2019 Cost-Effectiveness Study:

2020 Analysis of Low-Rise Residential Addendum – City of Alameda Analysis

Last Modified: 2020-12-07

Prepared by:
Frontier Energy, Inc.
Misti Bruceri & Associates, LLC

Prepared for:
Kelly Cunningham
Codes and Standards Program
Pacific Gas and Electric Company

LEGAL NOTICE

This report was prepared by Pacific Gas and Electric Company and funded by the California utility customers under the auspices of the California Public Utilities Commission.

Acronym List

ACH50 – Air Changes per Hour at 50 pascals pressure differential

AC – Air Conditioner

ACM – Alternative Calculation Method

AFUE – Annual Fuel Utilization Efficiency

B/C – Benefit-to-Cost; as in Lifecycle Benefit-to-Cost Ratio

BSC – Building Standards Commission

Btu – British Thermal Units

CASE – Codes and Standards Enhancement

CBECC-Res – California Building Energy Code Compliance – Residential: Computer program developed by the California Energy Commission for use in demonstrating compliance with the California Residential Building Energy Efficiency Standards

CFI – California Flexible Installation

CFL – Compact Fluorescent Lamp

CO_2e – Carbon Dioxide (CO_2)-equivalent

CPAU – City of Palo Alto Utilities

CSE – Compliance Simulation Engine

CZ – California Climate Zone

DHW – Domestic Hot Water

EDR – Energy Design Rating

EER – Energy Efficiency Ratio

GHG – Greenhouse Gas

gpm – Gallons per minute

HERS Rater – Home Energy Rating System Rater

HPWH – Heat Pump Water Heater

HVAC – Heating, Ventilation, and Air Conditioning

IC – Insulation Contact

IOU – Investor Owned Utility

kWh – Kilowatt Hour

kWDC – Kilowatt Direct Current; nominal rated power of a photovoltaic system

lb – Pound

LCC – Lifecycle Cost

LED – Light-emitting Diode

MF – Multifamily

NEEA – Northwest Energy Efficiency Alliance

NEM – Net Energy Metering

NPV – Net Present Value

PG&E – Pacific Gas and Electric Company

PV – Photovoltaic

SCE – Southern California Edison

SDG&E – San Diego Gas and Electric

SEER – Seasonal Energy Efficiency Ratio

SF – Single Family

SHGC – Solar Heat Gain Coefficient

SMUD – Sacramento Municipal Utility District

Sqft – Square foot (ft2)

CASE – Codes and Standards Enhancement

TDV – Time Dependent Valuation

Therm – Unit for quantity of heat that equals 100,000 Btu British thermal units

Title 24 – Title 24, Part 6

TOU – Time-Of-Use

UEF – Uniform Energy Factor

W – Watts

TABLE OF CONTENTS

Acronym List **3**

1 Introduction **6**

2 Methodology and Assumptions **7**

2.1 Building Prototypes 7
2.2 Efficiency Measures 10
2.2.1 Building Envelope/Non-Preempted Measures 10
2.2.2 Equipment Fuel Substitution Measures – Heat Pump Replacements 11
2.2.3 Photovoltaic (PV) and Battery Measures 12
2.2.4 Additional Measures: High Efficiency Equipment – Federally Preempted Measures 12
2.3 Efficiency Packages 12
2.3.1 Envelope and Duct Packages 12
2.3.2 Additional Packages 13
2.4 Measure Cost 14
2.4.1 Building Envelope/Non-Preempted Measures 14
2.4.2 PV and Battery Measures 14
2.4.3 Equipment Fuel Substitution Measures – Heat Pump Equipment 17
2.5 Cost-Effectiveness 17
2.5.1 On-Bill Customer LCC 18
2.5.2 TDV LCC 19
2.6 Greenhouse Gas (GHG) Emissions Reductions 20

3 Results **21**

4 Recommendations and Discussion **26**

4.1 Efficiency Measures 26
4.2 Fuel Substitution Measures 27
4.3 Other Considerations 28

5 References **30**

6 Appendices **31**

6.1 Appendix A – Utility Tariff Details 31

LIST OF TABLES

TABLE 1: PROTOTYPE CHARACTERISTICS 8
TABLE 2: EFFICIENCY CHARACTERISTICS FOR THREE VINTAGE CASES 9
TABLE 3: MEASURE DESCRIPTIONS & COST ASSUMPTIONS - NON-PREEMPTED MEASURES[A] 15
TABLE 4: MEASURE DESCRIPTIONS & COST ASSUMPTIONS –ELECTRIC REPLACEMENTS[A] 17
TABLE 5: UTILITY TARIFFS APPLIED 19
TABLE 6: SINGLE FAMILY EFFICIENCY UPGRADE COST-EFFECTIVENESS RESULTS – CLIMATE ZONE 3 22
TABLE 7: SINGLE FAMILY EFFICIENCY PACKAGES COST-EFFECTIVENESS RESULTS – CLIMATE ZONE 3 23
TABLE 8: SINGLE FAMILY PV & BATTERY COST-EFFECTIVENESS RESULTS – CLIMATE ZONE 3 24
TABLE 9: SINGLE FAMILY EQUIPMENT FUEL SUBSTITUTION COST-EFFECTIVENESS RESULTS – CLIMATE ZONE 3 25
TABLE 10: PG&E MONTHLY GAS RATE ($/THERM) 32

LIST OF FIGURES

NO TABLE OF FIGURES ENTRIES FOUND.

1 Introduction

The California Codes and Standards Reach Codes program provides technical support to local governments considering adopting a local ordinance (reach code) intended to support meeting local and/or statewide energy and greenhouse gas reduction goals. The program facilitates adoption and implementation of the code when requested by local jurisdictions by providing resources such as cost-effectiveness studies, model language, sample findings, and other supporting documentation. This cost-effectiveness study was sponsored by Pacific Gas and Electric Company (PG&E). Local jurisdictions that are considering adopting ordinances may contact the program for support through its website, LocalEnergyCodes.com.

The California Building Energy Efficiency Standards Title 24, Part 6 (Title 24) (CEC, 2019) is maintained and updated every three years by two state agencies: the California Energy Commission (the Energy Commission) and the Building Standards Commission (BSC). In addition to enforcing the code, local jurisdictions have the authority to adopt local energy efficiency ordinances—or reach codes—that exceed the minimum standards defined by Title 24 (as established by Public Resources Code Section 25402.1(h)2 and Section 10-106 of the Building Energy Efficiency Standards). Local jurisdictions must demonstrate that the requirements of the proposed ordinance are cost effective and result in buildings consuming less energy than is permitted by Title 24. In addition, the jurisdiction must obtain approval from the Energy Commission and file the ordinance with the BSC for the ordinance to be legally enforceable.

This report presents results from analysis conducted in response to a request from City of Alameda to reflect anticipated local energy costs more accurately. This report documents cost-effective combinations of measures within Alameda Municipal Power (AMP) electric territory that meet or exceed the minimum state requirements, the 2019 Building Energy Efficiency Standards, effective January 1, 2020. Local jurisdictions in California may consider adopting local energy ordinances to achieve energy savings beyond what will be accomplished by enforcing building efficiency requirements that apply statewide. This report was developed in coordination with the California Statewide Investor Owned Utilities (IOUs) Codes and Standards Program, key consultants, and engaged cities—collectively known as the Reach Code Team.

This analysis is an update to the prior cost-effectiveness study for existing building upgrades completed in February 2020 (Statewide Reach Codes Team, 2020) and evaluates the feasibility and cost-effectiveness of retrofit measures in existing single family homes built before 2010. Each jurisdiction must establish the appropriate threshold for triggering the requirements, often based on the value of the project or percent of floor area impacted. Alternatively, a jurisdiction could require the upgrades described in this analysis at the time of sale or listing of a home. Some of these measures could be triggered with a permit for another specific measure, such as a reroof. The analysis includes scenarios of individual measures, as well as package upgrades, and identifies cost-effective options based on the existing conditions of the building in California Climate Zone 3 (Alameda). This analysis does not evaluate the impact of retrofit measures on Title 24 compliance margins, as the proposed measures are required in addition to achieving compliance with all codes.

A final report evaluating existing single family buildings for all sixteen California Climate Zones is under development and will be completed later in 2020.

2 Methodology and Assumptions

This analysis uses two different metrics to assess cost-effectiveness of the proposed upgrades. Both methodologies require estimating and quantifying the incremental costs and energy savings associated with each energy efficiency measure. The main difference between the methodologies is the manner in which they value energy and thus the cost savings of reduced or avoided energy use:

- **Utility Bill Impacts (On-Bill)**: Customer-based Lifecycle Cost (LCC) approach that values energy based upon estimated site energy usage and customer on-bill savings using electricity and natural gas utility rate schedules over a 30-year duration accounting for discount rate and energy inflation.
- **Time Dependent Valuation (TDV)**: Energy Commission LCC methodology, which is intended to capture the "societal value or cost" of energy use including long-term projected costs such as the cost of providing energy during peak periods of demand and other societal costs such as projected costs for carbon emissions, as well as grid transmission and distribution impacts. This metric values energy use differently depending on the fuel source (natural gas, electricity, and propane), time of day, and season. Electricity used (or saved) during peak periods has a much higher value than electricity used (or saved) during off-peak periods (Horii et al, 2014). This is the methodology used by the Energy Commission in evaluating cost-effectiveness for efficiency measures in Title 24, Part 6. Both 2019 and 2022 TDV multipliers are evaluated and documented in this analysis.

The general approach applied in this analysis is to evaluate performance and determine cost-effectiveness of various energy retrofit measures, individually and as packages, in existing single family homes. Three unique building vintages are considered in this analysis: pre-1978, 1978-1991, and 1992-2005. The vintages were defined based on review of historic Title 24 code requirements and selecting year ranges with distinguishing features. The applied approach establishes recommendations based on existing conditions and cost-effectiveness of each measure or package.

The California Building Energy Code Compliance – Residential (CBECC-Res) 2019.1.2 and 2022.0.1 compliance simulation tools were used to evaluate energy savings for most measures, with the exception of those outside the code compliance scope. In these cases, a combination of the Department of Energy's BEopt™ software and EnergyPlus v9.3. simulation engine was used.

This analysis builds on the work completed earlier in 2020 for the 2019 Title 24 code (Statewide Reach Codes Team, 2020) and has been updated to reflect changes in measure costs over time as well as current utility tariffs. Energy simulations were re-evaluated in CBECC-Res 2019 to evaluate cost-effectiveness from a TDV perspective under the 2019 Title 24 code. TDV cost-effectiveness was also completed using the 2022 TDV and weather files to evaluate cost-effectiveness with the latest version of the software for future code cycles.

2.1 Building Prototypes

The Energy Commission defines building prototypes which it uses to evaluate the cost-effectiveness of proposed changes to Title 24 requirements. Average home size has steadily increased over time,[1] and the Energy Commission single family new construction prototypes are larger than many existing single family homes across California. For this analysis, an existing home prototype developed by the Energy Commission for residential ACM testing[2] was used with the following revisions. The original prototype includes an existing 1,440 square foot (sqft)space and a 225 sqft addition. For this analysis, the entire 1,665 sqft was evaluated as existing space and features (i.e., insulation levels, glazing) were applied across the entire building consistent with the existing home specifications in Table 2. Additions are not evaluated in this analysis as they are already addressed by the Title 24 code. Table 1 describes the basic characteristics of the single family prototype.

---

1 https://www.census.gov/const/C25Ann/sftotalmedavgsqft.pdf

2 Residential ACM test U12 can be accessed at the following website: http://www.bwilcox.com/BEES/cbecc2016.html

Table 1: Prototype Characteristics

	Single Family
Existing Conditioned Floor Area	1,665 ft^2
Num. of Stories	1
Num. of Bedrooms	3
Window-to-Floor Area Ratio	13%
Attached Garage	2-car garage

Three building vintages were evaluated to determine sensitivity of existing building performance on cost-effectiveness of upgrades. For example, it is widely recognized that adding attic insulation in an older home with no insulation is cost-effective, however, newer homes will likely have at least some existing insulation in the attic reducing the potential savings from the measure. The building characteristics for each vintage were determined based on either prescriptive requirements from the Title 24 code that were in effect or standard construction practice during that time period. Based on the vintages selected, this analysis covers homes built before 2010. The three vintages evaluated specifically cover homes built before 2006, however, those built between 2006 and 2010 are expected to be similar in envelope characteristics to the 1992-2005 era homes. Homes built under the 2001 Title 24, Part 6 code are subject to prescriptive envelope code requirements very similar to homes built under the 2005 code cycle, which was in effect until January 1, 2010.

Table 2 summarizes the assumptions for each of the three vintages. Additionally, the analysis assumed the following features when modeling the prototype buildings:

- Individual space conditioning and water heating systems, one per single family building.
- Split-system air conditioner with gas furnace. Efficiency defined by year of the most recent equipment replacement (based on standard equipment lifetime).
- Small storage gas water heater. Efficiency defined by year of most recent equipment replacement (based on standard equipment lifetime).
- Gas cooktop, oven, and clothes dryer.

Table 2: Efficiency Characteristics for Three Vintage Cases

Building Component Efficiency Feature	Vintage Case		
	Pre-1978	1978-1991	1992-2005
Envelope			
Exterior Walls	2x4 16"oc wood frame, R-0[a]	2x4 16"oc wood frame, R-11	2x4 16"oc wood frame, R-13
Foundation Type & Insulation	Uninsulated slab (CZ 2-15) Raised floor, R-0 (CZ 1 & 16)	Uninsulated slab (CZ 2-15) Raised floor, R-0 (CZ 1 & 16)	Uninsulated slab (CZ 2-15) Raised floor, R-19 (CZ 1 & 16)
Ceiling Insulation & Attic Type	Vented attic, R-11 @ ceiling level Vented attic, R-5 @ ceiling level (CZ 6 & 7)	Vented attic, R-19 @ ceiling level	Vented attic, R-30 @ ceiling level
Roofing Material & Color	Asphalt shingles, dark (0.10 reflectance, 0.85 emittance)	Asphalt shingles, dark (0.10 reflectance, 0.85 emittance)	Asphalt shingles, dark (0.10 reflectance, 0.85 emittance)
Radiant Barrier	No	No	No
Window Type: U-factor/SHGC[b]	Metal, single pane: 1.16/0.76	Metal, dual pane: 0.79/0.70	Vinyl, dual pane Low-E: 0.55/0.40
House Infiltration	15 ACH50	10 ACH50	7 ACH50
HVAC Equipment			
Heating Efficiency	78 AFUE (assumes 2 replacements)	78 AFUE (assumes 1 replacement)	78 AFUE
Cooling Efficiency	10 SEER (assumes 2 replacements)	10 SEER (assumes 1 replacement)	13 SEER, 11 EER
Duct Location & Details	Attic, R-2.1, 30% leakage	Attic, R-2.1, 25% leakage	Attic, R-4.2, 25% leakage
Whole Building Mechanical Ventilation	None	None	None
Water Heating Equipment[2]			
Water Heater Efficiency	0.575 Energy Factor (assumes 2 replacements)	0.575 Energy Factor (assumes 1 replacement)	0.575 Energy Factor
Water Heater Tank	40 gallon uninsulated tank	40 gallon uninsulated tank	40 gallon uninsulated tank
Pipe Insulation	None	None	None
Hot Water Fixtures	Standard, non-low flow	Standard, non-low flow	Standard, non-low flow

[a] Pre-1978 wall modeled w/R-5 cavity insulation to better simulate uninsulated wall performance with field data and not overestimate energy use.

[b] Window type selections were made based on conversations with window industry expert, Ken Nittler. If a technology was entering the market during the time period (e.g., Low-E during 1992-2005 or dual pane during 1978-1991) that technology was included in the analysis. This provides a conservative assumption for overall building performance and additional measures may be cost-effective for buildings with lower performing windows, for example buildings with metal single pane windows in the 1978-1991 vintage.

2.2 Efficiency Measures

The methodology used in the analyses for each of the prototypical building types begins with a design that matches the specifications as described in Table 2 for each of the three vintages. Prospective energy efficiency measures were modeled in each of the prototypes to determine the projected electricity and natural gas energy savings relative to the baseline vintage. In some cases, where logical, measures were packaged together. Unless specified otherwise, all measures were evaluated using CBECC-Res.

All measures are evaluated assuming they are not otherwise required by Title 24 code. For example, duct sealing is required by code whenever HVAC equipment is altered. For this analysis duct sealing was evaluated for those projects where it is not already triggered by code (i.e., no changes to the heating or cooling equipment). Where appropriate, measure requirements align with those defined in Title 24. In some cases, cost-effective measures were identified that exceed Title 24 requirements, such as attic insulation, cool roofs, and duct sealing.

Following are descriptions of each of the efficiency upgrade measures applied in this analysis.

2.2.1 Building Envelope/Non-Preempted Measures

Attic Insulation: Add attic insulation in buildings with vented attic spaces to meet R-49. This measure was also evaluated to include retrofitting of existing recessed can fixtures that are not rated for insulation contact (IC) to be airtight and allow for insulation contact. This can be accomplished by installing a recessed light cover over existing non-compliant fixtures and sealing the covers to the ceiling plane with foam or replacing non-IC-rated fixtures with IC-rated fixtures. The energy analysis includes savings from adding insulation and upgrading compact fluorescent lamp (CFL) recessed cans to LED lighting but does not include any reduced infiltration benefits.

Air Sealing and Weather-stripping: Apply air sealing practices throughout all accessible areas of the building. For this study, it was assumed that older vintage buildings would be leakier than newer buildings and that approximately 30 percent improvement in air leakage was achievable through air sealing of all accessible areas. For modeling purposes, it was assumed that air sealing can reduce infiltration levels from 15 to 10 air changes per hour at 50 Pascals pressure difference (ACH50) in the oldest vintages (pre-1978), from 10 to 7 ACH50 for the 1978 to 1991 vintage, and from 7 to 5 ACH50 in the 1992 to 2005 vintage.

Cool Roof: For steep slope roofs, install a roofing product rated by the Cool Roof Rating Council (CRRC) with an aged solar reflectance of 0.25 or higher and thermal emittance of 0.75 or higher. This measure only applies to buildings that are installing a new roof as part of the scope of the remodel; the cost and energy savings associated with this upgrade reflects the incremental step between a standard roofing product with one that is CRRC rated with an aged solar reflectance of 0.25. This is similar to cool roof requirements in 2019 Title 24 Section 150.2(b)1Ii but assumes a higher solar reflectance.

Raised Floor Insulation: In existing homes with raised floors and no insulation, add R-19 insulation.

Wall Insulation: Blow-in R-13 wall insulation in existing homes that currently have no insulation in the walls (pre-1978 vintages).

Window Replacement: Replace existing metal-frame windows with a non-metal dual-pane product, which has a U-factor equal to 0.30 Btu/hr-ft^2-°F or lower and a Solar Heat Gain Coefficient (SHGC) equal to 0.35 or higher. This measure was only evaluated for the two older vintages, pre-1992, which are assumed to have either single-pane or dual-pane, metal-frame windows. This aligns with new window requirements in 2019 Title 24.

Duct Sealing, New Ducts, and Duct Insulation: Air seal all ductwork to meet the requirements of the 2019 Title 24 Section 150.2(b)1E. For this analysis, final duct leakage values of both 15 percent (which corresponds to Option i in the Title 24 code section referenced), and 10 percent (proposed revised leakage rate for 2022 Title 24 code) were evaluated. Replacing existing ductwork with entirely new ductwork to meet Sections 150.2(b)1Di and 150.2(b)1Diia of the 2019 Title 24 code was also evaluated. This assumed new ducts meet 5 percent duct leakage and R-8 duct insulation.

Water Heater Blanket: Add R-6 insulation to the exterior of existing residential tank storage water heaters. For the analysis, the water heater was modeled within conditioned space, which is a typical configuration for older homes. This assumption is conservative since a water heater located in unconditioned space will tend to have higher tank losses and installing a water heater blanket in those situations will result in additional savings. The energy savings for this measure reflect water heating energy savings only, and do not include any impacts to the space conditioning load, which reduces space cooling loads and increases space heating loads. The impact on space conditioning energy used is minimal and in most climate zones, except for heating dominated ones, the combination of these two impacts results in net energy savings. This measure was evaluated using EnergyPlus for individual water heaters only and does not apply to central water heating systems.

Hot Water Pipe Insulation: Insulate all accessible hot water pipes with R-3 pipe insulation. In certain buildings, such as those with slab on grade construction, where the majority of pipes are located either underground or within the walls, most of the pipes are inaccessible. For the purposes of this analysis a conservative assumption that only 10 percent of the pipes could be insulated was applied. In buildings where pipes are located in the attic, crawlspace, or are otherwise more accessible, energy savings will be higher than those presented in this analysis. This measure was evaluated using BEopt and EnergyPlus.

Low Flow Fixtures: Upgrade sink and shower fittings to meet current Title 24, Part 11 (CALGreen) requirements, which require maximum flow rates of 1.8 gallons per minute (gpm) for showerheads and kitchen faucets, and 1.2 gpm for bathroom faucets. Baseline whole house hot water use was based on BEopt assumptions and this measure assumed the upgraded fixtures reduce flow rates by ten percent for showerheads and 20 percent for all faucets based on a 2010 water use study (ConSol, 2010). This measure was evaluated using BEopt and EnergyPlus.

LED Lighting: Replace screw-in incandescent lamps and CFLs with screw-in light-emitting diode (LED) lamps. This analysis was conducted external to the energy model and evaluated replacement of a 13W CFL lamp with an 11W LED lamp operating 620 hours annually. Annual hour estimates were based on whole building average hours of operation from a 2010 lighting study by KEMA (KEMA, 2010). Lifetime assumptions were 10,000 hours for CFLs and 25,000 hours for LED lamps. For incremental cost calculations it was assumed CFLs have a lifetime of 15 years, are installed 5 years prior to the retrofit, and would need to be replaced at year 10 and 25.

Exterior Lighting Controls: Evaluation of exterior lighting controls was completed on a per-fixture basis external to the energy model and assumes a screw-in photosensor control is installed in outdoor lighting luminaires. Energy savings of 12.1 kWh per year was applied based on analysis done by the Consortium for Energy Efficiency, assuming LED lamps, 2.6 hours per day of operation, and that photosensor controls reduce operating hours on average 20 percent each day (CEE, 2014). Energy savings will be higher for incandescent or CFL luminaires.

2.2.2 Equipment Fuel Substitution Measures – Heat Pump Replacements

The baseline for the retrofit analysis assumed a mixed-fuel baseline for all cases, with natural gas furnaces for space heating and natural gas storage tank water heaters for domestic hot water (DHW). For fuel substitution cases, the gas appliances were assumed to be replaced with heat pump technology at the end of equipment life, when the equipment is being replaced. The high-efficiency measures were evaluated, but they cannot be used to show cost-effectiveness in a local ordinance. In addition, an ordinance cannot specifically require installation of high efficiency equipment. Although the ordinance may not require it, applicants may use high efficiency equipment to comply in practice. The measures are presented here to show that there are several options to meet the performance targets.

Ducted Heat Pump: Replace existing ducted gas furnace and air conditioner (AC) with an electric heat pump. Minimum federal efficiency (14 SEER, 11.7 EER, 8.2 HSPF) and higher efficiency (16 SEER, 13 EER, 9 HSPF) heat pumps were evaluated as replacements to existing equipment. Savings are relative to a new ducted gas furnace/AC (14 SEER, 11.7 EER, 80 AFUE).

Heat Pump Water Heater (HPWH): Replace existing gas storage tank water heater with either a minimum efficiency (UEF 2.0) 50 gallon HPWH, or a HPWH that meets the Northwest Energy Efficiency Alliance (NEEA)[3] Tier 3 rating. The evaluated NEEA HPWH is an 80 gallon unit with a UEF of 3.45. Savings are relative to a new 50 gallon gas storage water heater (UEF 0.63).

[3] Based on operational challenges experienced in the past, NEEA established rating test criteria to ensure newly installed HPWHs perform adequately, especially in colder climates. The NEEA rating requires an Energy Factor equal to the ENERGY STAR® performance level and includes requirements regarding noise and prioritizing heat pump use over supplemental electric resistance heating.

2.2.3 Photovoltaic (PV) and Battery Measures

PV: Installation of on-site PV is required in the 2019 residential code for new construction but not for additions or alterations to existing buildings. This report does not focus on optimizing PV system sizing for each prototype. For this study, two PV system sizes were evaluated. The first is a 1kW_{DC} PV system and the second is sized to the 2019 new construction standards for a 1,665 sqft home (2.17kW_{DC} for Climate Zone 3). The latter system is sized to offset annual building electricity use for a new construction home and avoid oversizing which would violate net energy metering (NEM) rules. In all cases, PV is evaluated in CBECC-Res according to the California Flexible Installation (CFI) assumptions.

Energy Storage (Batteries): This measure includes installation of batteries to allow energy generated through PV to be stored and used later, providing energy cost and resiliency benefits. This report does not focus on optimizing battery sizes or controls for each prototype and climate zone. A 5 kWh battery system was evaluated in CBECC-Res in conjunction with a PV system sized to the 2019 Title 24 new construction standards, with control type set to “Time-of-Use” (TOU) and with default efficiencies of 95 percent for both charging and discharging. The TOU option assumes batteries are charged anytime PV generation is greater than the house load but controls when the battery storage system discharges. During the summer months (July – September) the battery begins to discharge at the beginning of the peak period at a maximum rate until fully discharged. During discharge the battery first serves the house load but will discharge to the electric grid if there is excess energy available. During other months, the battery discharges whenever the PV system does not cover the entire house load and does not discharge to the electric grid. This control option is considered to be most reflective of the current products on the market. This control option requires an input for the “First Hour of the Summer Peak” and the Statewide Reach Codes Team applied the default hour in CBECC-Res which differs by climate zone (either a 6pm or 7pm start).

2.2.4 Additional Measures: High Efficiency Equipment – Federally Preempted Measures

The following additional measures were evaluated, but because these measures require upgrading appliances that are federally regulated to high efficiency models, they cannot be used to show cost-effectiveness in a local ordinance. In addition, an ordinance cannot specifically require installation of high efficiency equipment. Although the ordinance may not require it, many applicants use high efficiency equipment to comply in practice. The measures and packages are presented here to show that there are several options for builders to meet the performance targets. Heating and cooling capacities are auto-sized by CBECC-Res in all cases.

High Efficiency Gas Furnace: Replace existing gas furnace with a 90 AFUE furnace.

High Efficiency AC: In buildings with cooling, replace existing AC with a single-speed 16 SEER, 13 EER unit.

High Efficiency Gas Water Heater: Replace existing gas storage tank water heater with either a condensing tankless water heater with a Uniform Energy Factor (UEF) of 0.92, or condensing storage water heater with a UEF of 0.83.

2.3 Efficiency Packages

Some of the measures described above were also evaluated as packages.

2.3.1 Envelope and Duct Packages

Five envelope and duct packages were developed as described below. Air sealing and attic insulation are very often applied as a package in building retrofits. From a performance perspective, air sealing of the boundary between the attic and living space should be addressed any time there is significant work in the attic, such as adding attic insulation and sealing or replacing ductwork. When the building shell is being improved, air sealing is an important component to be addressed. The boundary between the living space and vented attics is where a significant amount of building air leakage can occur and sealing these areas prior to covering the attic floor with insulation is both practical and effective. These measures also directly address occupant comfort, as they reduce heat transfer, and result in more even temperatures within the building. When ductwork is located in the attic there are synergies with addressing all three of these building aspects at the same time.

1. **R-49 Attic Insulation and Air Sealing**: This package includes attic insulation and air sealing measures, as described below:
   - R-49 attic insulation installed in attic.

- Air sealing and weatherstripping to reduce total building air leakage by 30 percent. Target air leakage assumptions are 10 ACH50 for pre-1978 vintage, 7 ACH50 for 1978 to 1991 vintage, and 5 ACH50 for the 1992 to 2005 vintage.
- Retrofitting all non-IC-rated recessed light fixtures to be airtight and allow for coverage by insulation. This submeasure only applies to homes without IC-rated recessed can fixtures.

2. **R-49 Attic Insulation and Duct Sealing**: This package includes attic insulation and duct sealing measures, as described below:
   - R-49 attic insulation installed in attic.
   - Ductwork sealed to 10 percent of nominal airflow.
   - Retrofitting all non-IC-rated recessed light fixtures to be airtight and allow for coverage by insulation. This submeasure only applies to homes without IC-rated recessed can fixtures.
3. **R-49 Attic Insulation, Air Sealing, and Duct Sealing**: This package includes attic insulation, air sealing, and duct sealing measures, as described below:
   - R-49 attic insulation installed in attic.
   - Ductwork sealed to 10 percent of nominal airflow.
   - Air sealing and weatherstripping to reduce total building air leakage by 30 percent. Target air leakage assumptions are 10 ACH50 for pre-1978 vintage, 7 ACH50 for 1978 to 1991 vintage, and 5 ACH50 for the 1992 to 2005 vintage.
   - Retrofitting all non-IC-rated recessed light fixtures to be airtight and allow for coverage by insulation. This submeasure only applies to homes without IC-rated recessed can fixtures.

   This combination of measures is common when a whole building performance upgrade is done in combination with HVAC equipment replacement. Incorporating these measures can allow for downsizing HVAC equipment by lowering heating and cooling loads in the house.
4. **R-49 Attic Insulation, Air Sealing, and Entirely New Ducts**: This package is similar to Package 3 above but assumes that all existing ductwork is replaced with new R-8 ducts and sealed to new construction standards (5 percent total leakage). This package assumes that if an existing HVAC system is being replaced with new ductwork, the area between the vented attic and conditioned space be air sealed and insulation added to the attic.
   - R-49 attic insulation installed in attic.
   - New R-8 ductwork sealed to 5 percent of nominal airflow.
   - Air sealing and weatherstripping to reduce total building air leakage by 30 percent. Target air leakage assumptions are 10 ACH50 for pre-1978 vintage, 7 ACH50 for 1978 to 1991 vintage, and 5 ACH50 for the 1992 to 2005 vintage.
   - Retrofitting all non-IC-rated recessed light fixtures to be airtight and allow for coverage by insulation. This submeasure only applies to homes without IC-rated recessed can fixtures.
5. **Advanced Envelope Package**: Attic Insulation, Recessed Cans, Air and Duct Sealing plus Wall Insulation, and New Windows: This package includes all the measures in Package 3, in addition to insulating exterior walls, and replacing existing single-pane windows with improved high-performance windows. This package only applies to older vintage buildings with no wall cavity insulation and single-pane windows.
   - R-49 attic insulation installed in attic.
   - Ductwork sealed to 10 percent of nominal airflow.
   - Air sealing and weatherstripping to reduce total building air leakage by 30 percent. Target air leakage assumptions are 10 ACH50 for pre-1978 vintage, 7 ACH50 for 1978 to 1991 vintage, and 5 ACH50 for the 1992 to 2005 vintage.
   - Retrofitting all non-IC-rated recessed light fixtures to be airtight and allow for coverage by insulation. This submeasure only applies to homes without IC-rated recessed can fixtures.
   - Insulate exterior walls to R-13.
   - New windows with 0.30 U-factor and 0.35 SHGC (for Climate Zone 3).

2.3.2 Additional Packages

Water Heating Package: Includes water heater blanket, hot water pipe insulation, and low-flow fixtures: These three water heating measures are all relatively low cost and work together to reduce building hot water energy use. Additional water savings measures and model language are documented on the LocalEnergyCodes.com site[4].

PV + Batteries: PV sized to Residential New Construction Standards and a 5-kWh battery system with TOU control.

2.4 Measure Cost

Measure costs were obtained from various sources, including prior reach code studies, past Title 24 Codes and Standards Enhancement (CASE) work, local contractors, internet searches, past projects, and technical reports.

2.4.1 Building Envelope/Non-Preempted Measures

Table 3 summarizes the cost assumptions for the building envelope and non-preempted HVAC measures evaluated.

2.4.2 PV and Battery Measures

The costs for installing PV and batteries are summarized in Table 3. For PV, they include first cost to purchase and install the system, inverter replacement costs, and annual maintenance costs. Upfront solar PV system costs are reduced by the federal income tax credit (ITC) by 11 percent due to a phased reduction in the credit through the year 2022.

Costs for batteries include first cost and replacement at year 15. Batteries are also eligible for the ITC if they are installed at the same time as the renewable generation source and at least 75 percent of the energy used to charge the battery comes from a renewable source.

[4] https://localenergycodes.com/

Table 3: Measure Descriptions & Cost Assumptions - Non-Preempted Measures[a]

Measure	Performance Level	Incremental Cost – Single Family Building			Source	Notes
		Pre 1978	1978 – 1991	1992 - 2005		
Building Envelope						
Wall Insulation	R-13	$3,360	n/a	n/a	Retrofit contractor[b]	$2.14/sqft exterior wall area. Drill 2" holes from outside.
Raised Floor Insulation	R-19	$3,147	n/a	n/a	Retrofit contractor[b]	$1.89/sqft of raised floor area. Assumes installation of R-19 batt insulation when existing condition is no insulation
Attic Insulation	R-38	$2,393	$1,936	n/a	2022 Alterations CASE Report	$1.44/sqft ceiling area to add insulation to existing R-11 insulation $1.16/sqft to add insulation to existing R-19 insulation
	R-49	$2,851	$2,393	$1,852		$1.71/sqft ceiling area to add insulation to existing R-11 insulation $1.44/sqft to add insulation to existing R-19 insulation
	R-49 + Recessed Can Retrofit	$3,332	$2,874	$2,333		Added cost of $0.29/sqft ceiling area to retrofit non-IC-rated to be airtight and allow coverage with insulation, and sealing the covers to the ceiling plane with foam.
Air sealing	10 ACH50	$1,474	n/a	n/a	Retrofit contractor[b]	Based on contractor quote to seal building shell and reduce building air leakage by 30%. Assumes all accessible leaks are sealed and assumes existing attic insulation is not removed.
	7 ACH50	n/a	$1,474	n/a		
	5 ACH50	n/a	n/a	$1,474		
Cool roof	Aged Solar Reflectance ≥ 0.25	$778	$778	$778	Research report[c]	Based on $0.32/sqft roof area incremental cost for cool asphalt shingle product, plus a 10% contractor markup. Includes 20 yr lifetime and NPV of replacement and residual costs. Higher reflectance values for lower cost are achievable for tile roof products
Window U-factor/SHGC	0.30/0.23	$9,810	n/a	n/a	Retrofit contractor[d]	Based on $45/sqft window area installed cost
HVAC/DHW						
Duct sealing	15% nominal airflow	$423	$423	$423	HVAC contractor	Assume ducts in attic with 5 wye branches, 8 supplies & 1 return. $223 in labor (~2 hours at $120/hour) and $20 material for 15% leakage. $463 in labor (~4 hours at $120/hour) and $40 material for 10% leakage. $180 for HERS Rater.
	10% nominal airflow	$683	$683	$683		Assume ducts in attic with 5 wye branches, 8 supplies & 1 return. $223 in labor (~2 hours at $120/hour) and $20 material for 15% sealing. $463 in labor (~4 hours at $120/hour) and $ $433 for contractor + $250 for HERS Rater
Entirely New Ducts	R-8 ducts. 5% duct leakage.	$3,986	$3,986	$3,986	Retrofit contractor[b]	Based on duct layout provided for prototype single story model, and all ducts located in attic.
Water heater blanket	R-6	$40			Internet search	$20 blanket + ½-hr labor ($40.30/hr laborer rate)[5]. Six-year life assuming that the water heater will need to be replaced after 6 years on average.
Hot water pipe insulation	3/4" (R-3)	$42			Internet search	$0.20/ft of ¾" pipe insulation. 10ft total + 1-hr labor ($40.30/hr common labor rate)[5]. 15-year life assumed.
Low flow fixtures	CALGreen	$126			Retrofit contractor[d]	Showerheads at $34.74 each + sink aerators at $5.37 each + 1-hr labor ($40.30/hr common labor rate)[5]. 2 showerheads & 3 aerators assumed for single family. 15-year life assumed.

Measure	Performance Level	Incremental Cost – Single Family Building			Source	Notes
		Pre 1978	1978 – 1991	1992 - 2005		
Lighting						
LED lamp	11W screw-in bulb	$3.99/luminaire			Internet search	$3.99 for LED dimmable A19 lamp 60W equivalent. $1.83 for an equivalent CFL product which was used to estimate total replacement costs at years 10 and 25. Cost based on a single LED lamp replacement.
Exterior Lighting Controls	Photocell control w/motion sensor	$10.50/device			Internet search	Incremental cost of $10.50, based on a screw-in photosensor control, was obtained from an on-line product search of available products. A five year lifetime for this type of control was assumed.
PV/Batteries						
PV	1kW$_{DC}$ and sized to 2019 new construction requirements, 2.17 kW for Climate Zone 3	$3.73/W$_{DC}$ (2.17 kW$_{DC}$) $3.73/W$_{DC}$ (1 kW$_{DC}$)			LBNL, 2019. California Energy Commission, 2017.	First costs are from LBNL's Tracking the Sun 2019 costs (Barbose et al., 2019) and represent costs for the first half of 2019 of $3.70/W$_{DC}$ for residential systems. These costs were reduced by 11% for the solar investment tax credit, which is the average credit over years 2021-2022. First costs for the smaller 1kW PV system are increased by 5% based on data from LBNL's Tracking the Sun 2019 costs. Inverter replacement cost of $0.14/W$_{DC}$ present value includes replacements at year 11 at $0.15/W$_{DC}$ (nominal) and at year 21 at $0.12/W$_{DC}$ (nominal) per the 2019 PV CASE Report (California Energy Commission, 2017). System maintenance costs of $0.31/W$_{DC}$ present value assume $0.02/W-DC (nominal) annually per the 2019 PV CASE Report (California Energy Commission, 2017).
Batteries	5 kWh, TOU controls	$1,023/kW			SGIP, 2020. E Source Companies, 2020.	$1,000/kWh first cost based on SGIP program residential participant cost data. This cost is reduced by the Residential Storage Step 6 SGIP incentive of $0.20/Wh and the solar investment tax credit. 11% is used for the solar investment tax credit, which is the average credit over years 2021-2022. Replacement cost at year 15 calculated based on today's cost of $1,000/kWh reduced by 7% annually over the next 10 years for a future value cost of $484 (present value of $311). The 7% reduction is based on SDG&E's Behind-the-Meter Battery Market Study (E Source Companies, 2020).

[a] Costs include contractor overhead and profit.

[b] Source: Retrofit contractor pricing. 2020. Phone outreach.

[c] Codes and Standards Enhancement (CASE) Initiative: Residential Roof Envelope Measures. 2013 Title 24. https://title24stakeholders.com/wp-content/uploads/2017/10/2013_CASE-Report_Residential-Roof-Envelope-Measures.pdf

[d] Source: Retrofit contractor pricing obtained by Davis Energy Group through the Stockton Energy Challenge neighborhood retrofit program (DEG, 2017).

2.4.3 Equipment Fuel Substitution Measures – Heat Pump Equipment

Table 4 summarizes the cost assumptions for fuel substitution measures. Incremental costs for the heat pump replacement measures were obtained from several sources, including a 2019 report on residential building electrification in California (E3, 2019), online equipment pricing, and contractor outreach. Both materials and labor costs are included, assuming that the existing equipment is being replaced.

For both the space heating and water heating cases, costs for service panel upgrades are not included as it is assumed many existing homes have the service capacity to support converting one appliance from gas to electric. In some homes and in cases where multiple end uses are electrified a larger electrical panel may be necessary.

Ducted Heat Pump: Costs include additional material costs to replace existing equipment with a heat pump instead of a minimum efficiency gas furnace/AC. It is assumed there is no incremental labor except in providing a new 220 volt electrical service to the air handler location.

The base case assumes that an existing AC is being replaced. In mild climates, where AC may not be installed, there will be additional costs for installing an outdoor unit, refrigerant lines, and condensate drain pan.

Equipment replacement costs were included based on equipment life of 15 years for heat pumps and 20 years for gas furnace/AC. Net present value (NPV) replacement costs are included in the LCC.

HPWH: Costs assume replacement of a gas storage water heater located in a garage and include all material and labor costs for a HPWH installation including providing a new 220 volt electrical service to the water heater location. Total installed costs are based on Sacramento Municipal Utility District (SMUD) HPWH incentive program in 2018 through 2020 (SMUD, 2020). Equipment replacement costs were included based on equipment life of 15 years for both base case and HPWH. NPV replacement costs are included in the LCC.

Table 4: Measure Descriptions & Cost Assumptions –Electric Replacements[a]

Measure	Performance Level	Incremental Cost – Single Family Building			Source	Notes
		Pre 1978	1978 – 1991	1992 - 2005		
Electric Heat Pump Replacement						
Ducted Heat Pump	14 SEER, 11.7 EER, 8.2 HSPF	$363 First cost, $2,724 LCC			Internet search, HVAC Contractor (E3, 2019)	Equipment costs from on-line sources and HVAC contractors. Other supply and labor costs from 2019 report on residential building electrification in California (E3, 2019). Includes disposal, electrical upgrade, and labor costs. LCC include equipment replacement cost at year 15 for heat pumps and at year 20 for gas furnace/AC, and remaining life value.
	16 SEER, 13 EER, 9 HSPF	$1,155 First cost, $4,024 LCC				
Ducted Heat Pump (no AC in base)	14 SEER, 11.7 EER, 8.2 HSPF	$4,383 First cost, $8,141 LCC				Not directly evaluated within this report.
Heat Pump Water Heater	2.0 UEF, 50 gallon	$2,418 First cost. $2,594 LCC			SMUD Electrification Costs (SMUD, 2020)	Assumes 80% of equipment cost compared to NEEA Tier 3 HPWH based on on-line product research. LCC includes equipment replacement cost at year 15.
	NEEA Tier 3, 3.45 UEF, 80 gallon	$2,555 First cost. $2,775 LCC				Based on 2018-2020 costs from SMUD incentive program. Includes incremental equipment cost, electrical upgrade, and labor. LCC includes equipment replacement cost at year 15.

[a] Costs include contractor overhead and profit.

2.5 Cost-Effectiveness

Cost-effectiveness was evaluated and is presented based on both TDV energy, using the Energy Commission's LCC methodology, and an On-Bill, customer-based approach using residential customer utility rates. Both methodologies require estimating and quantifying the value of the energy impact associated with energy efficiency, PV, storage, and fuel substitution measures over the life of the measures (30 years) as compared to the prescriptive Title 24 requirements.

Additional analysis included evaluating the measures using both the 2019 and proposed 2022 TDV multipliers. The proposed 2022 weather files were also used to evaluate On-Bill energy performance. The 2022 weather files were updated in 2019 and are considered to better represent conditions now and in the future. They tend to increase cooling and reduce space heating energy use, based on recent warming trends throughout the state.

Cost-effectiveness is presented using both lifecycle NPV savings and benefit-to-cost (B/C) ratio metrics, which represent the cost-effectiveness of a measure over a 30-year lifetime taking into account discounting of future savings and costs, and financing of incremental first costs.

- **NPV Savings**: NPV benefits minus NPV costs is reported as a cost-effectiveness metric. If the net savings of a measure or package is positive, it is considered cost-effective. Negative savings represent net costs. A measure that has negative energy cost benefits (energy cost increase) can still be cost-effective if the costs to implement the measure are more negative (i.e., material and maintenance cost savings).
- **B/C Ratio**: Ratio of the present value of all benefits to the present value of all costs over 30 years (NPV benefits divided by NPV costs). The criteria for cost-effectiveness is a B/C ratio greater than 1.0. A value of one indicates the NPV of the savings over the life of the measure is equivalent to the NPV of the lifetime incremental cost of that measure. A value greater than one represents a positive return on investment. The B/C ratio is calculated according to Equation 1.

Equation 1

$$Benefit - to - Cost\ Ratio = \frac{NPV\ of\ lifetime\ benefit}{NPV\ of\ lifetime\ cost}$$

Improving the efficiency of a project often requires an initial incremental investment. In most cases the benefit is represented by annual “On-Bill” utility or TDV savings, and the cost by incremental first cost and replacement costs. However, some packages result in initial construction cost savings (negative incremental cost), and either energy cost savings (positive benefits), or increased energy costs (negative benefits). In cases where both construction costs and energy-related savings are negative, the construction cost savings are treated as the ‘benefit’ while the increased energy costs are the ‘cost.’ In cases where a measure or package is cost-effective immediately (i.e., upfront construction cost savings and lifetime energy cost savings), B/C ratio cost-effectiveness is represented by “>1”. Because of these situations, NPV savings are also reported, which, in these cases, are positive values.

The lifetime costs or benefits are calculated according to Equation 2.

Equation 2

$$NPV\ of\ lifetime\ cost\ or\ benefit = \sum_{t=0}^{n} \frac{(Annual\ cost\ or\ benefit)_t}{(1+r)^t}$$

Where:

1. *n* = analysis term
2. *r* = discount rate

The following summarizes the assumptions applied in this analysis to both methodologies.

1. Analysis term of 30-years
2. 15-year analysis term for the water heating package
3. 5-year analysis term for the exterior light controls
4. Real discount rate of 3 percent

2.5.1 On-Bill Customer LCC

Residential utility rates at the time of the analysis were applied to calculate utility costs for all cases and determine On-Bill cost effectiveness for the proposed measures and packages. The Statewide Reach Code Team obtained the recommended utility rates from each utility based on the assumption that the reach codes go into effect in

2021. First year utility costs were calculated using hourly electricity and gas output from CBECC-Res and applying the utility tariffs summarized in Table 5. Appendix A – Utility Tariff Details includes details on the utility rate schedules used for this study.

Alameda Municipal Power D-1 tariff was used for electricity rates. The D-1 tariff includes three tiers. For cases with PV generation the Eligible Renewable Generation (ERG) program rules were applied. Per the Rider ERG, customers are billed at the end of each monthly billing cycle. For billing cycles where the customer is a net consumer of electricity the customer is charged per the tariff schedule for the net energy consumed over the period. For billing cycles where the customer is a net generator the customer is credited for net energy generated over the period at the actual avoided cost of procuring renewable energy for the previous year, $0.06968/kWh.

Table 5: Utility Tariffs Applied

	Electricity	Natural Gas
City of Alameda	AMP D-1	PG&E G1

Source: Utility websites, see Appendix A – Utility Tariff Details for details on the tariffs applied.

Utility rates are assumed to escalate over time, using assumptions from research conducted by Energy and Environmental Economics (E3) in the 2019 study Residential Building Electrification in California (Energy & Environmental Economics, 2019). Escalation of utility rates for the local utilities was not available and the assumptions used in this analysis are based on assumptions for PG&E in the statewide studies (Statewide Reach Code Team, 2019) (Statewide Reach Code Team, 2020). Natural gas escalation between 2020 and 2022 is based on the currently filed General Rate Cases (GRCs) for PG&E. From 2023 through 2025, gas rates are assumed to escalate at 4% per year above inflation, which reflects historical rate increases between 2013 and 2018. Escalation of electricity rates from 2020 through 2025 is assumed to be 2% per year above inflation, based on electric utility estimates. After 2025, escalation rates for both natural gas and electric rates are assumed to drop to a more conservative 1% escalation per year above inflation for long-term rate trajectories beginning in 2026 through 2050.

First incremental costs are assumed to be financed into a mortgage or loan, with the exception of the lighting and water heating measures. These are low cost measures that may be more likely to be installed by the homeowner relative to the other measures evaluated. A 30-year loan term and 4 percent interest rate are applied in this analysis. Present value of replacement cost is included for measures with equipment lifetimes less than the evaluation period.

2.5.2 TDV LCC

Cost-effectiveness was also assessed using the Energy Commission's TDV LCC methodology. TDV is a normalized monetary format developed and used by the Energy Commission for comparing electricity and natural gas savings, and it considers the cost of electricity and natural gas consumed during different times of the day and year. Both 2019 and proposed 2022 TDV values were used and are based on long term discounted costs of 30 years for all residential measures. The CBECC-Res simulation software results are expressed in terms of TDV kBtu. The present value of the energy cost savings in dollars is calculated by multiplying the TDV kBtu savings by a NPV factor, also developed by the Energy Commission. The 30-year NPV factor $0.173/TDV kBtu, used for both 2019 and 2022 Title 24 code cycles for residential buildings, was used.

Like the customer B/C ratio, a TDV B/C ratio value of one indicates the savings over the life of the measure are equivalent to the incremental cost of that measure. A value greater than one represents a positive return on investment. The ratio is calculated according to Equation 3.

Equation 3

$$TDV\ Benefit-to-Cost\ Ratio = \frac{TDV\ energy\ savings * NPV\ factor}{NPV\ of\ lifetime\ incremental\ cost}$$

2.5.2.1 2019 and 2022 TDV Differences

There were key changes to the 2022 TDV methodology as compared to the 2019 TDV, including the major updates below:

1. Updated weather files to reflect historical data from recent years.

2. New load profiles representing building and transportation electrification and renewable generation.
3. Addition of internalized cost streams to account for carbon emissions.
4. Shaped retail rate adjustment partially scaled to hourly marginal cost of service.
5. Addition of non-combustion emissions from methane and refrigerant leakage.

The impact of these key changes for electricity TDV are lower values during the mid-day that correspond with an abundance of solar production and a shift of the peak TDV to later in the day as a result of increasing levels of rooftop PV systems. However, the overall magnitude of the 2022 TDV does not increase significantly relative to 2019 TDV. For natural gas TDV there is a large increase in magnitude with the 2022 TDV roughly 70 percent higher than in 2019. This is driven by the new retail rate forecast, increased fixed costs for maintaining the distribution system, and the new carbon cost component. Additional details about 2022 TDV are described in the final 2022 TDV methodology report (Energy & Environmental Economics, 2020)

The updated weather files represent an updated dataset based on historical weather sampled from recent years (1998-2017) to reflect the impacts of climate change. Cooling loads increase significantly, particularly for the mild climates zones where cooling energy use was previously low. Heating loads decrease on average 30 percent across all climate zones. The weather files used for the 2019 code cycle had not been updated since the 2013 code cycle and represented data only up until 2009. The Energy Commission and the Statewide Reach Codes Team contend that the updated 2022 weather files better reflect changing climate conditions in California. Therefore, the 2022 files are used for all the analysis reported in this study.

2.6 Greenhouse Gas (GHG) Emissions Reductions

Equivalent CO_2 emission reductions were calculated based on outputs from the CBECC-Res simulation software. Electricity emissions vary by region and by hour of the year. CBECC-Res applies two distinct hourly profiles, one for Climate Zones 1 through 5 and 11 through 13, and another for Climate Zones 6 through 10 and 14 through 16. For natural gas a fixed factor of 11.7 lbs per therm is used. To compare the mixed-fuel and all-electric cases side-by-side, GHG emissions are presented as pound (lb) CO_2-equivalent (CO_2e) emissions for the 1,665 sqft prototype.

3 Results

The primary objective of the evaluation is to identify cost-effective energy upgrade measures and packages for existing single family buildings to support the design of local ordinances requiring upgrades, which may be triggered by different events, such as at the time of a significant remodel or addition. Cost-effectiveness analysis was completed based on single family prototype designs representing building features commonly used during three vintage periods.

Table 6 through Table 9 summarize cost-effectiveness of the efficiency measures and packages evaluated. Cost-effectiveness analysis was evaluated using both On-Bill and TDV cost-effectiveness criteria described in Section 2.5. Site energy savings, cost savings, measure cost, and cost-effectiveness including lifecycle B/C ratio and NPV of savings are provided.

Where measures are dependent on building vintage (envelope efficiency measures), cost-effectiveness is reported for each vintage. Some measure results do not differ between the vintages such as LED lamp replacement and water heating upgrades. The water heating and LED lighting measures are cost-effective in all cases.

On-Bill cost effectiveness for individual measures and packages is limited to duct sealing in the older vintages, lighting measures, the water heating package, PV systems, NEEA Tier 3 HPWHs at time of water heater replacement, and heat pumps combined with PV at time of equipment replacement.

There are additional measures cost effective based on 2019 or 2022 TDV including attic insulation, duct sealing, new ducts, wall insulation, envelope and duct packages, battery systems coupled with PV, heat pump at HVAC replacement, and HPWH at water heater replacement. In most cases the 2022 TDV results in improved cost effectiveness and higher lifetime savings than the 2019 TDV.

Table 6: Single Family Efficiency Upgrade Cost-effectiveness Results – Climate Zone 3

Measure	Vintage	Measure Cost ($)	Electricity Savings (kWh)	Gas Savings (therms)	GHG Savings (lb CO2e)	Utility Cost Savings		Customer On-Bill		2019 TDV		2022 TDV	
						Year 1	Avg Annual	B/C Ratio	NPV	B/C Ratio	NPV	B/C Ratio	NPV
R-49 Attic Insulation	Pre-1978	$3,332	151	33	359	$87	$72	0.58	-$1,569	0.67	-$953	1.40	$1,138
	1978-1991	$2,874	90	17	184	$47	$39	0.36	-$2,066	0.40	-$1,443	1.04	$98
	1992-2005	$2,333	58	6	65	$22	$18	0.20	-$2,088	0.19	-$1,504	0.22	-$1,438
Reduced Infiltration	Pre-1978	$1,474	10	14	143	$28	$24	0.43	-$944	0.65	-$1,182	0.63	-$552
	1978-1991		7	9	90	$17	$14	0.26	-$1,220	0.42	-$1,672	0.41	-$869
	1992-2005		4	6	57	$11	$9	0.17	-$1,378	0.26	-$1,733	0.24	-$1,114
Duct Sealing	Pre-1978	$683	40	30	315	$64	$54	2.12	$857	0.47	-$783	3.68	$1,832
	1978-1991	$683	18	17	175	$35	$29	1.15	$116	0.30	-$1,030	1.97	$659
	1992-2005	$423	4	5	48	$10	$8	0.51	-$234	0.20	-$1,186	0.72	-$118
New Ducts	Pre-1978	$3,986	77	54	567	$116	$97	0.65	-$1,553	2.59	$1,086	1.20	$781
	1978-1991		43	38	392	$79	$66	0.44	-$2,491	1.51	$348	0.79	-$826
	1992-2005		14	16	164	$32	$27	0.18	-$3,665	0.69	-$129	0.26	-$2,952
R-13 Wall Insulation	Pre-1978	$3,360	49	44	458	$90	$76	0.60	-$1,498	0.00	-$1,089	1.00	$10
Windows	Pre-1978	$9,810	100	27	309	$71	$59	0.16	-$9,247	0.20	-$7,843	0.50	-$4,916
	1978-1991		57	25	276	$57	$48	0.13	-$9,574	0.17	-$8,131	0.38	-$6,071
LED lamp vs CFL	All	$2.26	1.2	0	n/a	$0.21	$0.17	2.19	$2.69	n/a	n/a	n/a	n/a
Exterior photosensor	All	$42.58	12.1	0	n/a	$2.10	$1.66	1.17	$7.15	n/a	n/a	n/a	n/a

[1] Values in red and shaded grey indicate measures is not cost effective with a B/C ratio less than 1.

Table 7: Single Family Efficiency Packages Cost-effectiveness Results – Climate Zone 3

Measure	Vintage	Measure Cost ($)	Electricity Savings (kWh)	Gas Savings (therms)	GHG Savings (lb CO2e)	Utility Cost Savings		Customer On-Bill		2019 TDV		2022 TDV	
						Year 1	Avg Annual	B/C Ratio	NPV	B/C Ratio	NPV	B/C Ratio	NPV
R49 Attic & Air Sealing Package	Pre-1978	$4,806	111	47	511	$117	$97	0.54	-$2,484	0.60	-$1,902	1.09	$453
	1978-1991	$4,348	45	26	276	$64	$54	0.33	-$3,276	0.38	-$2,691	0.77	-$987
	1992-2005	$3,807	11	12	123	$33	$27	0.19	-$3,459	0.23	-$2,919	0.27	-$2,785
R49 Attic & Duct Sealing Package	Pre-1978	$4,015	127	61	651	$145	$121	0.81	-$868	0.96	-$163	1.60	$2,405
	1978-1991	$3,557	52	33	346	$79	$66	0.49	-$2,020	0.61	-$1,379	1.08	$299
	1992-2005	$2,756	10	11	113	$31	$26	0.25	-$2,325	0.32	-$1,871	0.35	-$1,797
R49 Attic, Air Sealing & Duct Sealing Package	Pre-1978	$5,489	138	74	788	$172	$143	0.70	-$1,859	0.82	-$963	1.34	$1,856
	1978-1991	$5,031	59	41	430	$95	$79	0.42	-$3,268	0.52	-$2,435	0.88	-$604
	1992-2005	$4,230	15	16	169	$42	$35	0.22	-$3,713	0.28	-$3,066	0.31	-$2,917
R49 Attic, Air Sealing & New Ducts Package	Pre-1978	$8,792	164	97	1,029	$220	$184	0.56	-$4,353	0.68	-$2,837	1.07	$598
	1978-1991	$8,334	79	60	632	$135	$113	0.36	-$5,981	0.46	-$4,505	0.71	-$2,427
	1992-2005	$7,793	24	27	279	$62	$52	0.18	-$7,205	0.23	-$5,969	0.26	-$5,789
Advanced Envelope Package	Pre-1978	$18,659	222	137	1,451	$302	$253	0.36	-$13,364	0.45	-$10,354	0.74	-$4,911
Water Heating Package	All Vintages	$208	n/a	n/a	n/a	$32	$394	1.68	$160	n/a	n/a	n/a	n/a

[1] Values in red and shaded grey indicate measures is not cost effective with a B/C ratio less than 1.

Table 8: Single Family PV & Battery Cost-effectiveness Results – Climate Zone 3

Measure	Vintage	Measure Cost ($)	Electricity Savings (kWh)	Gas Savings (therms)	GHG Savings (lb CO2e)	Utility Cost Savings		Customer On-Bill		2019 TDV		2022 TDV	
						Year 1	Avg Annual	B/C Ratio	NPV	B/C Ratio	NPV	B/C Ratio	NPV
1 kW_{DC} PV System	Pre-1978	$3,986	1,596	0	104	$206	$162	1.13	$549	1.66	$2,560	1.37	$1,425
	1978-1991					$198	$156	1.08	$366	1.66	$2,557	1.37	$1,422
	1992-2005					$194	$153	1.06	$275	1.66	$2,560	1.37	$1,425
2.17 kW_{DC} PV System	Pre-1978	$8,088	3,464	0	226	$399	$315	1.06	$494	1.66	$5,350	1.36	$2,878
	1978-1991					$389	$307	1.03	$244	1.66	$5,344	1.36	$2,872
	1992-2005					$384	$303	1.01	$117	1.66	$5,344	1.36	$2,872
2.17 kW_{DC} PV + Battery	Pre-1978	$13,201	3,328	0	679	$388	$306	0.63	-$5,338	1.37	$4,908	1.12	$1,556
	1978-1991			0	683	$377	$298	0.61	-$5,589	1.37	$4,888	1.16	$2,120
	1992-2005			0	684	$372	$293	0.61	-$5,715	1.37	$4,882	1.14	$1,786

[1] Values in red and shaded grey indicate measures is not cost effective with a B/C ratio less than 1.

Table 9: Single Family Equipment Fuel Substitution Cost-effectiveness Results – Climate Zone 3

Measure	Vintage	Measure Cost ($)	Electricity Savings (kWh)	Gas Savings (therms)	GHG Savings (lb CO2e)	Utility Cost Savings		Customer On-Bill		2019 TDV		2022 TDV	
						Year 1	Avg Annual	B/C Ratio	NPV	B/C Ratio	NPV	B/C Ratio	NPV
Heat Pump at HVAC Replacement	Pre-1978	$1,555	-2,496	241	1,527	$1	$24	0.45	-$878	0	-$6,181	1.32	$501
	1978-1991		-1,895	178	1,030	$13	$26	0.50	-$807	0	-$5,781	0.78	-$340
	1992-2005		-1,651	164	793	$42	$48	0.89	-$171	0	-$3,779	1.06	$89
High-Effic. Heat Pump at HVAC Replacement	Pre-1978	$4,024	-2,284	241	1,624	$49	$62	0.44	-$2,319	0	-$7,423	0.85	-$613
	1978-1991		-1,737	178	1,104	$46	$53	0.38	-$2,581	0	-$7,354	0.54	-$1,852
	1992-2005		-1,524	164	850	$68	$69	0.49	-$2,106	0	-$5,502	0.57	-$1,748
Heat Pump at HVAC Replacement + 2.17 kW_{DC} PV	Pre-1978	$9,643	968	241	1,753	$456	$383	1.09	$912	0.92	-$789	1.35	$3,405
	1978-1991		1,569	178	1,256	$443	$366	1.04	$424	0.96	-$405	1.26	$2,550
	1992-2005		1,812	164	1,018	$453	$372	1.06	$592	1.17	$1,611	1.31	$2,988
HPWH at Water Heater Replacement	Pre-1978	$2,594	-1,308	164	1,378	-$43	-$19	0	-$3,467	0	-$3,565	1.31	$808
	1978-1991		-1,317	165	1,386	-$32	-$11	0	-$3,216	0	-$3,542	1.33	$845
	1992-2005		-1,320	165	6,211	-$35	-$14	0	-$3,312	0	-$3,539	1.28	$727
NEEA Tier 3 HPWH at Replacement	Pre-1978	$2,775	-986	163	1,488	$516	$422	1.02	$191	0.28	-$1,991	1.81	$2,249
	1978-1991		-990	164	1,500	$509	$416	1.00	$19	0.28	-$1,986	1.81	$2,249
	1992-2005		-993	164	5,883	$495	$404	0.97	-$327	0.29	-$1,963	1.76	$2,119
HPWH at Water Heater Replacement + 2.17 kW_{DC} PV	Pre-1978	$10,682	2,155	164	1,604	$516	$422	1.07	$791	1.19	$1,984	1.36	$3,885
	1978-1991		2,146	165	1,611	$509	$416	1.05	$619	1.19	$2,004	1.37	$3,916
	1992-2005		2,143	165	1,612	$495	$404	1.02	$273	1.19	$2,007	1.36	$3,798

[1] Values in red and shaded grey indicate measures is not cost effective with a B/C ratio less than 1.

4 Recommendations and Discussion

This analysis evaluated the feasibility and cost-effectiveness of retrofit measures in California existing homes built before 2010. The Reach Codes team used both customer- and TDV-based LCC approaches to evaluate cost-effectiveness and quantify the energy cost savings associated with energy efficiency measures compared to the incremental costs associated with the measures.

Based on the analysis, the following measures or packages of measures were found to be cost effective under certain conditions. Each jurisdiction must determine what measures are appropriate for their area and which cost-effectiveness methods are acceptable for justification of a reach code. They also must establish the appropriate threshold for triggering the requirements.

4.1 Efficiency Measures

Descriptions of each measure or package and the relevant requirements are provided below. In most cases, exceptions are defined which would exempt a particular project from a measure if certain conditions exist. These exceptions are based on existing on-site conditions and cost-effectiveness.

Attic Insulation: In vented attics insulation shall be installed to achieve a weighted U-factor of 0.020 or insulation installed at the ceiling level shall result in an installed thermal resistance of R-49 or greater for the insulation alone. Recessed downlight luminaires in the ceiling shall be covered with insulation to the same depth as the rest of the ceiling. Luminaires not rated for insulation contact must be replaced or fitted with a fire-proof cover that allows for insulation to be installed directly over the cover.

> Exception 1: Buildings with at least R-38 existing insulation installed at the ceiling level
>
> Exception 2: Buildings where the alteration would directly cause the disturbance of asbestos unless the alteration is made in conjunction with asbestos abatement.
>
> Exception 3: Buildings with knob and tube wiring located in the vented attic.
>
> Exception 4: Where the accessible space in the attic is not large enough to accommodate the required R-value, the entire accessible space shall be filled with insulation provided such installation does not violate Section 806.3 of Title 24, Part 2.5.
>
> Exception 5: Where the attic space above the altered dwelling unit is shared with other dwelling units and the attic insulation requirement is not triggered for the other dwelling units.

Air Sealing: Seal all accessible cracks, holes and gaps in the building envelope at walls, floors, and ceilings. Pay special attention to penetrations including plumbing, electrical, and mechanical vents, recessed can light fixtures, and windows. Weather-strip doors if not already present. Verification shall be conducted following a prescriptive checklist (to be developed) which outlines what building aspects need to be addressed by the permit applicant and verified by an inspector. Compliance can also be demonstrated with blower door testing showing at least a 30 percent reduction from pre-retrofit conditions.

> Exception 1: Buildings that can demonstrate blower door test results showing 5 ACH50 or lower or can otherwise demonstrate that air sealing meeting the requirements of this ordinance was conducted within the last 12 months.

Duct Sealing: Air seal all space conditioning ductwork to meet the requirements of the 2019 Title 24 Section 150.2(b)1E, with the exception that the duct sealing requirements be reduced from the current code requirement of 15 percent to 10 percent in alignment with the 2022 Title 24 code change proposal. The duct system must be tested to confirm that the requirements have been met. The building department may allow the contractor to self-certify, but cost-effectiveness was based upon costs for a third-party HERS Rater to verify the duct sealing.

> Exception 1: All exceptions as stated in the 2019 Title 24 Section 150.2(b)1E are allowed.
>
> Exception 2: Buildings without ductwork or where the ducts are in conditioned space.

New Ducts: Replace existing space conditioning ductwork with new R-8 ducts that meet the requirements of 2019 Title 24 Section 150.0(m)11.

Exception 1: Buildings without ductwork or where the ducts are in conditioned space.

Wall Insulation: Insulate all existing uninsulated walls with a minimum of R-13 cavity insulation in 2x4 framing and R-19 cavity insulation in 2x6 framing.

Envelope and Duct Packages: From a performance perspective, air sealing of the boundary between the attic and living space should be addressed any time there is significant work in the attic, such as adding attic insulation and sealing or replacing ductwork. When the building shell is being improved, air sealing is an important component to be addressed. The boundary between the living space and vented attics is where a significant amount of building air leakage can occur and sealing these areas prior to covering the attic floor with insulation is both practical and effective. For this reason, several envelope and duct packages were evaluated and are recommended where cost-effective. Detailed requirements and relevant exceptions are listed above for the individual measures.

Attic Insulation, Air Sealing and Duct Packages: These requirements can be triggered when an entirely new or complete replacement duct system is installed in a vented attic space in alignment with the 2022 Title 24 code change proposal. Addressing air sealing and attic insulation when attic ductwork is being replaced avoids lost opportunities to improve the building shell. While replacing ductwork the contractor accesses most areas of the ceiling and there are efficiencies to be gained with performing air sealing at the same time. Other benefits to addressing air sealing and ceiling insulation when HVAC systems and ductwork are being replaced is the potential ability to downsize equipment by reducing heating and cooling loads.

Water Heating Package: Add exterior insulation meeting a minimum of R-6 to storage water heaters. Insulate all accessible hot water pipes with pipe insulation a minimum of ¾" inch thick. This includes insulating the supply pipe leaving the water heater, piping to faucets underneath sinks, and accessible pipes in attic spaces or crawlspaces. Upgrade fittings in sinks and showers to meet current Title 24, Part 11 (CALGreen) requirements.

Exception 1: Water heater blanket is not required on water heaters less than 20 gallons.

Exception 2: Water heater blanket not required if application of a water heater blanket voids the warranty on the water heater.

Exception 3: Fixtures with rated or measured flow rates no more than ten percent greater than current CALGreen (Title 24, Part 11) requirements.

Lighting Measures – LED Lamps and Exterior Photocell Sensors: Replace all interior and exterior screw-in (A-base) incandescent, halogen, and compact fluorescent lamps with screw-in LED lamps. Install photocell controls on all exterior lighting fixtures.

Installation of PV: Install a PV system that meets the requirements of 2019 Title 24 Section 150.1(c)14. Alternatively, a smaller PV system can be required as analysis found that cost-effectiveness results do not change appreciably with a PV system as small as $1kW_{DC}$.

Exception 1: All exceptions as stated in the 2019 Title 24 Section 150.1(c)14 are allowed.

Exception 2: A smaller PV system may be installed if the proposed system capacity is larger than the maximum size allowed by the electric utility based on NEM requirements.

Installation of PV and Battery: Install a PV system that meets the requirements of 2019 Title 24 Section 150.1(c)14 and a battery system that meets the requirements of 2019 Title 24 Joint Appendix 12.

Alternatively, instead of requiring a battery system, battery-ready measures could be required with a PV installation including locating and reserving a zone for installation of a battery storage system, running conduit for a future battery storage system, and possibly panel upgrades if the main service panel is replaced as part of the scope of work.

Exception 1: All exceptions as stated in the 2019 Title 24 Section 150.1(c)14 are allowed.

4.2 Fuel Substitution Measures

HVAC Heat Pump: Replace an existing ducted gas furnace/AC with a ducted heat pump at time of equipment replacement. While it is cost-effective based on 2022 TDV for some vintages, replacement of the HVAC equipment with a minimum efficiency heat pump results in higher utility costs in some cases, resulting in negative impact on customer's ability to recover costs. Operating costs are sensitive to utility rate structures and changes in natural gas and electricity rates over time.

> Exception 1: Non-ducted space conditioning systems and systems without central air conditioning
>
> Exception 2: Ducted space conditioning systems where only the gas furnace is replaced.
>
> Exception 3: The main service panel does not have the capacity or space to accommodate an additional 240V, 30A circuit, and the cost to upgrade the main service panel and run required electrical service to the heat pump air handler is prohibitive as determined by the jurisdiction.

HPWH: Replace an existing gas storage water heater with a heat pump at time of equipment replacement. This measure is cost-effective based on 2022 TDV; although it is not cost effective based on On-Bill it does result in lower annual utility costs. Like the space conditioning heat pump, operating costs are sensitive to utility rate structures and future changes in natural gas and electricity rates.

This requirement could apply when replacing an existing water heater under the following conditions:

1. Electric resistance water heater located in a garage or vented closet with adequate space and ventilation
2. Natural gas or propane water heater located in a garage or vented closet with adequate space and ventilation, and
3. There is adequate space in the main service panel for a 240V, 30A dedicated breaker.

> Exception 1: The proposed location of the new water heater is located within conditioned space.
>
> Exception 2: The proposed location of the replacement water heater is not large enough to accommodate a HPWH equivalent in size and 1 hour capacity to the existing water heater or the next nominal size available.
>
> Exception 3: The main service panel does not have the capacity or space to accommodate an additional 240V, 30A circuit, or the cost to upgrade the main service panel and run required electrical service to the water heater is prohibitive as determined by the jurisdiction.
>
> Exception 4: A solar water heating system is installed meeting the installation criteria specified in Reference Residential Appendix RA4.20 and with a minimum solar savings fraction of 60 percent.

4.3 Other Considerations

Measure Tradeoffs for Energy Performance Equivalency: Jurisdictions looking to provide flexibility in their reach codes for existing buildings can use an energy performance equivalency results to allow projects to select alternative measures or packages to meet the energy performance of the ordinance. This approach also allows an applicant to value previous upgrades made to the building in determining which ordinance requirements should apply. If tradeoffs are adopted by a jurisdiction, it can also provide flexibility to applicants to choose upgrades from the points menu that result in equivalent performance to the applicable reach code requirement, or allow a jurisdiction to encourage installation of fuel substitution measures, such as space conditioning heat pumps or HPWHs as an equivalent alternative path to the adopted reach code measure or package. This approach is under development and will be described in the statewide report that will be published later in 2020.

HERS Rater Field Verification: HERS Rater field verification applies to duct sealing and new duct measures. It also may be required for other measures depending on the project work scope.

Combustion Appliance Safety and Indoor Air Quality: Implementation of some of the recommended measures will affect the pressure balance of the home which can subsequently impact the safe operation of existing combustion appliances as well as indoor air quality. Buildings with older gas appliances can present serious health and safety problems which may not be addressed in a remodel if the appliances are not being replaced. It is recommended that the building department require inspection and testing of all combustion appliances after completion of the retrofit work. It is also recommended that jurisdictions require combustion safety testing by a certified professional whenever air sealing and insulation measures are applied, and existing combustion appliances are located within the pressure boundary of the building.

Jurisdictions may also want to consider requiring mechanical ventilation in homes where air sealing has been conducted. In older buildings, outdoor air is typically introduced through leaks in the building envelope. After air sealing a building, it may be necessary to forcefully bring in fresh outdoor air using supply and/or exhaust fans to minimize potential issues associated with indoor air quality.

Required Measures Included in Title 24 Performance Simulation: If any of the measures above are included in a performance Title 24 compliance report, it's suggested that trade-offs be allowed as long as all minimum code requirements are met. For example, if a project is installing new windows and a new roof and insulating the attic and is demonstrating compliance with Title 24 with a performance simulation run, it would be acceptable if the installed roof did not meet the requirements listed above as long as this was traded off with either an increase in attic insulation or better performing windows. This would also allow trade-offs for projects that are installing high impact measures, such as solar water heating or whole house fans. This would require two simulation runs; however, it's not expected this approach would be utilized often. Run #1 would evaluate the proposed building upgrades. This would also be the report submitted to the building department for the permit application demonstrating compliance with Title 24. Run #2 would also be completed with the minimum ordinance requirements modeled for each of the affected building components. In order to show compliance with the ordinance the applicant would need to demonstrate that the proposed upgrades (#1) would result in annual time dependent valuation (TDV) energy use equal to or less than the annual TDV energy use of the case based on the ordinance requirements (#2).

5 References

California Energy Commission. 2018a. 2019 Alternative Calculation Method Approval Manual. CEC-400-2018-023-CMF. December 2018. California Energy Commission. https://www.energy.ca.gov/2018publications/CEC-400-2018-023/CEC-400-2018-023-CMF.pdf

California Energy Commission. 2018b. 2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings. CEC-400-2018-020-CMF. December 2018. California Energy Commission. https://www.energy.ca.gov/2018publications/CEC-400-2018-020/CEC-400-2018-020-CMF.pdf

ConSol. 2010. Water Use in the California Residential Home. January 2010. http://www.cbia.org/uploads/5/1/2/6/51268865/2010_-_chf_water_use_study.pdf

DEG. 2017. Large Scale Residential Retrofit Program. Prepared for the California Energy Commission by Davis Energy Group. January 2017. http://www.energy.ca.gov/2017publications/CEC-500-2017-009/CEC-500-2017-009.pdf

E Source Companies. 2020. Behind-the-Meter Battery Market Study. Prepared for San Diego Gas & Electric. February 2020. https://www.etcc-ca.com/reports/behind-meter-battery-market-study?dl=1582149166

Energy & Environmental Economics. 2020. Time Dependent valuation of Energy for Developing Building Efficiency Standards. 2022 Time Dependent Valuation (TDV) and Source Energy Metric Data Sources and Inputs. Prepared for the California Energy Commission. May 2020. https://efiling.energy.ca.gov/GetDocument.aspx?tn=233345&DocumentContentId=65837

KEMA. 2010. *Final Evaluation Report: Upstream Lighting Program, Vol 1.* KEMA, Inc. February 2010. http://www.energydataweb.com/cpucfiles/18/finalupstreamlightingevaluationreport_2.pdf

RSMeans. 2014. RSMeans Residential Cost Data 2014.

Self-Generation Incentive Program (SGIP). 2020. Weekly Statewide Reports. https://www.selfgenca.com/report/weekly_statewide_archives/. Accessed November 2020.

Statewide Reach Codes Team. 2018. *Existing Building Efficiency Upgrade Cost-Effectiveness Study*. June 8, 2018. https://localenergycodes.com/download/378/file_path/fieldList/Residential%20Retrofit%20Cost-Eff%20Report

Statewide Reach Codes Team, 2019. 2019 *Cost-effectiveness Study: Low-Rise Residential New Construction.* August 1, 2019. https://localenergycodes.com/download/73/file_path/fieldList/2019%20Res%20NC%20Cost-eff%20Report.pdf

Statewide Reach Codes Team. 2020. *2019 Cost-Effectiveness Study: Existing Low-rise Residential Building Efficiency Upgrade.* February 6, 2020. https://localenergycodes.com/download/96/file_path/fieldList/2019%20Res%20Retrofit%20Cost-eff%20Report.pdf

6 Appendices

6.1 Appendix A – Utility Tariff Details

Following are the Alameda Municipal Power (AMP) D-1 electricity tariffs applied in this study.

For cases with PV generation the Eligible Renewable Generation (ERG) program rules were applied. Per the Rider ERG, customers are billed at the end of each monthly billing cycle. For billing cycles where the customer is a net consumer of electricity the customer is charged per the tariff schedule for the net energy consumed over the period. For billing cycles where the customer is a net generator the customer is credited for net energy generated over the period at the actual avoided cost of procuring renewable energy for the previous year, $0.06968/kWh.

Monthly Charges:				
	Distribution	**Public Purpose**	**Generation**	**TOTAL**
Tier I: **Baseline Quantities, per kWh**	$0.03804	$0.00521	$0.06843	**$0.11168**
Tier II: **130% Baseline Quantities, per kWh**	$0.08963	$0.00521	$0.08469	**$0.17953**
Tier III: **Excess Quantities, per kWh**	$0.13524	$0.00521	$0.13188	**$0.27233**
Customer Charge	$17.30			**$17.30**

PRIMARY HEAT SOURCE	SEASON	BILLING CODE	Tier I kWh Per Dwelling Unit PER MONTH	Tier II kWh Per Dwelling Unit PER MONTH
Natural Gas / Other	Summer	B	259	336
Natural Gas / Other	Winter	B	310	404
Permanently Installed Electric Heat	Summer	H	317	412
Permanently Installed Electric Heat	Winter	H	581	756

The PG&E monthly gas rate in $/therm was applied on a monthly basis for the 12-month period ending April 2020 according to the rates shown in Table 10. Rates are based on historical data provided by PG&E.[5]

Baseline territory T was used for Climate Zone 3.

[5]The PG&E procurement and transportation charges were obtained from the following site: https://www.pge.com/tariffs/GRF.SHTML#RESGAS

Table 10: PG&E Monthly Gas Rate ($/Therm)

Month	Procurement Charge	Transportation Charge		Total Charge	
		Baseline	Excess	Baseline	Excess
Jan 2020	$0.45813	$0.99712	$1.59540	$1.45525	$2.05353
Feb 2020	$0.44791	$0.99712	$1.59540	$1.44503	$2.04331
Mar 2020	$0.35346	$1.13126	$1.64861	$1.48472	$2.00207
Apr 2020	$0.23856	$1.13126	$1.64861	$1.36982	$1.88717
May 2019	$0.21791	$0.99933	$1.59892	$1.21724	$1.81683
June 2019	$0.20648	$0.99933	$1.59892	$1.20581	$1.80540
July 2019	$0.28462	$0.99933	$1.59892	$1.28395	$1.88354
Aug 2019	$0.30094	$0.96652	$1.54643	$1.26746	$1.84737
Sept 2019	$0.25651	$0.96652	$1.54643	$1.22303	$1.80294
Oct 2019	$0.27403	$0.98932	$1.58292	$1.26335	$1.85695
Nov 2019	$0.33311	$0.96729	$1.54767	$1.30040	$1.88078
Dec 2019	$0.40178[7/]	$0.96729	$1.54767	$1.36907	$1.94945

GAS SCHEDULE G-1 Sheet 2
RESIDENTIAL SERVICE

BASELINE QUANTITIES: The delivered quantities of gas shown below are billed at the rates for baseline use.

BASELINE QUANTITIES (Therms Per Day Per Dwelling Unit)

Baseline Territories ***	Summer (April-October) Effective Apr. 1, 2020		Winter Off-Peak (Nov,Feb,Mar) Effective Nov. 1, 2019		Winter On-Peak (Dec, Jan) Effective Dec. 1, 2019		(T)
P	0.39	(R)	1.88	(R)	2.16	(I)	
Q	0.59	(R)	1.55	(R)	2.16	(I)	
R	0.36	(R)	1.28	(R)	1.97	(I)	
S	0.39	(R)	1.38	(R)	2.06	(I)	
T	0.59	(R)	1.38	(R)	1.81	(I)	
V	0.62	(R)	1.51	(R)	1.84	(I)	
W	0.39	(R)	1.18	(R)	1.84	(I)	
X	0.49	(R)	1.55	(R)	2.16	(I)	
Y	0.69	(R)	2.15	(R)	2.65	(I)	

SEASONAL CHANGES: The summer season is April-October, the winter off-peak season is November, February and March, and the winter on-peak season is December and January. Baseline quantities for bills that include the April 1, November 1 and December 1 seasonal changeover dates will be calculated by multiplying the applicable daily baseline quantity for each season by the number of days in each season for the billing period.