for Analysis

Electric Replacement (Efficiency)	Installed Cost	Source / Notes
Electric Boiler (99%)	$379	Estimated 40% lower installed cost from EIA Updated Buildings Sector Appliance and Equipment Costs and Efficiencies. Nov 2016 - Scaled to match output of electric boiler[95]
Electric Heat Pump (RTU, COP 3)	$148	Assume same cost as commercial RTU with gas furnace – TRC report for City of Palo Alto[96] suggests 20% incremental cost, EIA 2016 cost estimates suggest 20% lower cost
Electric Water Heater (99%)	$12	Estimated 40% lower installed cost from EIA Updated Buildings Sector Appliance and Equipment Costs and Efficiencies. Nov 2016 - Scaled to match output of electric boiler
Electric Heat Pump Water Heater (COP 4)	$8.7	TRC Report for Palo Alto estimates 15% incremental cost premium for commercial heat pump models over gas model
Electric Convection Oven (FSTC Baseline)	$77	Estimate based on Work Paper PGECOFST101 (August 2016), per 1,000 SF, total installed cost
Electric Fryer (FSTC Baseline)	$93	Estimate based on Workpaper PGECOFST102 (June 2016), per 1,000 SF, total installed cost
Electric Clothes Dryer (Baseline)	$24	Estimate based on Potential and Goals data, per 1,000 SF, total installed cost

Source: Navigant analysis

A.4 Electrical Infrastructure Upgrade Assumptions

Table A-13 provides the estimated costs for electrical infrastructure upgrades for existing residential and commercial buildings to switch to electric appliances. This analysis assumes that an existing building has natural gas appliances, and therefore building owners may need to upgrade at least part of their electrical infrastructure to accommodate electric appliances. We analyze the impacts of different electric infrastructure upgrade cost projections, including upgrade requirements for 0% and 50% of residential and commercial buildings.

Limited information exists on the average electrical upgrade costs for existing buildings, and anecdotal estimates range widely based on the type of electrical appliance (e.g., electric HPWH, solar PV system, electric vehicle charger), age of building, contractor prices, etc. Recently constructed or new buildings will

[95] EIA. 2016. "Updated Buildings Sector Appliance and Equipment Costs and Efficiency." Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/

[96] TRC Solutions. 2016. "Palo Alto Electrification Final Report." City of Palo Alto. Available at: https://www.cityofpaloalto.org/civicax/filebank/documents/55069

likely have lower infrastructure upgrade costs than most existing buildings, or none. In addition, future changes to Title 24 codes to accommodate electric vehicles and other technologies may eliminate incremental costs for electrical infrastructure. Discussed later in this section, we conduct a sensitivity analysis for electric appliances with and without electrical upgrade costs to account for these issues.

- **Residential:** Limited information exists on the electrical upgrade requirements and costs for existing homes. An existing home may require an electrical infrastructure upgrade to accommodate an electric HPWH at an estimated cost up to $4,671. The upgrades include a higher capacity electrical panel (100 Amp to 200 Amp, estimated $3,181), branch circuit to the HPWH (15 Amp to 30 Amp, estimated $640), and utility service connection fee (estimated $850).[97] In addition, the analysis assumes that baseline buildings have air conditioning, so the electrical infrastructure for an electric heat pump for space heating is available. Some existing homes (particularly newer homes and those with a swimming pool or solar PV) may have sufficient electrical infrastructure and require minimal electrical upgrade costs. Navigant evaluated economic projections assuming 0% ($0) and 50% ($2,336 = 50% x $4,671) of homes would require electrical infrastructure upgrades.
- **Commercial**: Limited information exists on the electrical upgrade requirements and costs for existing commercial buildings. A 2016 report by TRC for City of Palo Alto provides estimates for several commercial buildings and estimates that most commercial buildings have electrical panel capacity to accommodate electric appliances, and only requires higher capacity branch circuits to meet the electric loads. For small office building, the study estimated the electrical infrastructure upgrade cost of approximately 10% of appliance installed cost ($4,399 for branch circuit upgrade to accommodate five rooftop heat pumps at a total average cost of $48,276 [$7,563 to $11,500 per unit]).[98] Navigant evaluated economic projections assuming 0% (0% upgrade cost addition) and 50% (5% upgrade cost addition = 50% x 10%) of commercial buildings would require electrical infrastructure upgrades.

[97] TRC Solutions, *Palo Alto Electrification Final Report*, City of Palo Alto, 2016. Available at: https://www.cityofpaloalto.org/civicax/filebank/documents/55069

[98] TRC Solutions. 2016.

Table A-13. Electrical Infrastructure Upgrade Cost

Building Segment	Appliance	Electrical Infrastructure Upgrade Cost	Source / Notes
Residential	Water Heating Only	\$0 - \$2,336	• The upgrades include a higher capacity electrical panel (100 Amp to 200 Amp, estimated \$3,181), branch circuit to the HPWH (15 Amp to 30 Amp, estimated \$640), and utility service connection fee (estimated \$850). • Navigant evaluated economic projections assuming 0% (\$0) and 50% (\$2,336 = 50% x \$4,671) of homes would require electrical infrastructure upgrades.
Commercial	All Appliances	0% - 5% of equipment cost	• Estimate of 10% upgrade cost including branch circuit upgrades, assumes existing electrical panel is sized for increased load. • Navigant evaluated economic projections assuming 0% (0% upgrade cost addition) and 50% (5% upgrade cost addition = 50% x 10%) of commercial buildings would require electrical infrastructure upgrades.

Source: Navigant analysis based on TRC report.[99]

A.5 Residential Water Heater Cost Estimates

Table A-14 presents a comparison of the several data sources for gas and electric residential water heaters. KPF Group estimates[100] represent builder and contractor costs in Southern California, including local tax, labor, overhead, profit margins, and other cost elements. The UC Berkeley/Berkeley Lab study[101] uses national appliance cost and installation estimates citing EIA 2016 reference.[102] The 2017 Potential and Goals Study references a 2015 Itron measure cost study for CPUC[103] including incremental appliance cost and installation estimates over baseline appliances. The economic analysis in Section 4 uses two residential HPWH estimates (KPF Group and UC Berkeley/Berkeley Lab) to present a range of results.

---

[99] TRC Solutions. 2016.

[100] Appliance costs from Gilbert Kitching of KPF Group in 2016. SoCalGas provided KPF Group research to Navigant for use in this report.

[101] Raghavan et al. 2017. “Scenarios to Decarbonize Residential Water Heating in California.” *Energy Policy, 109*. 441-451. Available at: https://rael.berkeley.edu/publication/scenarios-to-decarbonize-residential-water-heating-in-california/

[102] EIA. 2016. “Updated Buildings Sector Appliance and Equipment Costs and Efficiencies – Appendix A.” Latest version dated November 9, 2016. Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/

[103] Itron. 2014. “2010-2012 WO017 Ex Ante Measure Cost Study Final Report.” Prepared for CPUC. May 27, 2014. Available at: http://www.calmac.org/publications/2010-2012_WO017_Ex_Ante_Measure_Cost_Study_-_Final_Report.pdf

Table A-14 Comparison of Residential Water Heater Cost Estimates

Installed Cost Factors for Res. Water Heaters	KPF Group		UC Berkeley/Berkeley Lab citing EIA Measure Cost Study		2017 Potential and Goals Study citing 2014 Itron Measure Cost Study	
Home Type	Existing Home	Existing Home	Existing Home	Existing Home	Existing Home	Existing Home
Fuel Type	Natural Gas	Electricity	Natural Gas	Electricity	Natural Gas	Electricity
Baseline Water Heater	Gas Storage Water Heater	Electric HPWH	Gas Storage Water Heater	Electric HPWH	Gas Storage Water Heater	Electric
Equipment Cost	$598	$1,600	$850	$1,400	$921	$1,565
Misc. Equipment	$41	$278	N/A	N/A	N/A	N/A
Materials	$64	$346	N/A	N/A	N/A	N/A
Tax (8%, Percent of Equipment)	$56	$178	N/A	N/A	N/A	N/A
Labor	$90	$210	N/A	N/A	N/A	N/A
Warranty	$30	$30	N/A	N/A	N/A	N/A
Subtotal	$879	$2,643	N/A	N/A	N/A	N/A
Overhead (Percent of Equipment, Materials, and Labor)	$134	$377	N/A	N/A	N/A	N/A
Profit (Percent of Equipment, Materials, and Overhead)	$434	$1,294	N/A	N/A	N/A	N/A
Total Installed Cost	$1,448	$4,313	$1,350	$1,900	$1,274	$2,033
Possible Infrastructure Upgrade	N/A	$4,671	N/A	$500	N/A	N/A
Notes	Infrastructure Upgrade from TRC Solutions Report for City of Palo Alto[104]		The study cites ENERGY STAR level for gas water heater in EIA resource to align with updated federal standard. If using 0.62 EF or 2020 values in EIA resource, $525 appliance cost estimate The study cites Typical level for HPWH in 2020 study (range of $1,400-$1,700 appliance cost and installed cost of $1,510-$2,230).		Assumes like-for-like replacement rather than conversion from a gas appliance to electric appliance.	

Source: Navigant analysis

[104] TRC Solutions. 2016. "Palo Alto Electrification Final Report." City of Palo Alto. Available at: https://www.cityofpaloalto.org/civicax/filebank/documents/55069

APPENDIX B. MODELING METHODOLOGY

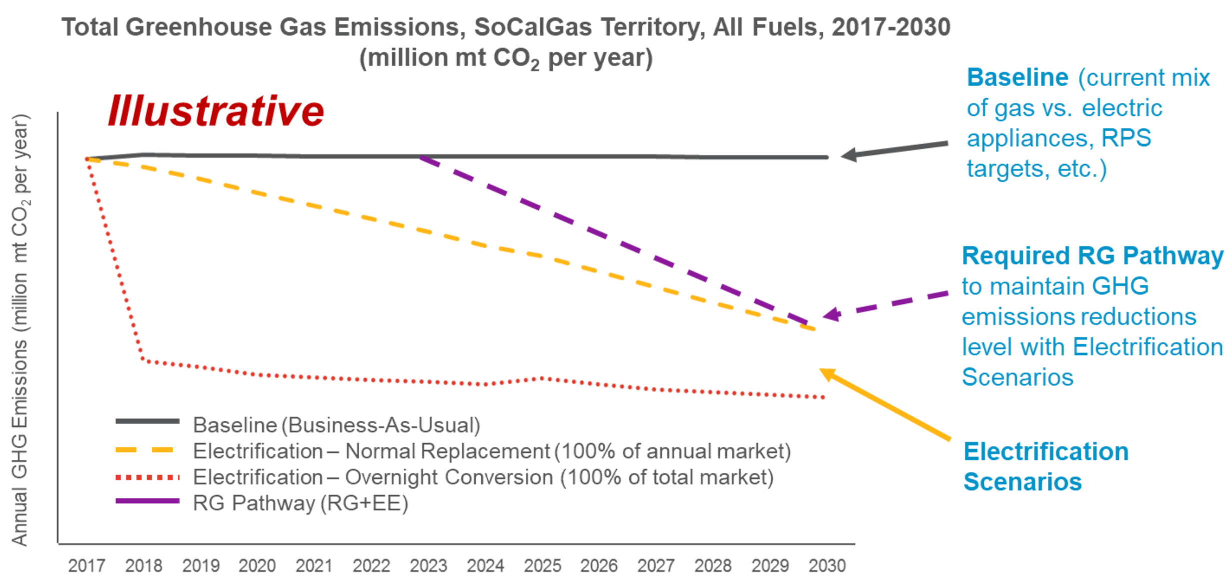
Appendix B provides details on the modeling methodology, including the modeling approach and the key data sources.

B.1 GHG Emissions Methodology

Figure B-1 provides an illustrative figure to summarize the modeling approach:

- Develop a business-as-usual baseline case for residential and commercial building stock for future years.
    - Focus on 10 most impactful appliance / building type combinations and project impacts over entire customer base.
- Develop GHG emissions timeline for natural gas and electricity based on hourly consumption patterns of baseline case and RPS timeline.
- Determine the GHG emissions reductions from converting natural gas to electricity in different scenarios: Overnight Conversion, Normal Replacement (end of life).
- Estimate the amount of RG required to maintain GHG emissions no worse than electric appliances in different scenarios.

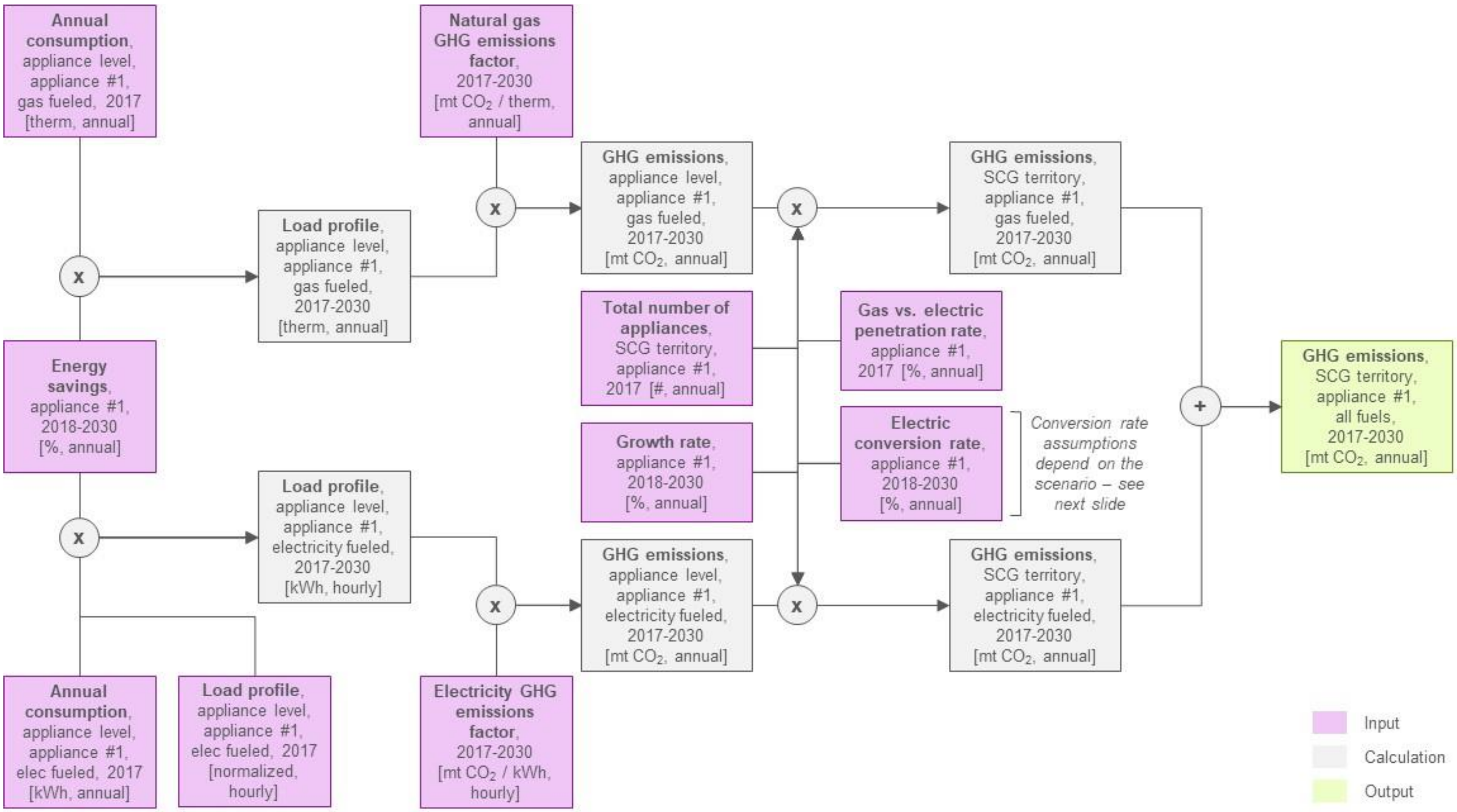
Figure B-1. California Total GHG Emissions: Historic and Projected by Scenario



Source: Navigant analysis

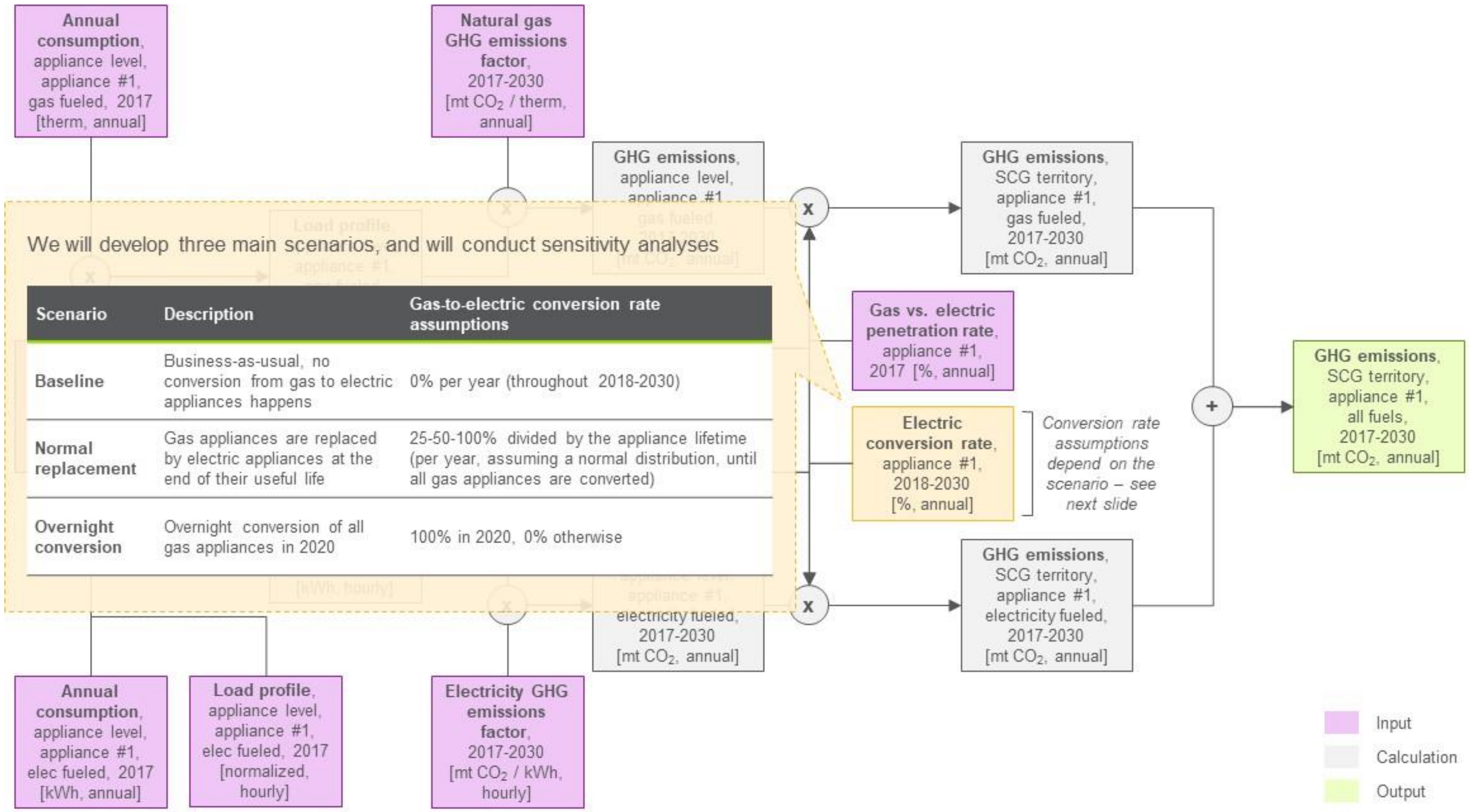
Figures B-2, B-3, and B-4 provide further details on the modeling approach for how territory-level GHG emissions are estimated for each electrification and RG scenario.

Figure B-2. California Total GHG Emissions: Historic and Projected by Scenario



Source: Navigant analysis

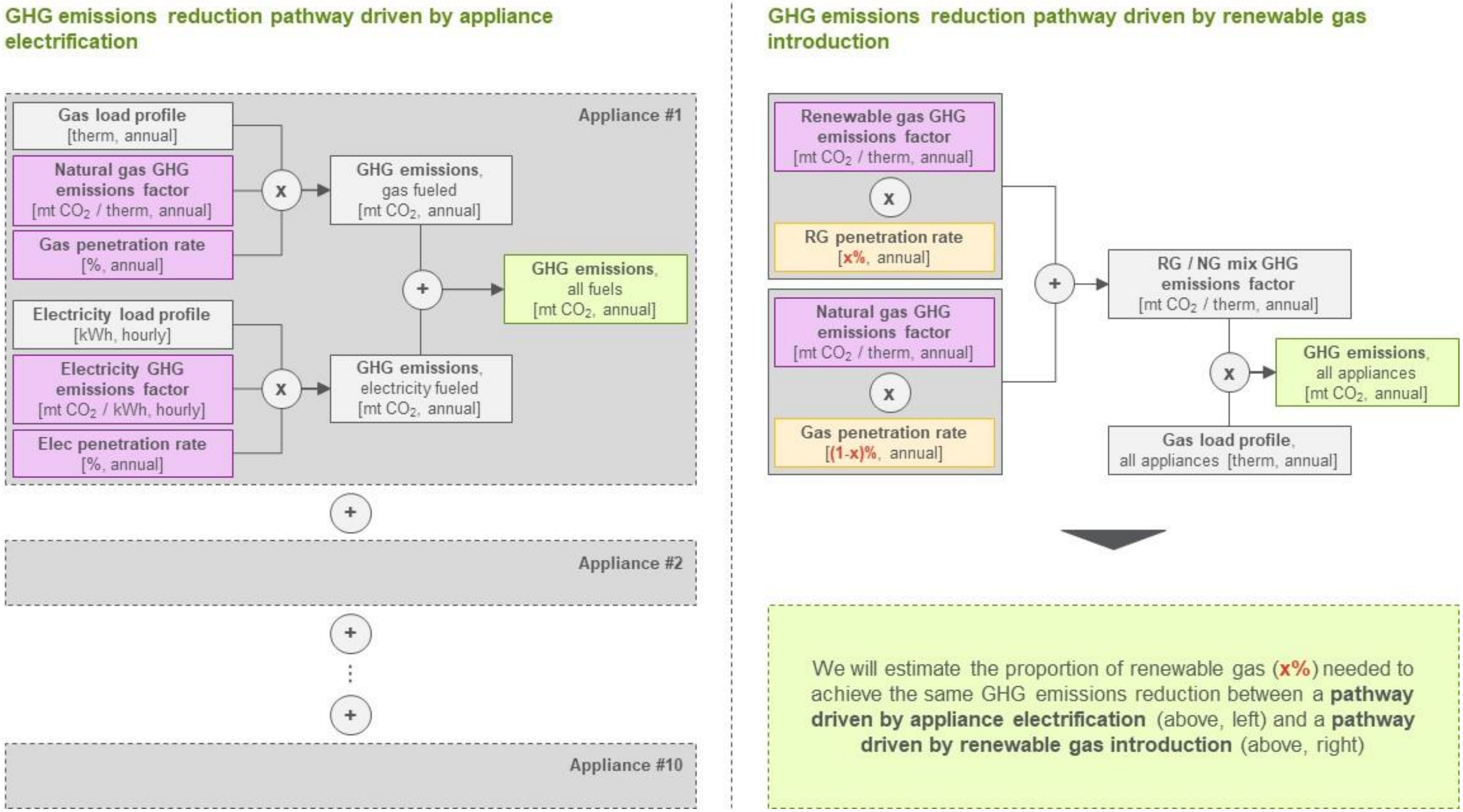
Figure B-3. California Total GHG Emissions: Historic and Projected by Scenario



Scenario	Description	Gas-to-electric conversion rate assumptions
Baseline	Business-as-usual, no conversion from gas to electric appliances happens	0% per year (throughout 2018-2030)
Normal replacement	Gas appliances are replaced by electric appliances at the end of their useful life	25-50-100% divided by the appliance lifetime (per year, assuming a normal distribution, until all gas appliances are converted)
Overnight conversion	Overnight conversion of all gas appliances in 2020	100% in 2020, 0% otherwise

Source: Navigant analysis

Figure B-4. California Total GHG Emissions: Historic and Projected by Scenario



Source: Navigant analysis

Table B-1 summarizes key data sources for the GHG emissions model.

Table B-1. Modeling Approach – Key Data Sources

Metric	Unit	Source
Annual consumption, appliance level, gas and electricity fueled, 2017	therm, kWh annual	• Average of SoCalGas installed base for efficiency, climate zone, and building type. • California Public Utilities Commission (CPUC) Potential and Goals Study
Electricity load profile, appliance level 2017	normalized, hourly	• E3 Pathways model
Energy savings, appliance level, 2018-2030	%, annual	• CPUC Potential and Goals Study, federal appliance standards, etc.
Natural gas GHG emissions factor, 2017-2030	mt CO_2 / therm, annual	• Assumed constant for baseline scenario (0.0053 mt CO_2 / therm)
Electricity GHG emissions factor, 2017-2030	mt CO_2 / kWh, hourly	• Hourly emissions factor from E3 Pathways model • Hourly electricity supply forecast for each generator type (2018-2030) • Assumes "50% RPS Updated Scoping Plan" scenario
Total number of appliances, SoCalGas territory, appliance #1, 2017	#, annual	• CPUC Potential and Goals Study
Growth rate for total number of appliances, appliance #1, 2018-2030	%, annual	• CPUC Potential and Goals Study
Gas- vs. electricity-fueled appliance penetration rate, appliance #1, 2017	%, annual	• CPUC Potential and Goals Study and other California data sources
Gas-to-electric conversion rate, appliance #1, 2018-2030	%, annual	• Scenario-based assumptions • Appliance lifetime: CPUC Potential and Goals Study
Annual consumption for replacement electric appliance, 2018-2030	kWh, annual	• Equivalent consumption determined by converting gas appliance load to electric • Electric efficiency provided by CPUC Potential and Goals Study, FSTC reports, and other California data sources

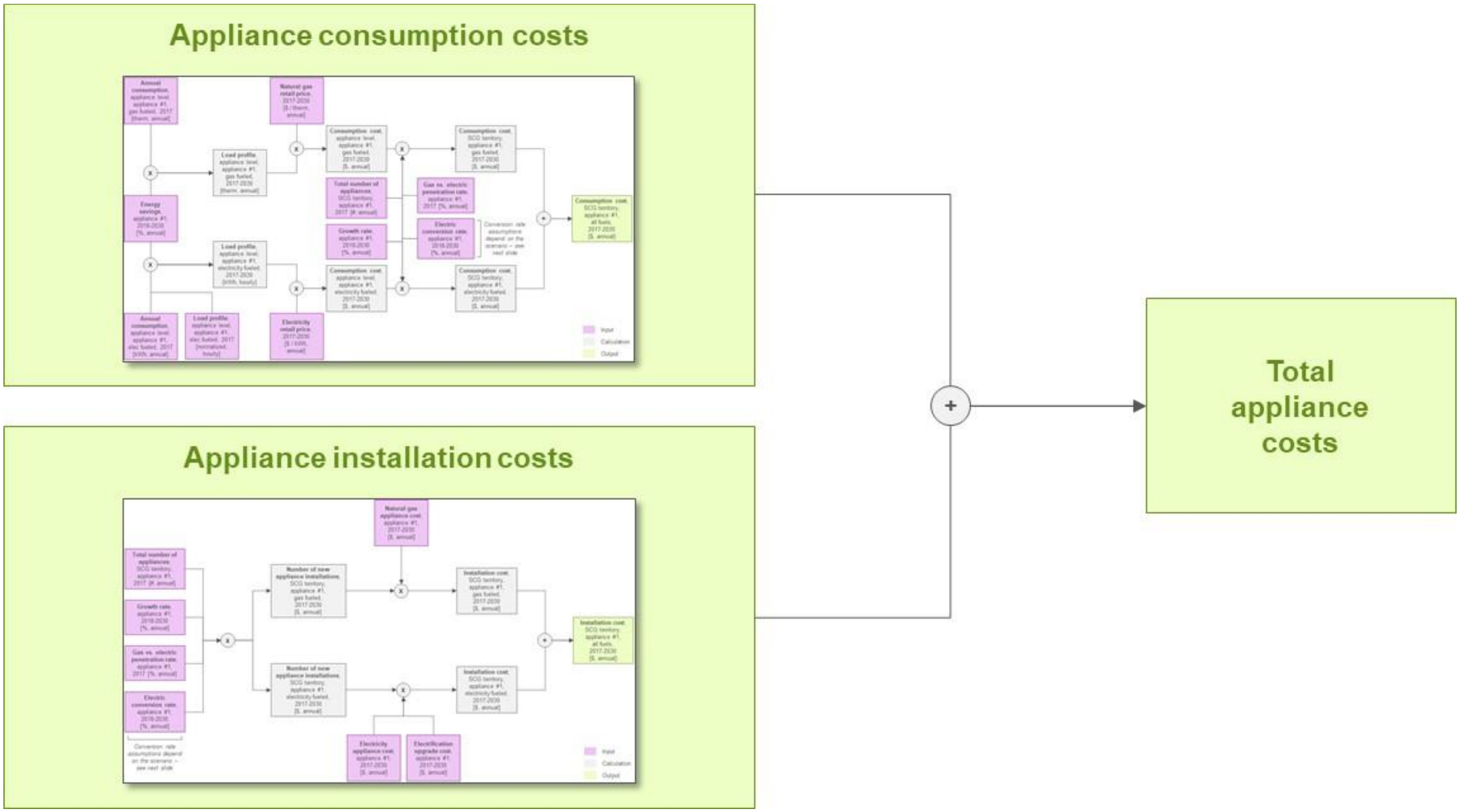
Sources: Various, described in table

Economic Evaluation Methodology

The economic modeling calculated the total costs of implementing each scenario. The total costs were broken into two categories: consumption costs and installation costs.

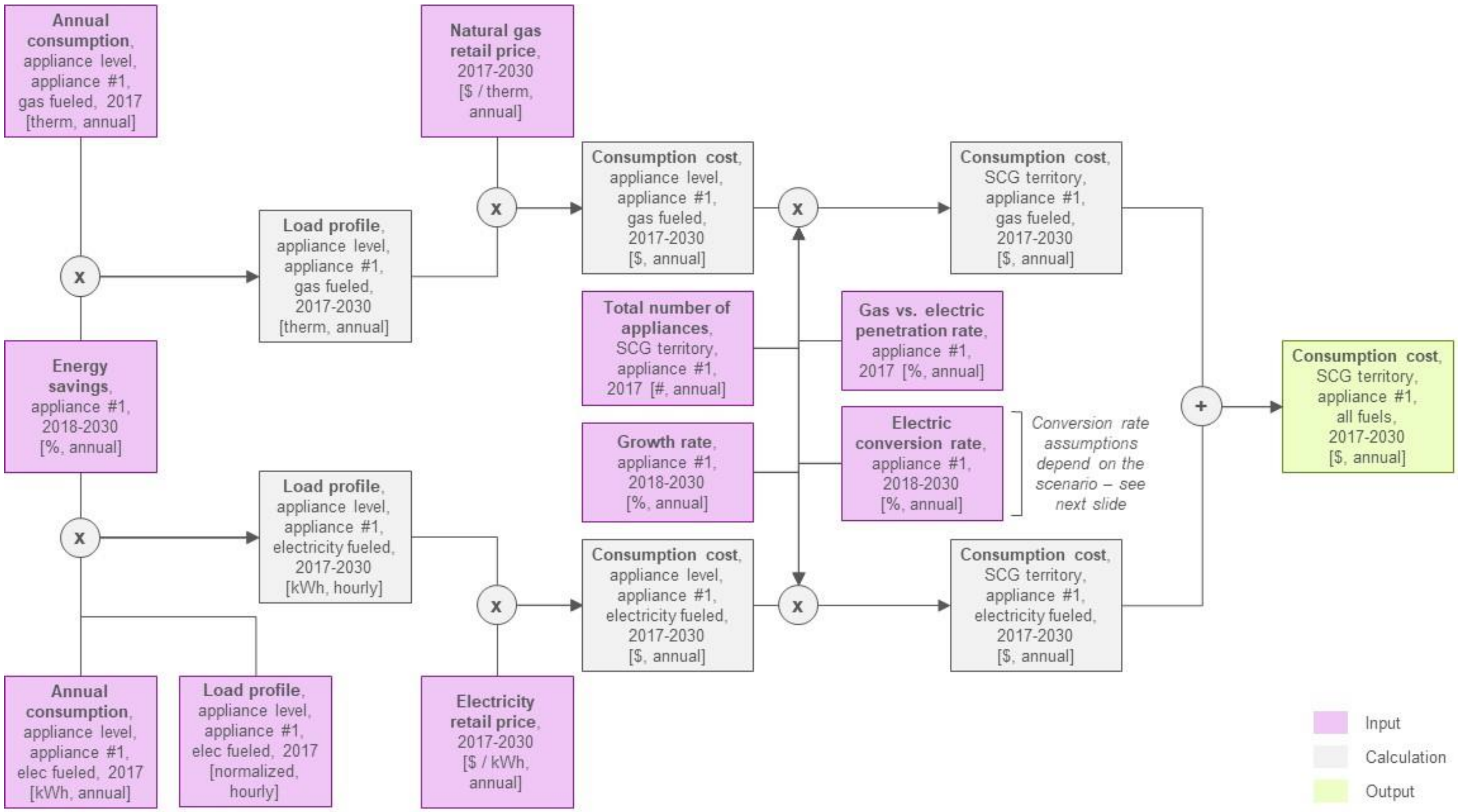
Figures B-5, B-6, B-7, and B-8 provide further details on the modeling approach for how territory-level total costs are estimated for each electrification and RG scenario.

Figure B-5. Economic Evaluation Methodology: Total Costs



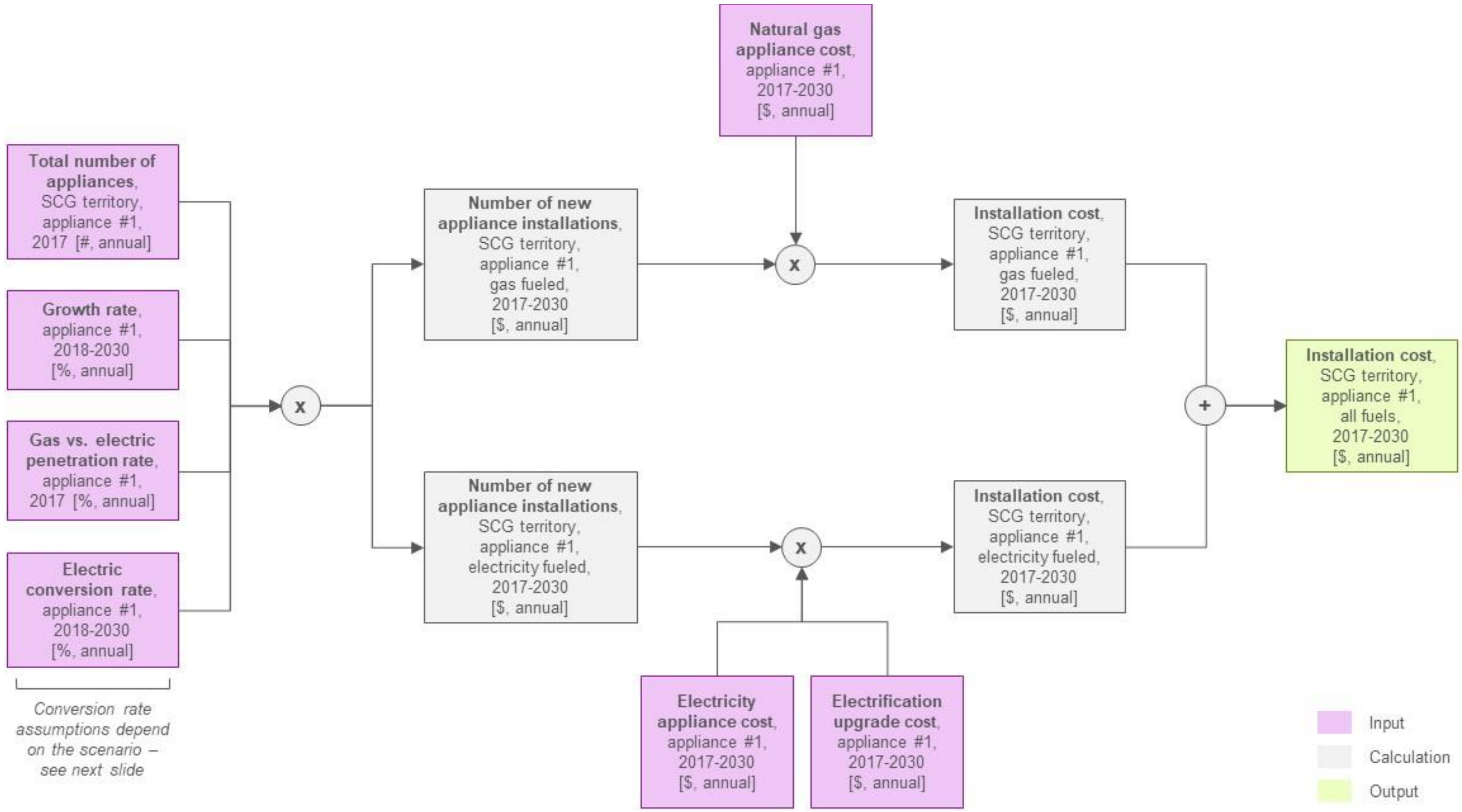
Source: Navigant analysis.

Figure B-6. Economic Evaluation Methodology: Consumption Costs



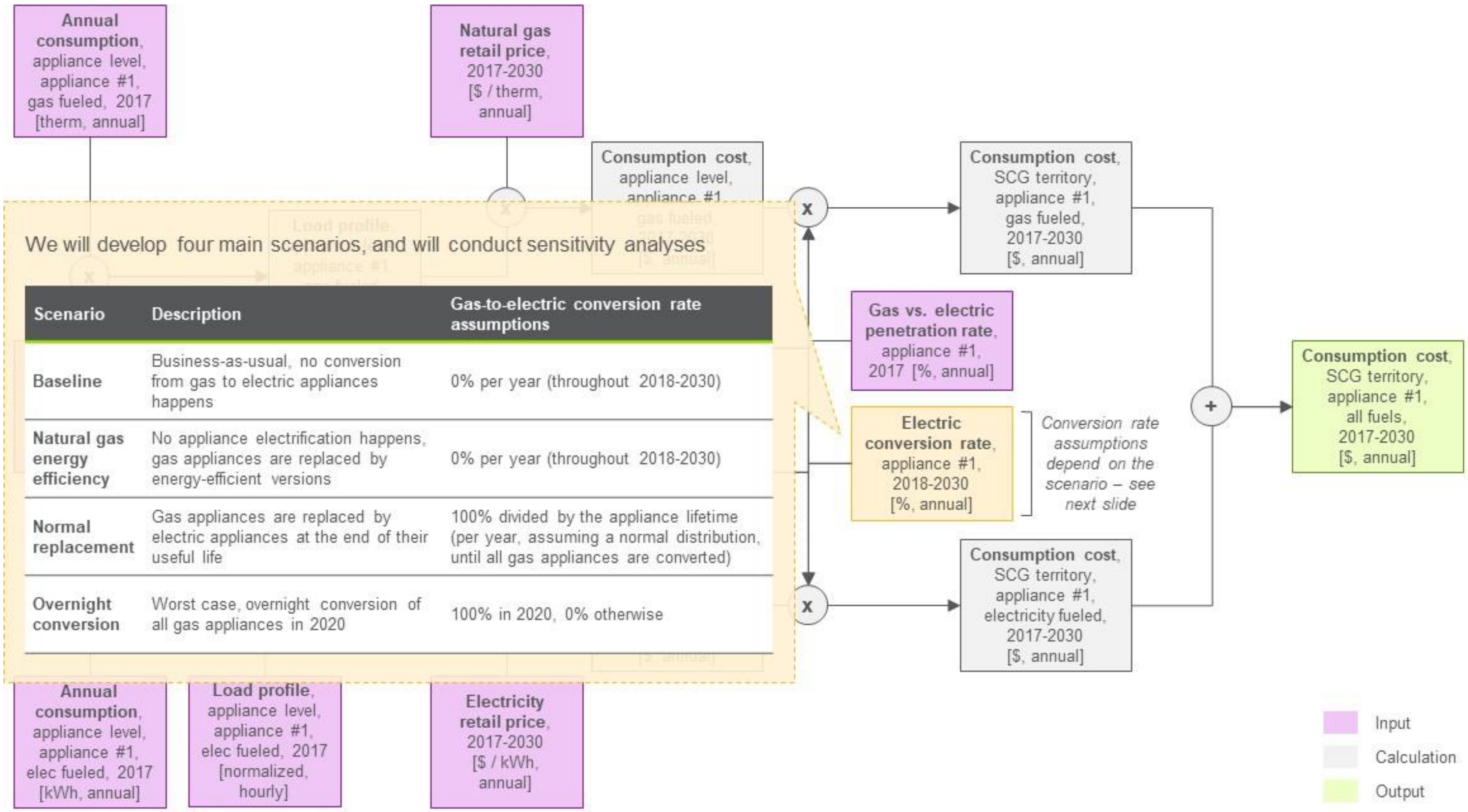
Source: Navigant analysis

Figure B-7. Economic Evaluation Methodology: Installation Costs



Source: Navigant analysis

Figure B-8. Economic Evaluation Methodology: Range of Scenarios



We will develop four main scenarios, and will conduct sensitivity analyses

Scenario	Description	Gas-to-electric conversion rate assumptions
Baseline	Business-as-usual, no conversion from gas to electric appliances happens	0% per year (throughout 2018-2030)
Natural gas energy efficiency	No appliance electrification happens, gas appliances are replaced by energy-efficient versions	0% per year (throughout 2018-2030)
Normal replacement	Gas appliances are replaced by electric appliances at the end of their useful life	100% divided by the appliance lifetime (per year, assuming a normal distribution, until all gas appliances are converted)
Overnight conversion	Worst case, overnight conversion of all gas appliances in 2020	100% in 2020, 0% otherwise

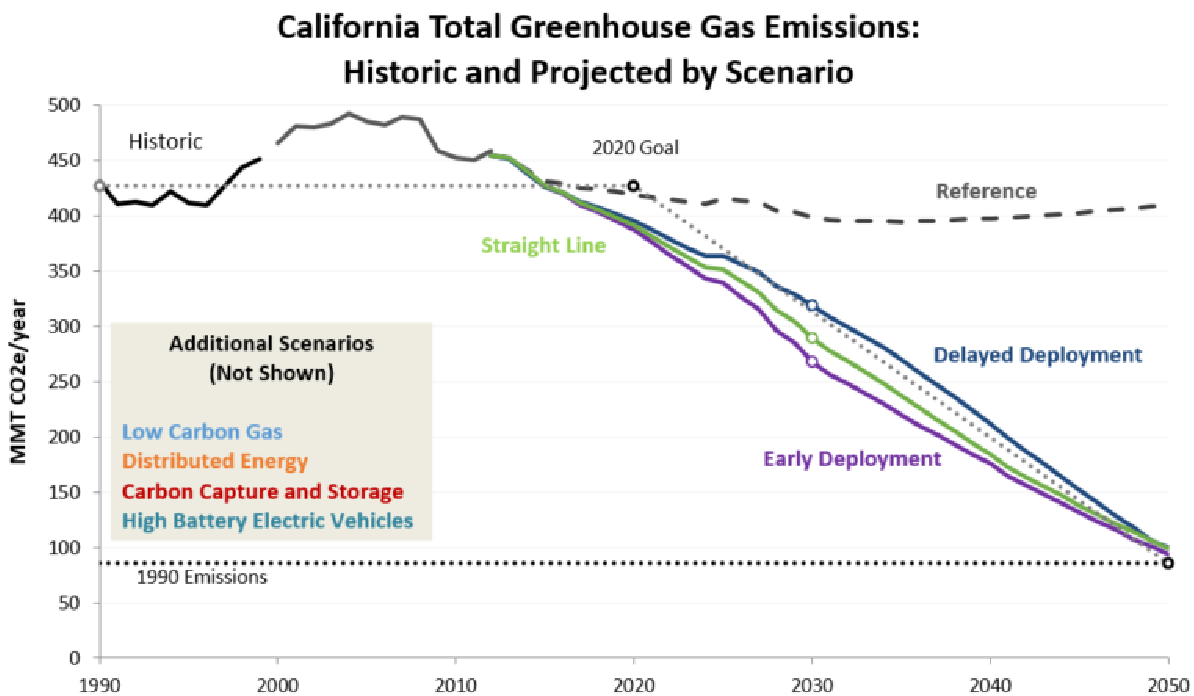
Source: Navigant analysis

APPENDIX C. E3 PATHWAYS MODEL METHODOLOGY

Appendix C describes the E3 Pathways model, the scenario Navigant has chosen for this study, and the data sources that have been directly extracted from the E3 Pathways model for this study.

Pathways model is a long horizon energy model developed by Energy and Environmental Economics, Inc. (E3)[105] as Figure C-1 shows. It can be used to assess the cost and GHG emissions impacts of California's energy demand and supply choices. The model is built to contextualize the impacts of different individual energy choices on energy supply systems (electricity grid, gas pipeline) and energy demand sectors (residential, commercial, industrial) as well as examine the combined impact of disparate strategies designed to achieve deep decarbonization targets.

Figure C-1. California Total GHG Emissions: Historic and Projected by Scenario[106]



Source: E3 Pathways Model Overview

[105] California PATHWAYS Model Framework and Methods
https://www.arb.ca.gov/cc/scopingplan/california_pathways_model_framework_jan2017.pdf

[106] E3 Pathways Model webpage: https://www.ethree.com/tools/pathways-model/

C.1 Scenario Description

E3 Pathways model provides several different scenarios, and Navigant has chosen "50% RPS Updated Scoping Plan"[107] scenario to extract the necessary data. Table C-1 listed the assumptions used in this particular scenario.

Table C-1. Assumptions for 50% RPS Updated Scoping Plan Scenario

Factor	Assumption
Electricity Supply	• 50% RPS by 2030 (not including banked RPS credits) • 18 GW behind-the-meter solar PV in 2030
Electrification of Buildings	• No new electrification
Energy Efficiency	• 2x 2015 Integrated Energy Policy Report (IEPR) Mid-Additional Achievable Energy Efficiency (AAEE) in buildings, industry and agriculture
RG for Buildings	• No renewable gas
Transportation	• 4.2 million zero emissions vehicles by 2030
Carbon Pricing	• Assumes cap-and trade program in Proposed Scoping Plan
Biofuels	• Additional biofuel needed to meet an 18 percent reduction in carbon intensity by 2030 after accounting for other transportation measures

Source: California Air Resources Board – 2017 Scoping Plan, Appendix D Pathways.

C.2 Data Resources Extracted from E3 Pathways Model

Navigant has extracted four data sources directly from E3 Pathways model:

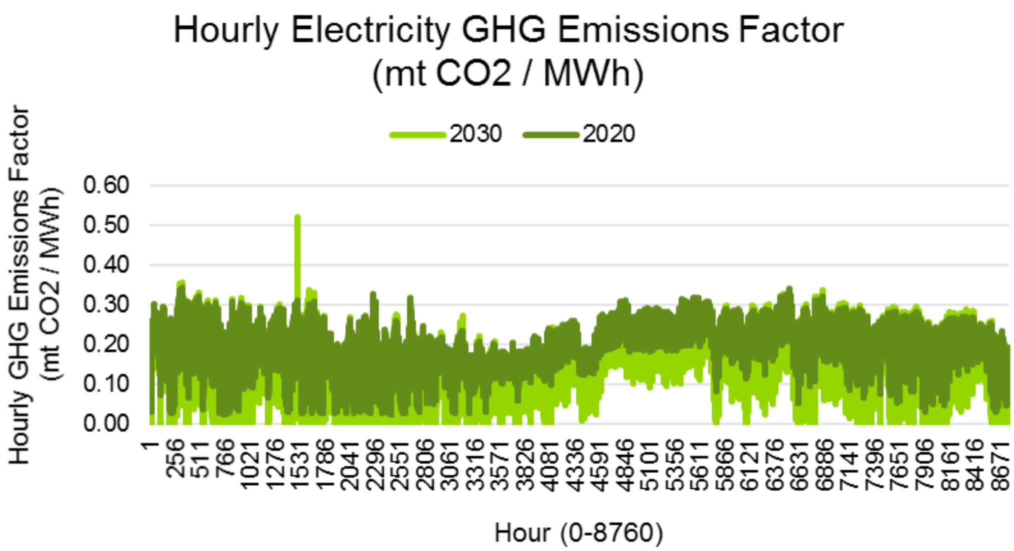
1. End-use load shapes. It includes 8 load shapes, covering water heating, space heating, space cooling, and cooking for both residential and commercial.
2. Emissions factor for each fuel (Metric Tons of CO_2 per MMBtu)
3. Hourly electrical supply database from 2018~2030 for each generation type (MW)
4. Heat rate for each generation type (Btu per kWh)

By using the above four data sources from the E3 Pathways model, Navigant obtained appliance load shapes and calculated hourly emissions factors (Metric Tons of CO_2 per kWh) from 2018 to 2030, which are inputs to the model in this study. Since the hourly electric supply from E3 Pathways model is statewide, Navigant has adjusted reflect the emissions for delivered electricity in SoCalGas territory, described in Section 2.2.

[107]California Air Resources Board – 2017 Scoping Plan, Appendix D Pathways https://www.arb.ca.gov/cc/scopingplan/2030sp_appd_pathways_final.pdf

Figure C-2 provides the hourly electricity emissions factors in 2020 and 2030 to show the seasonal differences in electricity supply (e.g., summer has higher emissions factors) and trends with greater RPS penetration (e.g., many hours in 2030 have zero emissions due to high renewable penetration).

Figure C-2. Example Electricity GHG Emissions Factor



Source: Navigant analysis

APPENDIX D. DETAILED RESULTS BY ELECTRIFICATION SCENARIO

Appendix D provides GHG emissions results, reductions, and RG introduction timeline for each electrification scenario:

- Table D-1. Total GHG Emissions, All Appliances, 2017-2030
- Table D-2. Total GHG Emissions Reductions Percentage, All Appliances, 2017-2030
- Table D-3. RG Introduction Timeline Under Different Scenarios (% of Buildings Gas Use)
- Table D-4. RG Introduction Timeline Under Different Scenarios (% of Total Gas Throughput)

D.1 Total GHG Emissions and Reductions for Each Scenario

Table D-1 presents the total GHG emissions for each electrification scenario.

Table D-1. Total GHG Emissions, All Appliances, 2017-2030

Year	Total GHG Emissions, All Appliances, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	18.8	18.8	18.8	18.8	18.8
2018	18.8	8.9	18.2	18.5	18.6
2019	18.7	8.5	17.6	18.1	18.4
2020	18.6	8.1	16.8	17.7	18.2
2021	18.5	7.9	16.1	17.3	17.9
2022	18.4	7.8	15.4	16.9	17.6
2023	18.2	7.6	14.7	16.5	17.4
2024	18.1	7.5	13.9	16.0	17.1
2025	18.0	7.7	13.4	15.7	16.9
2026	18.0	7.4	12.6	15.3	16.6
2027	17.9	7.1	11.9	14.9	16.4
2028	17.8	7.0	11.1	14.5	16.2
2029	17.8	6.9	10.4	14.1	16.0
2030	17.8	6.7	9.7	13.7	15.7

Source: Navigant analysis

Table D-2 presents GHG emissions reductions percentage for each electrification scenario.

Table D-2. Total GHG Emissions Reductions Percentage, All Appliances, 2017-2030

Year	Total GHG Emissions Reductions Percentage, All Appliances, 2017-2030 (%)			
	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	0%	0%	0%	0%
2018	53%	3%	1%	1%
2019	54%	6%	3%	2%
2020	56%	9%	5%	2%
2021	57%	13%	6%	3%
2022	58%	16%	8%	4%
2023	58%	20%	10%	5%
2024	59%	23%	12%	6%
2025	57%	26%	13%	6%
2026	59%	30%	15%	7%
2027	60%	34%	17%	8%
2028	61%	38%	19%	9%
2029	61%	41%	21%	10%
2030	62%	45%	23%	11%

Source: Navigant analysis

D.2 RG Introduction Timeline Under Different Scenarios

Tables D-3 and D-4 present the required RG introduction timeline to meet the 2030 GHG emissions reductions targets, presented as both percentages of buildings gas use and total SoCalGas gas throughput. These timelines assume initial RG introduction in 2020 and a linear increase in supply to the 2030 target.

Table D-3. RG Introduction Timeline Under Different Scenarios (% of Buildings Gas Use)

Year	RG Introduction Timeline Under Different Scenarios (% of Buildings Gas Use)			
	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	0%	0%	0%	0%
2018	0%	0%	0%	0%
2019	0%	0%	0%	0%
2020	6%	4%	2%	1%
2021	11%	8%	4%	2%
2022	17%	13%	6%	3%
2023	23%	17%	8%	4%
2024	29%	21%	10%	5%
2025	34%	25%	13%	7%
2026	40%	29%	15%	8%
2027	46%	33%	17%	9%
2028	52%	38%	19%	10%
2029	57%	42%	21%	11%
2030	63%	46%	23%	12%

Source: Navigant analysis

Table D-4. RG Introduction Timeline Under Different Scenarios (% of Total Gas Throughput)

Year	RG Introduction Timeline Under Different Scenarios (% of Total Gas Throughput)			
	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	0%	0%	0%	0%
2018	0%	0%	0%	0%
2019	0%	0%	0%	0%
2020	2%	1%	1%	0%
2021	4%	3%	1%	1%
2022	6%	4%	2%	1%
2023	8%	6%	3%	2%
2024	10%	7%	4%	2%
2025	12%	9%	4%	2%
2026	14%	10%	5%	3%
2027	16%	12%	6%	3%
2028	18%	13%	6%	3%
2029	20%	14%	7%	4%
2030	22%	16%	8%	4%

Source: Navigant analysis

APPENDIX E. DETAILED RESULTS BY APPLIANCE

Appendix E provides GHG emissions results for each building segment, appliance, and fuel type combination with each electrification scenario:

Section E.1. Residential Appliances

- Table E-1. Total GHG Emissions for Residential Space Heating by Scenario
- Table E-2. Total GHG Emissions for Residential Water Heating by Scenario
- Table E-3. Total GHG Emissions for Residential Clothes Drying by Scenario

Section E.2. Commercial Appliances

- Table E-4. Total GHG Emissions for Commercial HVAC Boiler by Scenario
- Table E-5. Total GHG Emissions for Commercial Furnace by Scenario
- Table E-6. Total GHG Emissions for Commercial Water Heating Boiler by Scenarios
- Table E-7. Total GHG Emissions for Commercial Small Water Heater by Scenario
- Table E-8. Total GHG Emissions for Commercial Convection Oven by Scenario
- Table E-9. Total GHG Emissions for Commercial Fryer by Scenario
- Table E-10. Total GHG Emissions for Commercial Clothes Drying by Scenario

Appendix A outlines the key characteristics and baseline energy consumption for each building segment, appliance, and fuel type combination.

E.1 Residential Appliances

Table E-1. Total GHG Emissions for Residential Space Heating by Scenario

Year	Total GHG Emissions for Residential Space Heating with Difference Scenarios, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	8.1	8.1	8.1	8.1	8.1
2018	8.1	2.5	7.8	8.0	8.0
2019	8.1	2.5	7.5	7.8	8.0
2020	8.1	2.4	7.2	7.6	7.8
2021	8.0	2.3	6.9	7.4	7.7
2022	8.0	2.3	6.5	7.3	7.6
2023	7.9	2.2	6.2	7.1	7.5
2024	7.9	2.2	5.9	6.9	7.4
2025	7.8	2.3	5.6	6.7	7.3
2026	7.8	2.2	5.3	6.5	7.2
2027	7.8	2.1	5.0	6.4	7.1
2028	7.8	2.1	4.6	6.2	7.0
2029	7.7	2.1	4.3	6.0	6.9
2030	7.7	2.0	4.0	5.9	6.8

Source: Navigant analysis

Table E-2. Total GHG Emissions for Residential Water Heating by Scenario

Year	Total GHG Emissions for Residential Water Heating with Difference Scenarios, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	5.1	5.1	5.1	5.1	5.1
2018	5.1	1.9	4.9	5.0	5.1
2019	5.1	1.8	4.7	4.9	5.0
2020	5.1	1.7	4.4	4.8	4.9
2021	5.1	1.7	4.2	4.6	4.8
2022	5.0	1.7	3.9	4.5	4.8
2023	5.0	1.6	3.7	4.3	4.7
2024	5.0	1.6	3.4	4.2	4.6
2025	4.9	1.6	3.2	4.1	4.5
2026	4.9	1.6	2.9	3.9	4.4
2027	4.9	1.5	2.7	3.8	4.3
2028	4.9	1.5	2.4	3.6	4.3
2029	4.9	1.5	2.2	3.5	4.2
2030	4.9	1.4	1.9	3.4	4.1

Source: Navigant analysis

Table E-3. Total GHG Emissions for Residential Clothes Drying by Scenario

Year	Total GHG Emissions for Residential Clothes Drying with Difference Scenarios, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	1.2	1.2	1.2	1.2	1.2
2018	1.2	1.2	1.2	1.2	1.2
2019	1.1	1.2	1.2	1.1	1.1
2020	1.1	1.1	1.1	1.1	1.1
2021	1.1	1.1	1.1	1.1	1.1
2022	1.1	1.1	1.1	1.1	1.1
2023	1.1	1.1	1.1	1.1	1.1
2024	1.1	1.0	1.1	1.1	1.1
2025	1.1	1.1	1.1	1.1	1.1
2026	1.1	1.0	1.0	1.1	1.1
2027	1.1	1.0	1.0	1.0	1.1
2028	1.1	1.0	1.0	1.0	1.1
2029	1.1	0.9	0.9	1.0	1.0
2030	1.1	0.9	0.9	1.0	1.0

Source: Navigant analysis

E.2 Commercial Appliances

Table E-4. Total GHG Emissions for Commercial HVAC Boiler by Scenario

Year	Total GHG Emissions for Commercial HVAC Boiler with Difference Scenarios, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	2.1	2.1	2.1	2.1	2.1
2018	2.0	1.9	2.0	2.0	2.0
2019	2.0	1.8	2.0	2.0	2.0
2020	2.0	1.7	2.0	2.0	2.0
2021	2.0	1.7	1.9	2.0	2.0
2022	2.0	1.6	1.9	1.9	2.0
2023	2.0	1.6	1.9	1.9	1.9
2024	2.0	1.6	1.8	1.9	1.9
2025	2.0	1.6	1.8	1.9	1.9
2026	1.9	1.5	1.8	1.9	1.9
2027	1.9	1.5	1.7	1.8	1.9
2028	1.9	1.4	1.7	1.8	1.9
2029	1.9	1.4	1.6	1.8	1.8
2030	1.9	1.4	1.6	1.7	1.8

Source: Navigant analysis

Table E-5. Total GHG Emissions for Commercial Furnace by Scenario

Year	Total GHG Emissions for Commercial Furnace with Difference Scenarios, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	1.2	1.2	1.2	1.2	1.2
2018	1.2	0.5	1.2	1.2	1.2
2019	1.2	0.4	1.1	1.2	1.2
2020	1.2	0.4	1.1	1.1	1.2
2021	1.2	0.4	1.0	1.1	1.1
2022	1.2	0.4	1.0	1.1	1.1
2023	1.2	0.4	0.9	1.0	1.1
2024	1.2	0.4	0.9	1.0	1.1
2025	1.1	0.4	0.8	1.0	1.1
2026	1.1	0.4	0.8	1.0	1.1
2027	1.1	0.4	0.7	0.9	1.0
2028	1.1	0.3	0.7	0.9	1.0
2029	1.1	0.3	0.7	0.9	1.0
2030	1.1	0.3	0.6	0.9	1.0

Source: Navigant analysis

Table E-6. Total GHG Emissions for Commercial Water Heating Boiler by Scenario

Year	Total GHG Emissions for Commercial Water Heating Boiler with Difference Scenarios, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	0.7	0.7	0.7	0.7	0.7
2018	0.7	0.7	0.7	0.7	0.7
2019	0.7	0.6	0.7	0.7	0.7
2020	0.7	0.6	0.7	0.7	0.7
2021	0.7	0.6	0.7	0.7	0.7
2022	0.7	0.6	0.7	0.7	0.7
2023	0.7	0.6	0.6	0.7	0.7
2024	0.7	0.5	0.6	0.6	0.7
2025	0.7	0.6	0.6	0.6	0.7
2026	0.7	0.5	0.6	0.6	0.6
2027	0.7	0.5	0.6	0.6	0.6
2028	0.7	0.5	0.6	0.6	0.6
2029	0.7	0.5	0.6	0.6	0.6
2030	0.7	0.5	0.5	0.6	0.6

Source: Navigant analysis

Table E-7. Total GHG Emissions for Commercial Small Water Heating by Scenario

Year	Total GHG Emissions for Commercial Small Water Heating with Difference Scenarios, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	0.13	0.13	0.13	0.13	0.13
2018	0.13	0.04	0.12	0.13	0.13
2019	0.13	0.04	0.12	0.12	0.13
2020	0.13	0.04	0.11	0.12	0.12
2021	0.13	0.04	0.10	0.11	0.12
2022	0.12	0.04	0.09	0.11	0.12
2023	0.12	0.03	0.09	0.11	0.11
2024	0.12	0.03	0.08	0.10	0.11
2025	0.12	0.03	0.08	0.10	0.11
2026	0.12	0.03	0.07	0.09	0.11
2027	0.12	0.03	0.06	0.09	0.11
2028	0.12	0.03	0.05	0.09	0.10
2029	0.12	0.03	0.05	0.08	0.10
2030	0.12	0.03	0.04	0.08	0.10

Source: Navigant analysis

Table E-8. Total GHG Emissions for Commercial Convection Oven by Scenario

Year	Total GHG Emissions for Commercial Convection Oven with Difference Scenarios, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	0.17	0.17	0.17	0.17	0.17
2018	0.16	0.09	0.16	0.16	0.16
2019	0.16	0.09	0.15	0.15	0.16
2020	0.16	0.08	0.14	0.15	0.15
2021	0.16	0.08	0.13	0.14	0.15
2022	0.16	0.08	0.12	0.14	0.15
2023	0.15	0.08	0.11	0.13	0.14
2024	0.15	0.07	0.11	0.13	0.14
2025	0.15	0.07	0.10	0.13	0.14
2026	0.15	0.07	0.09	0.12	0.14
2027	0.15	0.07	0.08	0.11	0.13
2028	0.15	0.07	0.07	0.11	0.13
2029	0.15	0.06	0.06	0.10	0.13
2030	0.15	0.06	0.06	0.10	0.12

Source: Navigant analysis

Table E-9. Total GHG Emissions for Commercial Fryer by Scenario

Year	Total GHG Emissions for Commercial Fryer with Difference Scenarios, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	0.11	0.11	0.11	0.11	0.11
2018	0.11	0.05	0.11	0.11	0.11
2019	0.11	0.05	0.10	0.10	0.11
2020	0.11	0.04	0.09	0.10	0.10
2021	0.11	0.04	0.09	0.10	0.10
2022	0.11	0.04	0.08	0.09	0.10
2023	0.11	0.04	0.07	0.09	0.10
2024	0.11	0.04	0.07	0.09	0.10
2025	0.11	0.04	0.06	0.08	0.09
2026	0.10	0.04	0.05	0.08	0.09
2027	0.10	0.04	0.05	0.08	0.09
2028	0.10	0.04	0.04	0.07	0.09
2029	0.10	0.03	0.03	0.07	0.09
2030	0.10	0.03	0.03	0.06	0.08

Source: Navigant analysis

Table E-10. Total GHG Emissions for Commercial Clothes Dryer by Scenario

Year	Total GHG Emissions for Commercial Clothes Dryer with Difference Scenarios, 2017-2030 (million mt CO_2)				
	Baseline	Overnight conversion	Normal replacement (100%)	Normal replacement (50%)	Normal replacement (25%)
2017	0.023	0.023	0.023	0.023	0.023
2018	0.022	0.022	0.022	0.022	0.022
2019	0.022	0.021	0.022	0.022	0.022
2020	0.021	0.020	0.021	0.021	0.021
2021	0.021	0.019	0.020	0.021	0.021
2022	0.021	0.019	0.020	0.020	0.020
2023	0.020	0.018	0.019	0.020	0.020
2024	0.020	0.018	0.019	0.019	0.020
2025	0.020	0.018	0.019	0.019	0.020
2026	0.020	0.017	0.018	0.019	0.019
2027	0.019	0.016	0.017	0.018	0.019
2028	0.019	0.016	0.016	0.018	0.018
2029	0.019	0.015	0.015	0.017	0.018
2030	0.018	0.015	0.015	0.016	0.017

Source: Navigant analysis

APPENDIX F. UTILITY COST PROJECTIONS

Appendix F provides projections for gas and electricity utility rates.

- Table F-1. Projected Electricity Rates 2017-2030 ($/kWh)
- Table F-2. Projected Gas Rates 2017-2030 ($/kWh)

Table F-1. Projected Electricity Rates 2017-2030 ($/kWh)

Year	Projected Electricity Rates ($/kWh)	
	SCE IEPR Rates	High Electricity Rates
2017	$0.18	$0.18
2018	$0.18	$0.18
2019	$0.18	$0.19
2020	$0.18	$0.19
2021	$0.19	$0.20
2022	$0.19	$0.20
2023	$0.18	$0.21
2024	$0.18	$0.22
2025	$0.19	$0.22
2026	$0.19	$0.23
2027	$0.19	$0.24
2028	$0.19	$0.24
2029	$0.19	$0.25
2030	$0.19	$0.26

SCE IEPR based on February 2018 IEPR values.[108] High Electricity Rates based on projected 3% annual growth rate based on 2016 LADWP IRP[109]

Source: Navigant analysis

[108] Feb 21 2018 Workshop for Final 2017 IEPR Adoption, Mid-Mid Forecast http://www.energy.ca.gov/2017_energypolicy/documents/2018-02-21_business_meeting/2018-02-21_middemandcase_forecst.php

[109] https://www.ladwp.com/ladwp/faces/wcnav_externalId/a-p-doc?_adf.ctrl-state=iirytk0lc_4&_afrLoop=35208544433395

Table F-2. Projected Gas Rates 2017-2030 ($/therm)

Year	Projected Gas Rates 2017-2030 ($/therm)						
	SCG IEPR Rates (1)	RG Rate (In-State) (2)	Blended Gas Rate (In-State) (3)	RG Rate (Out-of-State) (4)	Blended Gas Rate (Out-of-State) (5)	RG Rate (Mixed 25% In-State / 75% Out-of-State) (6)	Blended Gas Rate (Mixed RG Source) (7)
2017	$0.93	$1.34	$0.93	$1.03	$0.93	$1.11	$0.93
2018	$0.94	$1.34	$0.94	$1.03	$0.94	$1.11	$0.94
2019	$0.97	$1.34	$0.97	$1.03	$0.97	$1.11	$0.97
2020	$0.99	$1.54	$1.01	$1.07	$0.99	$1.19	$0.99
2021	$0.99	$1.74	$1.06	$1.12	$1.00	$1.27	$1.02
2022	$1.00	$1.94	$1.12	$1.16	$1.02	$1.36	$1.05
2023	$1.01	$2.14	$1.20	$1.20	$1.04	$1.44	$1.08
2024	$1.02	$2.34	$1.29	$1.25	$1.07	$1.52	$1.12
2025	$1.03	$2.54	$1.41	$1.29	$1.09	$1.60	$1.17
2026	$1.04	$2.74	$1.54	$1.34	$1.13	$1.69	$1.23
2027	$1.05	$2.94	$1.68	$1.38	$1.16	$1.77	$1.29
2028	$1.06	$3.14	$1.84	$1.42	$1.19	$1.85	$1.36
2029	$1.07	$3.34	$2.02	$1.47	$1.23	$1.93	$1.43
2030	$1.08	$3.54	$2.21	$1.51	$1.28	$2.02	$1.51

RG costs from 2017 ICF report[110] and 2018 ICF memo to SoCalGas.[111] One therm equals 0.10 MMBtu.
1. Based on February 2018 IEPR values
2. Assumes 46% RG, for $1-$4 per therm in-state RG supply cost, $0.53/therm distribution
3. Blended rate for 46% RG, for $1-$4 per therm in-state RG supply cost, $0.53/therm distribution
4. Assumes 46% RG, for $0.5-$1.2 per therm out-of-state RG supply cost, $0.53/therm distribution
5. Blended rate for 46% RG, for $0.5-$1.2 per therm out-of-state RG supply cost, $0.53/therm distribution
6. Assumes 46% RG, for 25% In-State RG, 75% Out-of-State RG based on ICF Memo (May 2018)
7. Blended rate for 46% RG, for 25% In-State RG, 75% Out-of-State RG based on ICF Memo (May 2018)
Source: Navigant analysis

[110] Sheehy, Philip and Rosenfeld, Jeffrey. ICF. 2017. "Design Principles for a Renewable Gas Standard." Available at: https://www.icf.com/resources/white-papers/2017/design-principles-for-renewable-gas

[111] Memo from Philip Sheehy of ICF to SoCalGas. "Potential RNG Supply to California." May 2018. Provided by SoCalGas for this analysis.

APPENDIX G. ECONOMIC RESULTS BY SCENARIO

Appendix G provides the economic results for each GHG emissions reduction strategy to equal the GHG emissions reductions in 2030 from Normal Replacement 100%, 50%, and 25% scenarios.

Section G.1. GHG Emissions Costs for Equal GHG Emissions Reductions in 2030 from Normal Replacement 100% Scenario

- Table G-1. Combined Annual Cost (Annualized Over 15 Years.)
- Table G-2. Cost-Effectiveness of GHG Emissions Reduction Strategies in 2018-2030

Section G.2. GHG Emissions Costs for Equal GHG Emissions Reductions in 2030 from Normal Replacement 50% Scenario

- Table G-3. Combined Annual Cost (Annualized Over 15 Years.)
- Table G-4. Cost-Effectiveness of GHG Emissions Reduction Strategies 2018-2030

Section G.3. GHG Emissions Costs for Equal GHG Emissions Reductions in 2030 from Normal Replacement 25% Scenario

- Table G-5. Combined Annual Cost (Annualized Over 15 Years)
- Table G-6. Cost-Effectiveness of GHG Emissions Reduction Strategies 2018-2030

G.1 GHG Emissions Cost to Equal GHG Emissions Reductions in 2030 from Normal Replacement 100% Scenario

Table G-1. Combined Annual Cost (Annualized Over 15 Years) – Normal Replacement 100% Scenario

Year	Baseline (IEPR Gas & Elec Rates)	Renewable Gas (In-State Supply)	Renewable Gas (In-State) + Energy Efficiency	Renewable Gas (Out-of-State Supply)	Renewable Gas (Mixed In-State / Out-of-State)	Electrification (ROB, IEPR Rates, incl. Upgrades)	Electrification (ROB, High Rates, incl. Upgrades)	Electrification (ROB, IEPR Rates, w/o Upgrades)	Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)
2017	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6
2018	$3.9	$3.9	$3.9	$3.9	$3.9	$4.2	$4.2	$4.2	$4.1
2019	$4.2	$4.2	$4.3	$4.2	$4.2	$4.9	$4.9	$4.8	$4.7
2020	$4.5	$4.5	$4.7	$4.5	$4.5	$5.5	$5.6	$5.4	$5.2
2021	$4.7	$4.9	$5.1	$4.7	$4.8	$6.1	$6.3	$5.9	$5.7
2022	$4.9	$5.3	$5.5	$5.0	$5.1	$6.7	$7.0	$6.4	$6.1
2023	$5.2	$5.8	$6.0	$5.3	$5.4	$7.3	$7.7	$6.9	$6.6
2024	$5.4	$6.3	$6.5	$5.6	$5.7	$7.9	$8.4	$7.5	$7.0
2025	$5.6	$6.9	$7.0	$5.9	$6.1	$8.5	$9.2	$8.0	$7.5
2026	$5.9	$7.5	$7.6	$6.2	$6.5	$9.2	$10.0	$8.6	$8.1
2027	$6.2	$8.2	$8.2	$6.5	$7.0	$9.8	$10.9	$9.2	$8.5
2028	$6.4	$9.0	$8.8	$6.9	$7.4	$10.4	$11.8	$9.7	$9.0
2029	$6.7	$9.8	$9.5	$7.2	$7.9	$11.0	$12.7	$10.2	$9.5
2030	$6.9	$10.6	$10.2	$7.6	$8.3	$11.4	$13.6	$10.6	$9.8
Cumulative 2018-2030	$70	$87	$87	$73	$77	$103	$112	$97	$92
Incremental (Cumulative)	N/A	$17	$17	$3	$6	$33	$42	$27	$21
Percent Difference	N/A	24%	24%	4%	9%	46%	59%	38%	30%
Cumulative 2018-2030 NPV 3%	$58	$71	$71	$60	$63	$84	$91	$80	$75
Cumulative 2018-2030 NPV 9%	$42	$49	$50	$43	$45	$59	$63	$56	$53

Represents sum of costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed 2018-2030.
Source: Navigant analysis.

Table G-2. Cost Effectiveness of GHG Emissions Reduction Strategies 2018-2030 (Cumulative Incremental Cost and GHG Emissions Reductions with the Normal Replacement 100% Scenario, NPV 3% Discount Rate))

Projection	Cumulative Combined Annual Cost 2018-2030 ($ Billions)	Cumulative Incremental Cost 2018-2030 ($ Billions)	Cumulative GHG Emissions Reductions (million mt CO2e)	Cost Effectiveness ($/mt CO2e)
Renewable Gas (In-State Supply)	$71	$13	49	$260
Renewable Gas (In-State) + Energy Efficiency	$71	$13	52	$251
Renewable Gas (Out-of-State Supply)	$60	$2	49	$46
Renewable Gas (Mixed In-State / Out-of-State)	$63	$5	49	$99
Electrification (ROB, IEPR Rates, incl. Upgrades)	$84	$26	55	$472
Electrification (ROB, High Rates, incl. Upgrades)	$91	$33	55	$602
Electrification (ROB, IEPR Rates, w/o Upgrades)	$80	$21	55	$392
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$75	$17	55	$311

Incremental costs include sum of energy consumption costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed 2018-2030. Costs represent NPV with 3% discount rate.
Source: Navigant analysis.

G.2 GHG Emissions Costs to Equal GHG Emissions Reductions in 2030 from Normal Replacement 50% Scenario

Table G-3. Combined Annual Cost (Annualized Over 15 Years) – Normal Replacement 50% Scenario

Year	Baseline (IEPR Gas & Elec Rates)	Renewable Gas (In-State Supply)	Renewable Gas (In-State) + Energy Efficiency	Renewable Gas (Out-of-State Supply)	Renewable Gas (Mixed In-State / Out-of-State)	Electrification (ROB, IEPR Rates, incl. Upgrades)	Electrification (ROB, High Rates, incl. Upgrades)	Electrification (ROB, IEPR Rates, w/o Upgrades)	Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)
2017	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6
2018	$3.7	$3.7	$3.8	$3.7	$3.7	$3.9	$3.9	$3.9	$3.9
2019	$4.0	$4.0	$4.0	$4.0	$4.0	$4.3	$4.3	$4.3	$4.2
2020	$4.1	$4.2	$4.2	$4.1	$4.1	$4.7	$4.7	$4.6	$4.5
2021	$4.2	$4.3	$4.4	$4.2	$4.3	$5.0	$5.0	$4.8	$4.7
2022	$4.4	$4.5	$4.6	$4.4	$4.4	$5.3	$5.4	$5.1	$5.0
2023	$4.5	$4.7	$4.8	$4.5	$4.5	$5.5	$5.8	$5.4	$5.2
2024	$4.6	$4.9	$5.0	$4.6	$4.7	$5.8	$6.1	$5.6	$5.4
2025	$4.7	$5.1	$5.3	$4.8	$4.9	$6.2	$6.5	$5.9	$5.7
2026	$4.9	$5.4	$5.5	$4.9	$5.0	$6.5	$7.0	$6.2	$5.9
2027	$5.0	$5.6	$5.7	$5.1	$5.2	$6.8	$7.4	$6.5	$6.2
2028	$5.1	$5.9	$6.0	$5.2	$5.4	$7.1	$7.9	$6.8	$6.4
2029	$5.3	$6.2	$6.3	$5.4	$5.6	$7.4	$8.4	$7.1	$6.7
2030	$5.4	$6.5	$6.5	$5.6	$5.8	$7.7	$8.9	$7.3	$6.9
Cumulative 2018-2030	$60	$65	$66	$61	$62	$76	$81	$74	$71
Incremental (Cumulative)	N/A	$5	$6	$1	$2	$16	$21	$14	$11
Percent Difference	N/A	8%	10%	1%	3%	27%	36%	23%	18%
Cumulative 2018-2030 NPV 3%	$50	$54	$55	$50	$51	$63	$67	$61	$58
Cumulative 2018-2030 NPV 9%	$36	$39	$39	$37	$37	$45	$47	$43	$42

Represents sum of costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed 2018-2030.
Source: Navigant analysis.

Table G-4. Cost Effectiveness of GHG Emissions Reduction Strategies 2018-2030 (Cumulative Incremental Cost and GHG Emissions Reductions with the Normal Replacement 50% Scenario, NPV 3% Discount Rate))

Projection	Cumulative Combined Annual Cost 2018-2030 ($ Billions)	Cumulative Incremental Cost 2018-2030 ($ Billions)	Cumulative GHG Emissions Reductions (million mt CO2e)	Cost Effectiveness ($/mt CO2e)
Renewable Gas (In-State Supply)	$54	$4	24	$152
Renewable Gas (In-State) + Energy Efficiency	$55	$5	26	$183
Renewable Gas (Out-of-State Supply)	$50	$1	24	$22
Renewable Gas (Mixed In-State / Out-of-State)	$51	$1	24	$54
Electrification (ROB, IEPR Rates, incl. Upgrades)	$63	$13	27	$473
Electrification (ROB, High Rates, incl. Upgrades)	$67	$17	27	$615
Electrification (ROB, IEPR Rates, w/o Upgrades)	$61	$11	27	$393
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$58	$9	27	$311

Incremental costs include sum of energy consumption costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed 2018-2030. Costs represent NPV with 3% discount rate.
Source: Navigant analysis.

G.3 GHG Emissions Costs to Equal GHG Emissions Reductions in 2030 from Normal Replacement 25% Scenario

Table G-5. Combined Annual Cost (Annualized Over 15 Years) – Normal Replacement 25% Scenario

Year	Baseline (IEPR Gas & Elec Rates)	Renewable Gas (In-State Supply)	Renewable Gas (In-State) + Energy Efficiency	Renewable Gas (Out-of-State Supply)	Renewable Gas (Mixed In-State / Out-of-State)	Electrification (ROB, IEPR Rates, incl. Upgrades)	Electrification (ROB, High Rates, incl. Upgrades)	Electrification (ROB, IEPR Rates, w/o Upgrades)	Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)
2017	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6	$3.6
2018	$3.7	$3.7	$3.7	$3.7	$3.7	$3.8	$3.8	$3.8	$3.8
2019	$3.9	$3.9	$3.9	$3.9	$3.9	$4.0	$4.0	$4.0	$4.0
2020	$4.0	$4.0	$4.0	$4.0	$4.0	$4.2	$4.2	$4.2	$4.1
2021	$4.0	$4.0	$4.1	$4.0	$4.0	$4.4	$4.4	$4.3	$4.3
2022	$4.1	$4.1	$4.2	$4.1	$4.1	$4.5	$4.6	$4.5	$4.4
2023	$4.1	$4.2	$4.3	$4.1	$4.2	$4.7	$4.8	$4.6	$4.5
2024	$4.2	$4.3	$4.4	$4.2	$4.2	$4.8	$5.0	$4.7	$4.6
2025	$4.3	$4.4	$4.5	$4.3	$4.3	$5.0	$5.2	$4.9	$4.8
2026	$4.4	$4.5	$4.6	$4.4	$4.4	$5.2	$5.5	$5.0	$4.9
2027	$4.4	$4.6	$4.7	$4.5	$4.5	$5.3	$5.7	$5.2	$5.0
2028	$4.5	$4.8	$4.8	$4.5	$4.6	$5.5	$5.9	$5.3	$5.2
2029	$4.6	$4.9	$5.0	$4.6	$4.7	$5.7	$6.2	$5.5	$5.3
2030	$4.7	$5.0	$5.1	$4.7	$4.8	$5.8	$6.5	$5.6	$5.4
Cumulative 2018-2030	$55	$56	$57	$55	$55	$63	$66	$62	$60
Incremental (Cumulative)	N/A	$2	$2	$0.2	$1	$8	$11	$7	$5
Percent Difference	N/A	3%	5%	0%	1%	15%	20%	12%	10%
Cumulative 2018-2030 NPV 3%	$46	$47	$48	$46	$46	$52	$55	$51	$50
Cumulative 2018-2030 NPV 9%	$34	$34	$35	$34	$34	$38	$39	$37	$36

Represents sum of costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed 2018-2030.
Source: Navigant analysis.

Table G-6. Cost Effectiveness of GHG Emissions Reduction Strategies 2018-2030
(Cumulative Incremental Cost and GHG Emissions Reductions with the Normal Replacement 25% Scenario, NPV 3% Discount Rate))

Projection	Cumulative Combined Annual Cost 2018-2030 ($ Billions)	Cumulative Incremental Cost 2018-2030 ($ Billions)	Cumulative GHG Emissions Reductions (million mt CO2e)	Cost Effectiveness ($/mt CO2e)
Renewable Gas (In-State Supply)	$47	$1.3	12.7	$100
Renewable Gas (In-State) + Energy Efficiency	$48	$1.9	12.9	$150
Renewable Gas (Out-of-State Supply)	$46	$0.1	12.7	$11
Renewable Gas (Mixed In-State / Out-of-State)	$46	$0.4	12.7	$33
Electrification (ROB, IEPR Rates, incl. Upgrades)	$52	$6.5	13.7	$473
Electrification (ROB, High Rates, incl. Upgrades)	$55	$8.7	13.7	$639
Electrification (ROB, IEPR Rates, w/o Upgrades)	$51	$5.4	13.7	$393
Electrification (ROB, IEPR Rates, Low HPWH Cost, w/o Upgrades)	$50	$4.3	13.7	$311

Incremental costs include sum of energy consumption costs for all appliances (new and existing) and annualized appliance and upgrade cost (over 15 years) for appliances installed 2018-2030. Costs represent NPV with 3% discount rate.
Source: Navigant analysis.