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California Energy Commission

CONSULTANT REPORT

Fuel Substitution Forecasting Tools

Methods Supporting Senate Bill 350 Analysis

Prepared for: **California Energy Commission**
Prepared by: **Guidehouse Inc.**

Gavin Newsom, Governor
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California Energy Commission

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DISCLAIMER

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ABSTRACT

Mandated by Assembly Bill (AB) 3232 (Friedman, Chapter 373, Statutes of 2018), the California Energy Commission (CEC) must assess the potential for the state to reduce greenhouse gas (GHG) emissions from its residential and commercial building stock by at least 40 percent below 1990 levels by 2030. Furthermore, under Senate Bill (SB) 350 (De León, Chapter 547, Statutes of 2015), the CEC must set annual targets to achieve a statewide cumulative doubling of energy efficiency savings in electricity and natural gas by January 1, 2030. One method the state will use to achieve the AB 3232 and SB 350 goals is by decarbonizing buildings through fuel substitution. Fuel substitution, when electricity substitutes natural gas, results in an overall increase of electricity consumption and may result in an increase in electric generation capacity needed. Therefore, it is important to understand how fuel substitution affects the GHG emissions from California buildings and the carbon emissions resulting from increased electric load.

The report looks at all sectors and evaluates the potential barriers and opportunities for fuel substitution in new construction and retrofit situations. This report includes information on setting a 2030 GHG emissions target; researching decarbonization technologies, costs, and potential barriers; and identifying the possible grid impacts of building decarbonization.

The CEC conducted a preliminary assessment of the relative value and feasibility for substituting electricity for natural gas in residential and commercial buildings. That 2019 study developed a tool to assess annual and hourly natural impacts at an end-use level. The project team used the 2019 analysis to develop the fuel substitution scenario analysis tool described in this report. This new tool provides the CEC the ability to forecast GHG emissions, electricity, natural gas, and cost impacts under various fuel substitution scenarios at the utility, sector, and end-use levels.

Keywords: Senate Bill 350, SB 350, fuel substitution, electrification, barriers, solutions, electricity, natural gas, scenario analysis, tool

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EXECUTIVE SUMMARY

Mandated by law, the California Energy Commission (CEC) must assess the potential for the state to reduce greenhouse gas (GHG) emissions from residential and commercial buildings by at least 40 percent below 1990 levels by 2030. Also mandated by law, the CEC must set annual targets to double energy efficiency savings by 2030. One method the state will use to achieve the targets in these two mandates is by removing GHG emissions from the building energy sources (known as decarbonizing buildings) through fuel substitution.

"Fuel substitution" in this study is defined as the replacement of natural gas by electricity as the source of energy in California's buildings and appliances. As low-carbon renewable energy generation grows in California, it reduces the rate of GHG emissions of electricity generation in the state. At a certain point, using electricity to generate heat (for space heating, water heating, industrial processes, cooking, and so forth) becomes less carbon intensive than directly burning fossil fuel based natural gas for those same purposes.

While fuel substitution offers GHG savings, it has other implications as well. Increased use of electricity may result in an increase in electric generation capacity needed. It also means additional costs for equipment and installation that must be borne by building owners or state programs. Therefore, it is important to understand how fuel substitution affects California as a whole. This responsibility falls a multitude of entities, including the CEC.

Study Scope/Objective

The CEC contracted Guidehouse (the research team) to address its need for a clearer understanding of the impacts of fuel substitution. The research team was tasked with developing an analytic framework that identifies the barriers and opportunities of fuel substitution and creates an initial assessment of opportunities to reduce GHG emissions. More specifically, the research team was tasked with:

- Reviewing the policy, technical, and cost barriers to fuel substitution across various sectors and end uses (the energy consumed by the user and defined by the designated function for ultimate use — for example, space and water heating) and discussing possible solutions.
- Analyzing implications for the utility customer and utility infrastructure.
- Characterizing fuel substitution technologies including costs, energy use/savings, performance attributes, and hourly energy use profiles.
- Developing a Fuel Substitution Scenario Analysis Tool (the tool), a software tool that implements a framework to assess the following impacts of fuel substitution on the five largest California electric utilities: decreased natural gas use, increased electricity use, emissions impacts, and cost implications.
- Using the tool to analyze the effect of fuel substitution under three CEC defined scenarios on an annual basis from 2020 to 2030
- Using the results of the tool to develop emissions graphs that show the estimate of the volume and costs of opportunities to reduce GHG emissions (known as abatement cost curves) for fuel substitution technologies that could be compared to other emissions

reduction strategies identified by the California Air Resource Board's AB 32 Scoping Plan. The scoping plan describes the approach California will take to achieve the goal of reducing GHG emissions to 1990 levels by 2020.

- Training CEC staff on using the tool.

The product of this study is the tool itself. As such the research team and CEC staff placed highest priority on designing a flexible, functional tool that can be updated/enhanced by CEC staff. Initial results presented in this report are meant to be viewed as preliminary and illustrative. Results found in this report should not be used to inform policy or be interpreted by stakeholders as the CEC's definitive forecast for fuel substitution. Rather, CEC staff should conduct its own scenarios analysis using the tool and share results with stakeholders before policy decisions are made.

Tool Objectives and Scope

The research team designed the tool based on direction from CEC staff. The primary use of the tool is to assess the effect of fuel substitution scenarios that were designed to reach various policy objectives. The following items are within scope of the tool:

- Allow the substitution of natural gas to electricity technologies
- Conduct forecast based on average usage characteristics of each technology with (where appropriate) geographic variation based on climate
- Account for the impact of expected energy efficiency programs as forecasted in other CEC efforts
- Allow users to vary scenarios at the technology, end use, building type, sector, and utility levels
- Allow users to update technology and cost data as new data become available in the future
- Calculate emissions impacts based on added electric generation, avoided natural gas usage and leakage, and additional refrigerant leakages

The following items are outside the scope of the tool:

- Substituting electricity technologies to natural gas
- Substituting of other fuel types beyond natural gas to electricity technologies
- Forecasting efficiency savings from high-efficiency natural gas technologies beyond what is already included in existing CEC forecasts
- Assessing customer behavior or market conditions and the associated impacts on adoption of fuel substitution technologies
- Conducting any building level analysis of site-specific costs or impacts
- Determining cost-effectiveness of fuel substitution technologies or programs
- Serving as the definitive source of cost data related to fuel substitution

Organization of This Report

This report is structured as follows

- Chapter 1 provides policy background on the topic of fuel substitution.
- Chapter 2 discusses the implications for customers, public safety, and utility infrastructure in a future with increasing fuel substitution. This discussion includes a review and summary the literature available to date, identification of gaps in the research available, and recommendations for future research.
- Chapter 3 provides the research team's findings related to the policy, technical, and cost barriers associated with fuel substitution for major end uses in the residential and commercial sectors.
- Chapter 4 provides the research team's findings related to the policy, technical, and cost barriers associated with fuel substitution for major end uses in the industrial and agricultural sectors.
- Chapter 5 describes the Fuel Substitution Scenario Analysis Tool, including the detailed scope, analysis methods, input data, and scenario capabilities. It also provided example output graphics/results.
- Appendices provide additional details from the team's literature reviews and documentation of the team's methods and input assumptions.

CHAPTER 1: Background

Senate Bill (SB) 350 (De León, Chapter 547, Statutes of 2015)[1] directed the California Energy Commission (CEC) to establish energy efficiency targets that achieve a statewide, cumulative doubling of energy efficiency savings by 2030. The SB 350 Energy Efficiency Report[2] forecast of energy efficiency savings included potential savings from utility programs, codes and standards, and a set of beyond-utility programs — that is, programs and initiatives that may contribute to reduced energy use throughout the state that occur beyond any reported utility program savings. One of these programs included savings estimates from fuel substitution — specifically moving from natural gas to electricity — as a beyond-utility program.

Fuel substitution opportunities exist in residential, commercial, agricultural, and industrial sectors across various end uses,[3] but the opportunity is not uniform because the use of natural gas and electric appliances/systems differs among these sectors. CEC staff directed this study to define fuel substitution as replacing gas technologies with electric technologies. In buildings, the primary gas end uses are space heating, water heating, and appliances such as clothes dryers and cooktops. For the industrial and agricultural sectors, the primary gas end use is process heating, which is the thermal energy used to prepare or treat materials for production. This report looks at all sectors and evaluates the potential barriers and opportunities for fuel substitution in new construction and retrofits.

Assembly Bill (AB) 3232 (Friedman, Chapter 373, Statutes of 2018)[4] mandates the CEC assess the potential to reduce greenhouse gas (GHG) emissions to 40 percent below 1990 levels in residential and commercial buildings by 2030. More broadly, the Legislature has mandated through Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016) that the California Air Resources Board (CARB) reduce statewide GHG emissions to at least 40 percent below the 1990 emissions level by 2030.[5] The SB 350 statewide energy efficiency doubling target considers natural gas and electricity final end uses and includes possible energy savings from the agricultural and industrial sectors. CEC staff needs to assess numerous aspects of building decarbonization and compile that information into a combined SB 350 and AB 3232 action plan and future reporting. This action plan will include:

- Information on setting a 2030 GHG emissions target.

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[1] Senate Bill No. 350. De Leon, *Clean Energy and Pollution Reduction Act of 2015*, Chapter 547, Statutes of 2015.

[2] Navigant Consulting, Inc. January 2020. *Senate Bill 350 Doubling Energy Savings by 2030 Method Report*, prepared for California Energy Commission.

[3] "End use" is the energy consumed by the user and defined by the designated function for ultimate use. For example, a gas furnace is used for the heating end use.

[4] Assembly Bill No. 3232. Friedman, *Zero-Emissions Building and Sources of Heat Energy*, Chapter 373, Statutes of 2018.

[5] Senate Bill No. 32. Pavley, *California Global Warming Solutions Act of 2006: Emissions Limit.* Chapter 249, Statutes of 2016.

- Research on fuel substitution technologies, costs, and potential barriers.
- Identification of possible grid impacts of building decarbonization — in other words, removing GHG emissions from the building energy sources.

The California Public Utilities Commission (CPUC) is implementing fuel substitution activities to comply with Senate Bill 1477 (Stern, Chapter 378, Statutes of 2018).[6]

Because many state and local initiatives are driving the state toward aggressive decarbonization goals and GHG emissions reductions, the CEC requested a study that analyzes the full potential of fuel substitution to meet policy goals. However, fuel substitution requires an increase in overall electricity consumption and may result in an increase in the electric generation capacity needed. It is important to understand how fuel substitution affects the carbon emissions from California buildings as well as the carbon emissions resulting from increased electric load. In the context of the recent legislation and understanding of the barriers and potential solution, this study also developed a tool to allow the CEC to measure the fuel substitution potential for GHG reductions and peak-demand grid impacts.

As a result, this report also documents the CEC scenario analysis for fuel substitution as a strategy under AB 3232. In 2019, the CEC conducted a preliminary assessment of the relative value and feasibility of substituting electricity for natural gas in residential and commercial buildings.[7] The CEC developed a tool that can assess annual and hourly natural gas and electric load impacts at an end-use level. The CEC's analysis became a starting point for forecasting the amount and type of additional electrical generation resources that may be needed to accommodate fuel substitution. The research team used the structure of the CEC's analysis to develop the framework of the fuel substitution scenario analysis tool (FSSAT) described in this section. The FSSAT enhances the CEC's ability to forecast GHG emissions, electricity, natural gas, and cost impacts under various fuel substitution scenarios at the utility, sector, and end-use levels.

This report reconciles SB 350 requirements with the CPUC's policy and rulemaking decisions, including the fuel substitution test (formerly the "three-prong test"), program design, and the effect on ratemaking processes. While this study did not evaluate of the benefits and market changes achieved because of recent CPUC decisions, some electric publicly owned utilities (POUs) started planning and implementing fuel substitution programs. Research on this topic is ongoing across California. The research team attempted to assemble the most recent and best available information and summarize the findings in this report as of September 20, 2019. Appendix K includes a comprehensive list of the referenced data sources.

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[6] Senate Bill No. 1477. Stern, *Low-emissions Buildings and Source of Heat Energy*, Chapter 378, Statues of 2018.

[7] Jaske, Michael. 2020. *Fuel Substitution: An Exploratory Assessment of Electric Load Impacts*, California Energy Commission. <To be published>

CHAPTER 2:
Cross-Utility and Infrastructure Implications

This chapter discusses the implications for customers, public safety, and utility infrastructure in a future with increasing fuel substitution. In the following sections, the research team reviews and summarizes the literature available to date, identifies gaps in the research available, and provides recommendations for future research in the following topic areas:

- Customer experience when served by one or more utilities
    - Overview of customers served by California utilities
    - Requirements for electric and gas service
    - Cost impacts
    - Technology impacts
- Public health and safety impacts
- Gas utility impacts
    - Gas costs and revenue
    - Gas utility technology
- Electric utility impacts
    - Electric utility infrastructure upgrades
    - Changing electric utility demand load shapes[8]
    - Housing vintage stock and increased electric loads
- Smart transition planning for consideration when launching high levels of fuel substitution

Utility Customer Impacts

The research team analyzed the customer distribution across the use cases (in other words, example of applicable situations) before identifying the specific needs and recommendations to reduce barriers to fuel substitution. The specific combination of utilities serving the customers of interest in this report are as follows:

- An investor-owned utility (IOU) providing gas and electric service to the customer
- Two IOUs providing separate gas and electric service
- An IOU providing gas service to the customer while a POU provides electricity

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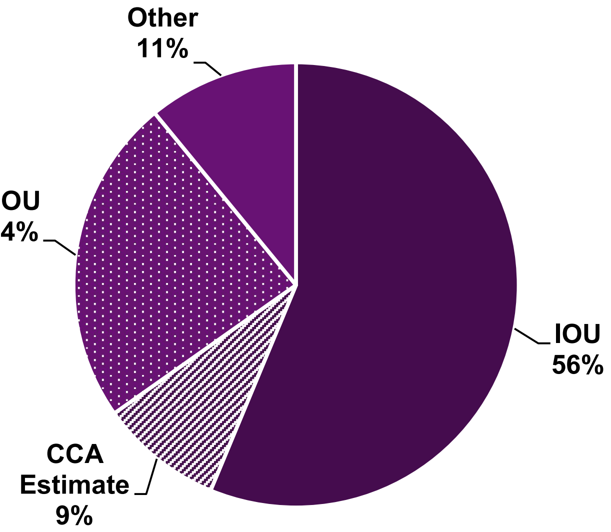
[8] A “load shape” is the annual normalized hourly contribution of energy use.

Overview of Customers Served by California Utilities

The service market for energy utilities in California consists primarily of IOUs and POUs. Customers are also served by community choice aggregators (CCAs).[9] The electric and natural gas utility service areas are split across many different utilities. Overlapping utilities and different regulatory structures lead to complications for fuel substitution. A sticking point is that the CPUC regulates the IOUs, oversees certain elements of CCA operations, and does not regulate California's POUs; POUs are governed by their respective local governments or their designees. This section discusses how customers can be served by different combinations of IOUs and POUs. Figure 1 and Figure 2 break down the energy consumption and customer allocation by each utility company type.

Figure 1: Distribution of Electric Consumption for IOUs, POUs, CCAs, and Other



IOUs, POUs, CCAs, and other utility entities serve the California market. IOUs are at 56 percent of the state electric consumption.
Source: Guidehouse analysis. Merged the average of CCA existing and projected values from CCA/IOU Load Data Spreadsheet, August 2017 workbook and CEC's 2018 statewide electricity consumption extract.

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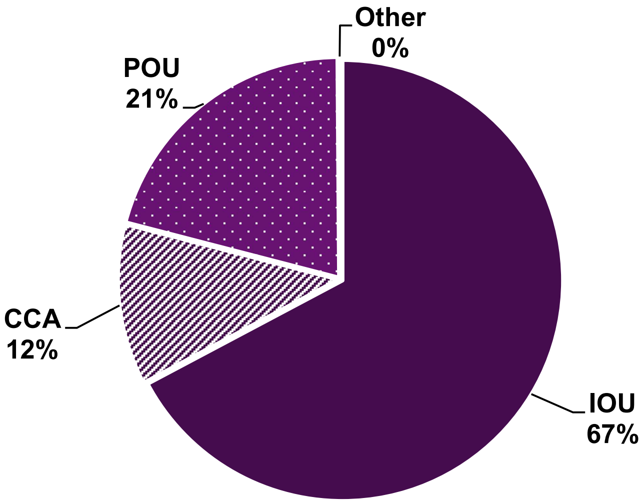
[9] "Community choice aggregators" are local governments that procure power on behalf of their residents, businesses, and municipal properties from a non-investor owned utility supplier.

Figure 2: Distribution of Electric Customers for IOUs, POUs, CCAs and Other



IOUs, POUs, and other utility entities serve the California market. IOUs are at 67 percent of the state natural gas consumption. IOUs include bundled and direct access customers, too.
Source: CEC

The literature reviewed for this report does not contain detailed information on the extent to which customers are receiving their gas and electric services from a utility or utilities. Understanding the number of electric and natural gas customers and their load profiles served by each IOU and POU, including if served by different utilities, is a critical first step in quantifying the barriers, opportunities, and costs associated with fuel substitution in California.

Understanding this distribution is important for multiple reasons. It is important to identify opportunities to coordinate utility operations, customer interactions, and even programs as customers substitute fuel sources and, in some cases, transition across different utilities. Educating customers, reducing confusion, coordinating incentives, and ensuring cost recovery of existing and new assets are likely to be easier for fuel-switching customers who receive electricity and natural gas from a single utility than for customers served by multiple utilities and are potentially in different jurisdictions.

For customers served by multiple CPUC jurisdictional utilities, coordinating messaging, incentives, and infrastructure investment and use must be carefully planned. That planning will happen in the context of each utility's internal governance, customer outreach, ratemaking and infrastructure investment, and retirement decision-making processes. Such coordination occurs now on certain renewables integration and procurement across all IOU and load-serving entities in the CPUC's Integrated Resource Plan proceeding.[10] As the CPUC noted in its 2019 decision addressing all statewide integrated resource plans:

> While local resource preferences may vary and should be respected to a degree, ultimately the electricity grid must operate as a system. With more than 40

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[10] An "integrated resource plan" documents the electric procurement policies and programs to ensure safe, reliable, and cost-effective electricity supply in the state.

> entities (and counting), the Commission is charged with evaluating whether resource procurement by all of these entities collectively will result in a reliable and affordable electric system that meets the GHG emissions reduction requirements of state law and policy.[11]

If the gas and electric utilities serving a fuel substituting customer are in separate jurisdictions (for example, provided gas service from an IOU regulated by the CPUC and electricity service by a POU that is municipally regulated), planning and coordination are complicated as specific regulatory and oversight requirements, goals, and timelines do not necessarily align across jurisdictional boundaries.

Requirements for Electric and Gas Service

When applying for new service or a change in current service, end users need to address the following according to their situation:

- **New construction barriers to utility connection:** Investigate any rules that bar customers from applying for electric and not applying for gas by service territory.
- **Existing construction barriers to change in utility consumption:** Investigate the conditions to disconnect from gas service.
- **Connections between customer program incentives:** For customers with service from two utilities, does a customer have to receive services to access electric or fuel substitution program incentives?

Cost Impacts

Changing the fuel use mix may result in upstream cost changes that affect the downstream customer:[12]

- Are there estimates for the magnitude of stranded costs for unused gas transmission, distribution, or supply contracts that may be used less or underused if utility gas demand decreases because of electrification? For example, identify the infrastructure investments, supply contract, and operations and maintenance costs associated with utility gas service.
- What are the precedents for easing natural gas service exits or other fees for recovering potential stranded natural gas system costs? Investigate parallels between fuel substitution cost effects and:
    - New solar adopters in Pacific Gas and Electric (PG&E) territory.
    - Power charge indifference adjustment and other departing load charges.[13]

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[11] California Public Utilities Commission. D.19-04-040. *Decision Adopting Preferred System Portfolio and Plan for 2017-2018 Integrated Resource Plan Cycle*, p. 104.

[12] Upstream refers to the utility side of fuel delivery versus the customer or end user who is downstream from the fuel supply.

[13] Per the CPUC: "Public Utility Code Sections 366.1 and 366.2 require the CPUC to make sure that customers leaving the utility do not burden remaining utility customers with costs which were incurred to serve them."

- The recently adopted fuel substitution test[14] addresses the program savings targets and budgets as it relates to allocating funds between gas and electricity customers for combined utilities — specifically for Southern California Edison (SCE) and Southern California Gas (SoCal Gas).

Technology Impacts

To prioritize targeted fuel substitution promotions to certain end users, program designers may rely on the immediate technical feasibility of changing technologies in specific segments. The programs should identify segments and distribution of customers unable or unwilling to implement fuel substitution and the effects on those customers:

- Is there a segment of the gas customer base that it is operationally or technologically impossible to switch from one fuel to another or for which it would be financially infeasible (for example, a bakery that has gas ovens and would have to replace all existing operational equipment)? If so, who are those customers, how many of them are there, and what are their loads and load shapes?
- Is there a segment of gas customers that is financially unable to implement fuel substitution (for example, low-income customers)? The Building Initiative for Low-Emissions Development (BUILD) program allocates at least 30 percent of funds to low-income homes, as defined by SB 1477.[15]

Public Health and Safety Impacts

Using less natural gas in the future decreases overall health and safety risks for customers. Existing literature does not detail any safety concerns to eliminating gas infrastructure or any increase in potential gas leaks. The safety discussion in this report is directed toward customer gas use in homes. Heat pump water heaters, air-source heat pumps, and ground-source/geothermal heat pumps are generally safer than gas-provided heating due to the lack of indoor gas combustion.[16] Generally, electrification at the site level decreases the risk for accidental combustion. There will be safety concerns during fuel substitution technology conversion, such as electric load increase to a home, if the electric panel is not sized properly. These concerns will need to be carefully coordinated among utilities, contractors, and laborers, especially when a customer receives gas and electric services from different sources. Furthermore, burning natural gas in homes can result in poor indoor air quality by potential exposure to nitrogen dioxide (which may induce asthma attacks) and particulate matter (under investigation).[17]

Gas leakage is a health and safety concern with natural gas infrastructure. GHG emitted by natural gas leakage takes the form of methane, which has a global warming potential 25 times

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[14] California Public Utilities Commission. 2019. *Decision Modifying The Energy Efficiency Three-Prong Test Related to Fuel Substitution*.

[15] The BUILD program provides incentives for using near-zero emissions technology to reduce GHG emissions in new single-family and multifamily homes.

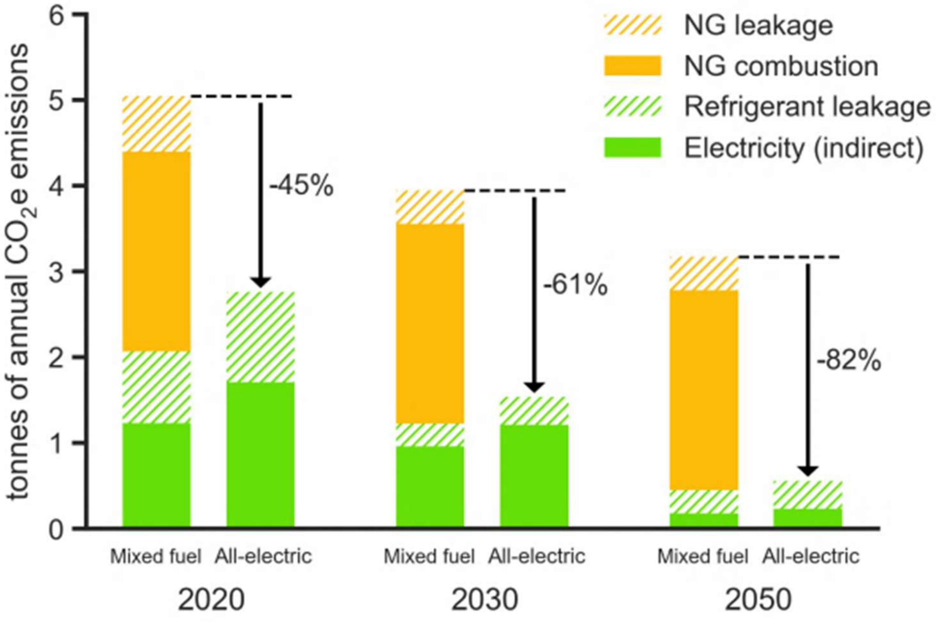
[16] Confidential research Navigant conducted for a northeast utility.

[17] California Energy Commission, "CEC Research on GHG impacts on the Natural Gas System," presented August 27, 2019.

greater than carbon dioxide (CO_2). A 1 percent leakage corresponds to a 9 percent effective increase in GHG emissions per unit of gas burned. Alvarez et al. estimates that there is a "national average leakage rate of 2.3 percent of consumption across the entire national natural gas supply chain."[18] While California has more rigorous goals for decarbonization, the state still imports roughly 90 percent[19] of its natural gas; therefore, the national average leakage rate provides better insight into the potential harm. California's gas utilities' systemwide leakage rate in 2017 was 0.33 percent, far below the national average.[20]

A CEC-sponsored and Lawrence Berkeley National Laboratory (Berkeley Lab) led project from 2015 to 2018 studied methane emissions from whole-house leaks and unburned methane from natural gas appliances. The study found an emissions rate of 0.5 percent from the residential sector.[21] Figure 3 shows projected changes in fuel leakage from Sacramento homes as the building stock transitions to all-electric through 2050. The methane leakage rate will likely continue as utilities maintain the gas infrastructure; as gas use and infrastructure decreases, the leakage rate should also decrease, reducing GHG emissions.

Figure 3: Annual Greenhouse Gas Emissions From Mixed Fuel and All-Electric 1990s Vintage Homes in Sacramento: 2020 – 2050



Bar chart showing annual GHG emissions for mixed fuel and all-electric homes. Electricity emissions for 2030 and 2050 bars assume that the next generation of low-global-warming-potential refrigerants used in all applicable systems, except for refrigerant leakage from

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[18] Alvarez, Ramon et al. July 2018. "Assessment of Methane Emissions From the U.S. Oil and Gas Supply Chain," *Science,* Vol. 361, no. 6398.

[19] Energy and Environmental Economics, Inc. April 2019. *Residential Building Electrification In California: Consumer Economics, Greenhouse Gases And Grid Impacts*.

[20] CPUC and CARB. January 2018. *Analysis of the Utilities' June 16, 2017, Natural Gas Leak and Emission Reports*.

[21] California Energy Commission, "CEC Research on GHG impacts on the Natural Gas System," presented on August 27, 2019.

refrigerators and freezers because they are the same in electric and natural gas homes.
Source: Energy and Environmental Economics, Inc., *Residential Building Electrification in California: Consumer economics, greenhouse gases and grid impacts*, April 2019.

Transmission and distribution (T&D) pipeline operators must continue to maintain the safety of the pipelines, regardless of reduced customer use, because a safety concern could affect more than just their customers. Because gas is transmitted in a pressurized manner, that same pressure must be maintained regardless of diminished use. The quality of the gas must also be maintained for similar safety issues.

The only safe way to reduce natural gas consumption is taking the pipeline out of service (complete decommissioning) – for example, removing all pipelines or natural gas delivery within the pipelines. Complete decommissioning must be paired with complete electrification in a pipeline transmission area.

Gas Utility Impacts

In Europe, complete decarbonization is accepted as definitive policy. Thanks partly to the efforts of the Gas for Climate Consortium,[22] the conversation has shifted from an electrification-only view to one that accepts a role for gas in a decarbonized future. Policy makers, advocacy groups, and gas and electric utilities have come together to constructively seek solutions to achieve a sustainable energy system.

While alternatives to natural gas are being considered in other parts of the world, those options are not discussed in this report. This section addresses only the move to electrification.

Gas Utility Cost and Revenue

With increased fuel substitution, the number of natural gas customers and the volume of natural gas sold are likely to significantly decrease. However, gas-providing utilities will expect to recover the costs of their prior investments and contracts in natural gas infrastructure and supply. Further, even if natural gas customer demand decreases due to successful electrification initiatives, the need for the utility to provide natural gas services for legacy end-use customers that do not electrify is likely to be ongoing, at least in the next 10 years.

There are four primary cost components to providing natural gas service. These components must be considered when evaluating the historical investments and contract costs utilities will want to recover:

- Commodity
- Transmission
- Storage
- Distribution

The only variable costs in these components are the commodity costs (including gas pressurization), which vary based on the volume sold and used by end users.

Natural gas transmission costs consist of two pieces:

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[22] For more information, see the Gas for Climate Consortium's website.

- Interstate gas transmission to the California border, regulated under Federal Energy Regulatory Commission jurisdiction
- Intrastate transmission pipeline costs

As a state operating under the Hinshaw Exemption,[23] California exerts jurisdiction over the regulation of all intrastate natural gas pipelines serving the state. Natural gas utilities reserve capacity on interstate and intrastate natural gas pipelines on behalf of their residential and small commercial and industrial customers (that is, the core customer base). These capacity reservations often consist of a mix of long- and short-term contracts or reservations on the intrastate and interstate pipelines; utility procurement designs these reservations to meet the peak winter demands of the utility's core customer base. Larger end-use customers, natural gas-based generators, and aggregators (the noncore customer segment) make their own long- and short-term natural gas transmission pipeline reservations, often based on their respective peak demands.

Depending on the structure, the price and duration of these core and noncore customer contracts differ for intrastate and interstate capacity reservation. Decreasing natural gas demand may reduce the revenue from these sales over the long term and may be considered a stranded contract utility cost over the short term in any fuel-switching scenario. Essentially, pipeline (T&D costs) contracts are long-term and already-sunk costs for gas-providing utilities. The research team recommends identifying the terms of such contracts, to the extent commercially available, as a factor in optimizing in any fuel-switching plan.

The literature does not directly discuss the future of gas corporations; rather, it focuses on delegating gas connection costs. Energy and Environmental Economics suggests shifting the costs of gas hookups to the builders to reduce cost increases to existing gas customers.[24] To date, the cost burden has been on the utility. Based on the literature and experts' ideas, the researchers made some inferences. Natural gas firms will want to maintain their revenue or, at a minimum, recoup the costs of any stranded assets, but the dollars-per-unit volume will need to increase because there will be less volume traveling through the pipelines.

Natural gas commodity gas costs are typically calculated and recovered separately from gas infrastructure revenue requirements. Capital investments and ongoing maintenance of systems are about equal.[25] If the industry can reduce the costs of natural gas pipeline replacement and expansion, there will still be a strong operations and maintenance component to maintain the system for existing users and overall public safety for any natural gas service requirements that remain. In some cases, systems will require replacement infrastructure for some components deemed still useful as the systems age or become obsolete.

The mechanisms that gas utilities will use to recoup costs are unclear. The revenue loss for the gas utilities will continue occur for the ongoing maintenance for system safety and delivery

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[23] "NGA Hinshaw Pipelines," General Information – Intrastate Transportation, Federal Energy Regulatory Commission, last updated December 2, 2016.

[24] Energy and Environmental Economics, Inc. April 2019. *Residential Building Electrification in California: Consumer Economics, Greenhouse Gases and Grid Impacts*.

[25] Energy and Environmental Economics, Inc. "Draft Results: Future of Natural Gas Distribution in California." CEC Staff Workshop for CEC PIER-16-011. June 6, 2019.

to remaining customers. Implementing exit fees, passing on costs to other customers, and continuing to bill exited customers are a few options for utilities. The experiences of direct access utility customers[26] and CCA end users provide guidance and ideas; other solutions may exist.

Gas Utility Technology

One factor not addressed here is the possibility of gas utilities converting natural gas to renewable natural gas or hydrogen. This topic is addressed in other studies — for example, studies completed for SoCal Gas and the CEC.[27]

Electric Utility Impacts

Proponents of the electrification-only decarbonization pathway often focus on low-cost renewables and the GHG emissions of natural gas. What is often missed is the cost to electrify the entire energy system — including electric infrastructure upgrades, storage and other resources required to support system reliability, and the costs associated with stranded natural gas assets (discussed in the prior section). Regulators and the market will also need to address equity issues, as widespread electrification could have disproportionate effects on the low-income demographic.

In reviewing the various elements affecting the electric distribution grid, researchers found that electrification may or may not have a major impact at the local level. Distribution nodes such as feeders have multiple triggers that may affect the ability of the grid to meet loads. In allocating the costs and value of the potential changes to load on a distribution node, the decision makers will need to assess the contribution of each item, including:

- Percentage under capacity.
- Scheduled upgrade due to aging infrastructure.
- Grid modernization needs.
- Distributed energy resources (DER)[28] — photovoltaics (PV), electric vehicles (EVs), energy storage — served by the feeder or on the receiving end.
- End-use load types and sectors.
- Wildfire management/prevention requirements.
- Growth in fuel substitution.

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[26] "Direct Access (DA) service is retail electric service where customers purchase electricity from a competitive provider called an Electric Service Provider (ESP), instead of from a regulated electric utility. The utility delivers the electricity that the customer purchases from the ESP to the customer over its distribution system." California Public Utilities Commission, California Direct Access Program, accessed February 2020.

[27] Navigant Consulting, Inc. July 2018. *Analysis of the Role of Gas for a Low-Carbon California Future*; Energy and Environmental Economics, Inc. "Draft Results: Future of Natural Gas Distribution in California." CEC Staff Workshop for CEC PIER-16-011. June 6, 2019.

[28] DER, as defined by the California Public Utilities Commission, are "distribution-connected distributed generation resources, energy efficiency, energy storage, electric vehicles, and demand response technologies." California Public Utilities Commission. May 2017. *California's Distributed Energy Resources Action Plan: Aligning Vision and Action*.

- Amount of available flexible load: Electrification adds to the potential revenue streams of flexible loads, including the opportunity to grow the virtual power plant model.[29] A virtual power plant consists of aggregated and optimized distributed resources that virtually provide the same service as a power plant. The more electrification occurs, the more loads are available to support the virtual power plant model.

Fuel substitution is just one of many considerations distribution resource planners need to account for when assessing infrastructure costs; fuel substitution may or may not be the tipping point that affects actual costs. Utilities must analyze the costs and barriers of an upgrade on a feeder-by-feeder basis.

Electric Utility Infrastructure Upgrades

The literature contained minimal information about the necessary infrastructure changes due to increasing fuel substitution. Aside from natural load growth due to population growth, multiple variables may affect the changes on the utility side of the meter. Figure 4 exhibits the different variables that may affect the need to upgrade the utility side of the meter.

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[29] Tarbish, Herman K. "Hollywood's Next Star Could Be Virtual Power Plants as LADWP Closes Out Natural Gas," *Utility Dive*, August 13, 2019.

Figure 4: Illustration of Load Stacking on Local Distribution Substations

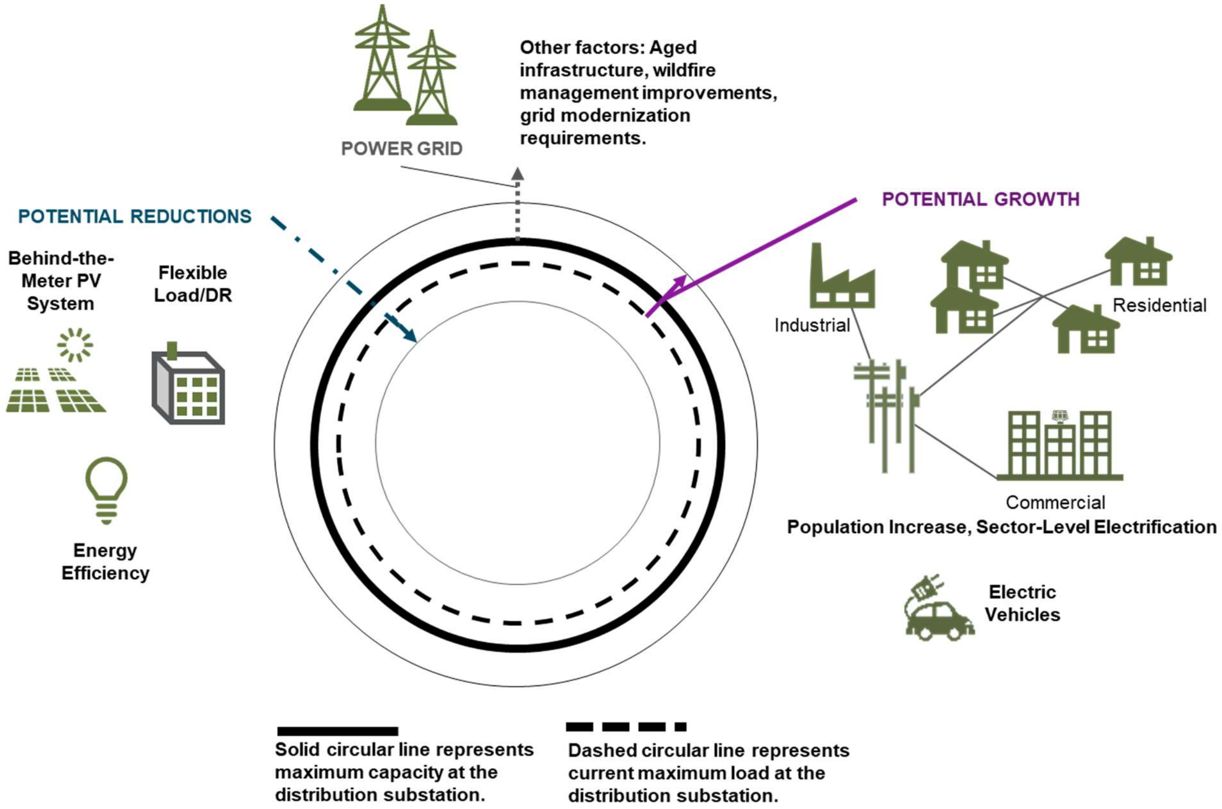

Illustration of the potential reduction and growth on the electrical system infrastructure where the need to upgrade depends on the percent capacity of the distribution substation.
Source: Guidehouse

Figure 4 exhibits the variables that may affect system upgrades on the utility side of the meter because of demand variations. Demand is not the only factor that drive grid-side updates. The following factors may affect the need for an electric utility infrastructure upgrade:

- Grid side
  - Station nearing capacity
  - Aged system
  - Grid modernization plan
  - Wildfire management improvement
- Customer side
  - Load mix (by sector and local population and business growth)
  - Proliferation of distributed generation, for example, solar PV systems
  - Availability of flexible loads
    - Storage
    - Demand response (DR)[30]

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[30] "Demand response" is a voluntary program that end users may participate in to reduce their electricity usage during a period of higher prices.

  - EVs
  - Energy efficiency
  - Electrification

Figure 4 also illustrates how conditions of each customer side factor listed can decrease or increase the load on a substation. The effects of the changing demand would need to be compared to the existing maximum load as well as the capacity of the substation. The research team presents several hypothetical substations to illustrate how increased customer side electrification may affect the grid:

- **Example A:** Substation capacity far exceeds the current maximum load to the point that load growth from electrification may not require a substation upgrade.
- **Example B:** Substation capacity exceeds the current maximum load; electrification will cause load growth that will exceed that capacity. However, customer-side DER may counteract electrification such that substation upgrades may not be needed.
- **Example C:** Substation capacity barely exceeds the current maximum load, and electrification will cause load growth that will significantly exceed the capacity. Customer-side DERs are not enough to counteract the load increase, requiring substation upgrades.
- **Example D:** The substation is scheduled for a capacity expansion tied to external needs (grid modernization, resiliency hardening) regardless of fuel substitution.

Without appropriate data on actual capacity constraints and other factors not related to electrification, researchers do not know what kinds of costs would affect various substations because of widespread fuel substitution. Researchers can assume what percentage of feeders exceed a certain threshold capacity and are in danger of not meeting load. However, they may not be able to quantify the incremental cost associated with upgrading the feeder because of fuel substitution or other reasons that may have triggered the need for an upgrade.

The actual electric utility infrastructure T&D upgrades needed will differ based on who owns the channels since they are owned by various entities. Some POUs such as Palo Alto own their transmission lines, while some use transmission lines owned by larger entities such as PG&E. Major infrastructure changes may include larger wires and updated planning to accommodate a winter peaking system, but these changes should not greatly alter the means of delivery.

Changing Electric Utility Demand Load Shapes

As fuel substitution proliferates, the load shape of combined consumption will change because of the increased contribution from heating, cooling, and water heating shapes. One example includes the penetration of space cooling where no air conditioning was present and space heating is electric in the place of natural gas. A Berkeley Lab electrification study[31] states that incremental electrification changes within specific buildings are unlikely to affect the grid; however, extensive changes to large industrial plants or an accumulation of smaller changes within a major city could require distribution system upgrades — and, in the long run,

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[31] Lawrence Berkeley National Laboratory. March 2018. *Electrification of Buildings and Industry in the United States: Drivers, Barriers, Prospects, and Policy Approaches*.

transmission system upgrades. The change to electric heating systems in regions lacking large air-conditioning loads such as San Francisco could trigger a new winter and summer peak period, subsequently requiring local distribution upgrades to meet these new peak loads. These upgrades have long lifetimes, which means they will be operating in 2050 when electric power producers may be required to reduce GHG emissions by 80 percent.[32] Section Hourly Demand and Emissions include the hourly analysis results from the FSSAT to forecast potential grid impacts. Figure 26 and Figure 27 provides hourly peak impacts for the summer and winter peak due to fuel substitution. Because of increased heat pump penetration, winter morning electricity spikes from electric heating are expected to occur.

Service Upgrades

An Energy and Environmental Economics study described infrastructure costs incurred by the builders of new construction but did not consider utility infrastructure costs. The study implies that the builders would incur capital cost savings, but if the study included utility costs in the cost-effectiveness analysis, "the capital cost savings for all-electric new construction would likely be significantly larger."[33] The electrical panel capacity of most commercial buildings can accommodate increased electric loads, and the most likely needed update is increasing circuit capacity.

Comments during the CEC's Zero Emission Buildings workshop[34] highlight how California's Title 24 Building Energy Code does not require that gas infrastructure be cost-effective, as is done with all newly adopted measures. Gas and electricity service connections have always been assumed as no-cost in Title 24. A commenter suggested that amendments to California's Title 24 Building Energy Code include the cost of gas infrastructure to allow appropriate burdening of costs and allow holistic comparisons to the baseline requirements, highlighting the effects of gas versus electric infrastructure in new construction. The comments suggest an electric infrastructure upgrade rather than replacing gas infrastructure once pipelines reach the end of useful life.

Housing Vintage Stock and Increased Electric Loads

Many older homes will require upgrades to infrastructure to accommodate fuel substitution. Many of these homes are inhabited by lower-income and disadvantaged California residents, so policies, programs, and incentives should be targeted toward those customers to make electrification upgrades accessible to all California residents. Understanding where the fuel substitution penetration may occur and how it may affect the grid locally is important. In planning for targeted electrification, the utility must consider the implications for delivering

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[32] Energy and Environmental Economics, Inc. April 2019. *Residential Building Electrification in California: Consumer Economics, Greenhouse Gases and Grid Impacts*.

[33] Ibid.

[34] "Presentations – June 14, 2018, IEPR Commissioner Workshop on Achieving Zero Emission Buildings," California Energy Commission, accessed August 2019.

more power in areas where delivery was previously lower than average for similar building stock.

The CPUC has a stated directive to focus on disadvantaged communities to encourage widespread participation but has not defined the details of these programs.[35] POUs have developed their own rebates and incentive programs to encourage broader electrification. The programs include rebates for heat pump installations and solar water heaters, among other measures. The Sacramento Municipal Utility District (SMUD), for example, developed rebates for electric water heaters, sealing and insulating programs, and gas-to-electric conversion.[36]

Pre-1978 vintage homes with 60 amperes (A) or 100 A service may require upgrades to 200 A. Specifically, homes with 60 A or 100 A service that have central air conditioning or a heat pump (a small proportion of homes) will likely require an upgrade. While most studies state the difficulty in determining the precise number of existing homes that fit these criteria, the California Residential Appliance Saturation Study[37] estimates that roughly one-third of homes in California have no central air conditioning and were built before 1982. A Navigant (now Guidehouse) report for an IOU assumes 50 percent of California homes will need a 200 A panel upgrade; however, the report does not provide a basis for this estimate.[38]

Smart Transition Planning

Several reports and studies recommend smart transition planning as key to fuel substitution to minimize the impacts to the gas and electrical infrastructure. In a Gridworks report, several strategies are outlined to help achieve this transition plan:

- "Initiate **interagency, integrated long-term planning** for gas demand, infrastructure, and the transition of the delivery system."
- "Consider requiring **all new residential and commercial construction to be all-electric as quickly as possible**, to mitigate future stranded gas infrastructure costs and to avoid committing to decades of future GHG emissions from gas combustion in buildings. Consider elimination of gas line extension allowances as a first step in that direction."
- "Identify **alternatives to significant new investments in the gas delivery system**, not otherwise needed to maintain system safety and reliability, such as electrifying neighborhoods to avoid replacing aging gas infrastructure or downrating local transmission lines to distribution by reducing the pressure as a means of reducing future maintenance costs."
- "**Anticipate and organize a just transition for the gas delivery system workforce** and any corresponding support services, such as customer service center staff and 'call before you dig' workers."

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[35] California Energy Commission and CPUC. July 2019. *California Public Utilities Commission and California Energy Commission Staff Proposal for Building Decarbonization Pilots – Draft*.

[36] Sacramento Municipal Utilities District, for example, includes electric technologies with higher rebates when switching from gas-to-electric, SMUD Residential Rebates, accessed Feb 2020.

[37] KEMA, Inc. 2009. *2009 California Residential Appliance Saturation Study*.

[38] Navigant Consulting, Inc. July 2018. *Analysis of the Role of Gas for a Low-Carbon California Future*.

- “Develop a **comprehensive strategy to ensure low-income and disadvantaged communities are empowered** through, benefit from, and are not left behind in the transition.”
- “**Clarify that a gas utility’s ‘obligation to serve’ could be met with alternative fuels** when doing so would avoid significant future investments in the gas system, reducing costs for all gas customers.”
- “Consider **aligning financial recovery of new gas infrastructure investments** with the time horizons determined in the integrated long-term gas infrastructure plan.”
- “Consider **ratemaking adjustments** such as the following to cushion the impact of the transition on customers, particularly low-income customers.”
- “Explore **external funding sources to recover gas transition costs** from sources beyond gas utility customers, such as the electric customers who benefit from increased electric load and taxpayers more broadly.”[39]

Data Gaps

While a lot of information is in circulation, there are significant gaps in what the literature provides, and significant questions are left unanswered. Fuel substitution data gathering and analysis would benefit from having estimates of the distribution of electricity and natural gas utility customers served by one or more utilities. Such data can be compiled against California census and other ZIP code data to estimate the distribution of gas and electricity customers by utilities serving the customers. Furthermore, the literature does not detail the effect on revenue to natural gas-providing utility companies, nor does it detail specific necessary upgrades for customers. Many of these gaps are due to a lack of information regarding how many sources provide consumers with their utilities. Most of the literature focused on end-user costs rather than detailing specific utility infrastructure upgrades. Consequently, further study on how customer classes are using natural gas would prove useful.

The literature briefly touched on differences between more modern buildings and buildings with older infrastructure that need upgrades; however, insufficient data provide proper information about the effects on vintage housing and lower income communities. It is also unclear whether decreasing the volume of natural gas provided to the grid will affect overall health and safety for California residents.

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[39] Gridworks. 2019. *California’s Gas System in Transition – Equitable, Affordable, Decarbonized and Smaller*, pp. 4-23.

CHAPTER 3:
Residential and Commercial Sectors

This chapter provides the research team's findings related to the policy, technical, and cost barriers associated with fuel substitution for major end uses in the residential and commercial sectors in existing and new construction buildings. The team prioritized a literature review to identify possible solutions, as well as associated policy implementation and costs, to fuel substitution adoption barriers.

This section summarizes the market as well as the barriers and opportunities for fuel substitution in the residential and commercial sectors in three subsections:

- **Market and End-Use Characterization:** Overview of the fuel substitution opportunities in various end uses in the residential and commercial sectors.
- **End-Use Barriers and Needs:** Literature review findings for the policy, technical, and cost barriers for fuel substitution in the residential and commercial sectors and a description of associated solutions and opportunities for electrifying these sectors.
- **Data Gaps:** Existing data gaps to support future research plans.

Market and End-Use Characterization

The U.S. Census estimated that of around 14 million housing units in California, single-family units compose 64 percent of the building stock, while multifamily and mobile home units combine for 36 percent.[40]

When combining these data with the 2009 California Residential Appliance Saturation Study (RASS),[41] the research team estimates that roughly 76 percent of existing homes have natural gas space heating and 72 percent have gas water heating, about 10.7 million housing units have gas space heating, and about 10.1 million housing units have gas water heating. Thus, there is significant technical potential for fuel substitution for these two end uses in homes.

Gas space heating and water heating have a high penetration in the existing commercial building stock, another high-potential area for fuel substitution.

Residential

The 2009 RASS, sponsored by the CEC, generated unit energy consumption[42] estimates for 37 existing residential end uses and appliance saturations within California service areas of the following utilities:

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[40] "Selected Housing Characteristics" U.S. Census Bureau, 2018: California Housing Units, accessed February 2020. These values are based on 1-year estimates.

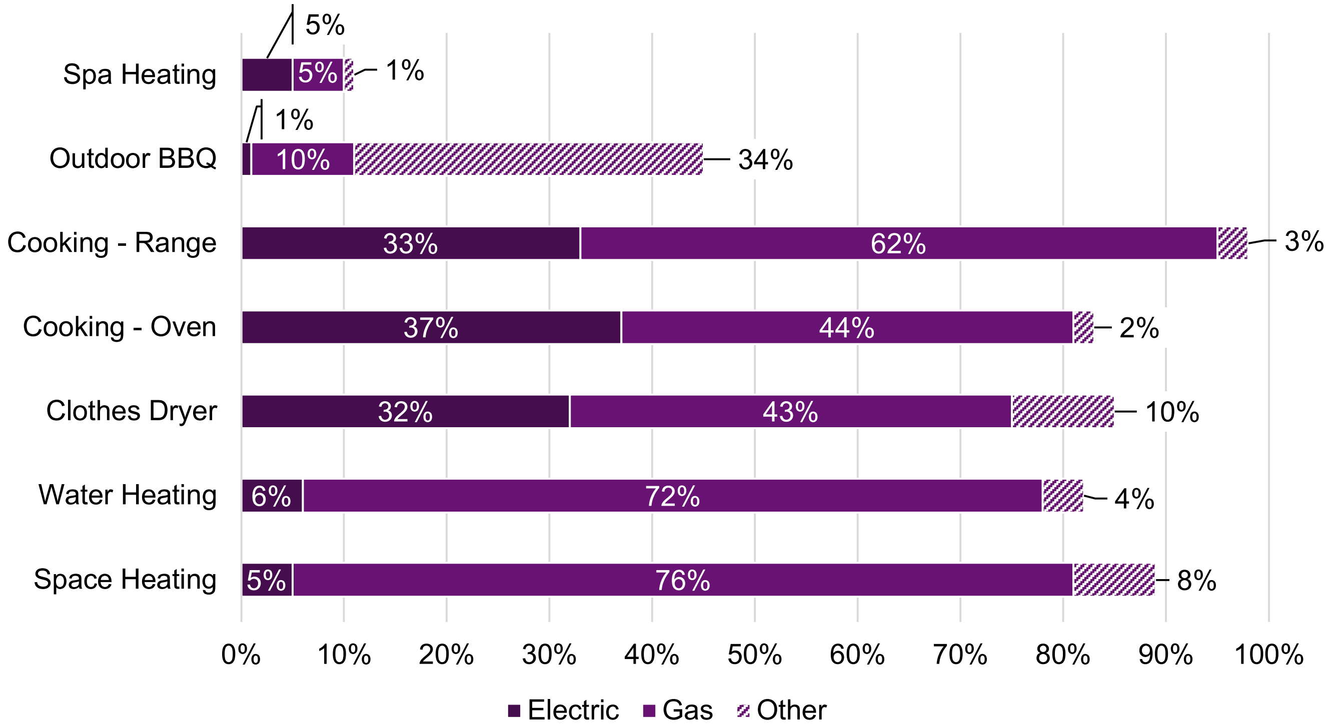
[41] California Energy Commission. 2009. *Residential Appliance Saturation Survey*.

[42] "Unit energy consumption" is the energy consumption on a per household or per square footage basis (typical scaling for commercial buildings).

- PG&E
- San Diego Gas and Electric (SDG&E)
- SCE
- SoCal Gas
- Los Angeles Department of Water and Power (LADWP)

Of the residential end uses, 27 were electric and 10 were natural gas. Research adapted Figure 5 from the 2009 RASS study; the figure portrays the combined electric, natural gas, and other fuel saturations among existing homes. Saturation does not sum to 100 percent, implying that a portion of homes do not have these end uses.

Figure 5: Fuel Type Saturations for Individually Metered Households in the 2009 California Residential Appliance Saturation Survey

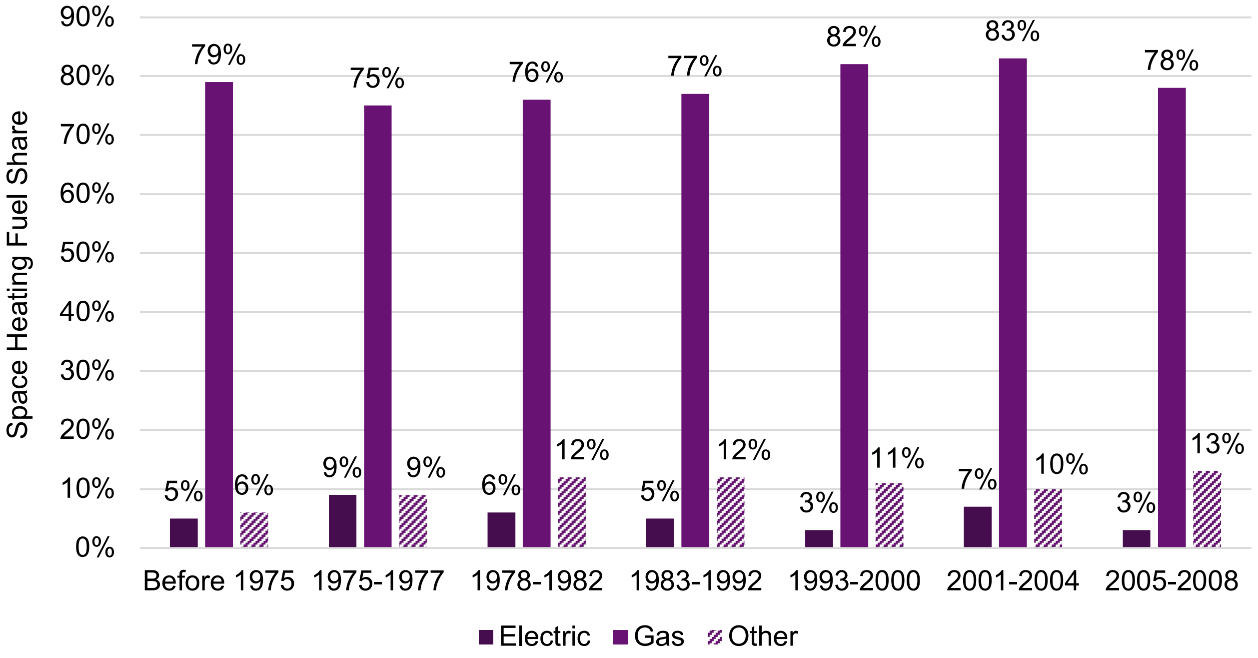


The bar graph shows the distribution of fuel types serving major household end uses as per a 2009 California survey; gas saturation is 76 percent and 72 percent for space heating and water heating, respectively.

Source: 2009 California RASS Study, p. 12

The most prevalent natural gas end uses are space heating, water heating, cooking (range and oven), and clothes dryers. Space and water heating are the highest priority for fuel substitution because they have the highest gas saturation of the end-use types. Figure 6 shows that buildings constructed between 1993 and 2004 had slightly higher shares of space heating served by gas fuel types relative to other periods. The data suggest all house vintages are good candidates for residential fuel substitution projects.

Figure 6: Natural Gas Space Heating in California by House Vintage in the 2009 California Residential Appliance Saturation Survey



This side-by-side bar chart depicts the high saturation (75 percent and greater) of natural gas space heating among dwellings built during the last 40 years.
Source: 2009 RASS Study, p. 15

Commercial

The 2006 California Commercial End-Use Survey report — prepared by Itron, Inc. for the CEC — details mixed fuel usage by end use throughout 2,800 commercial facilities in the PG&E, SDG&E, SCE, SoCal Gas, and SMUD service territories.[43] Figure 7 illustrates the proportions of energy use by various end uses among commercial buildings.

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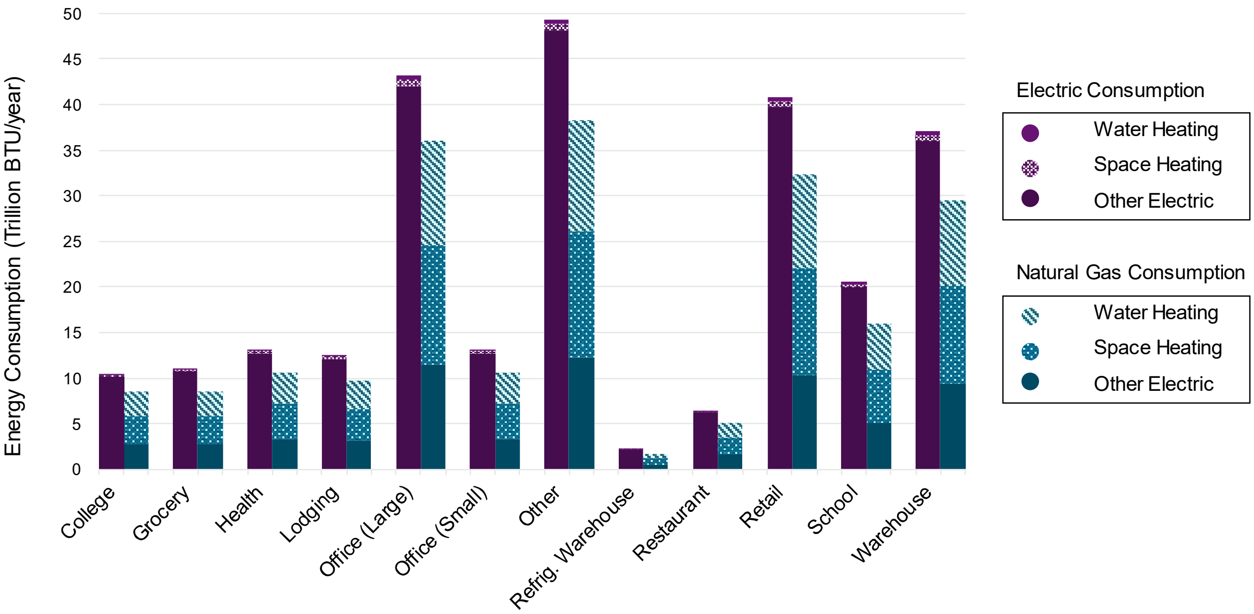
[43] Itron, Inc. 2006. *California Commercial End-Use Survey*.

Figure 7: Investor-Owned Utility Electricity and Natural Gas Consumption Overview by Commercial Building Type



Side-by-side bar chart showing electric and natural gas consumption allocation by water heating, space heating, and other by commercial building type. Large office, other, retail, and warehouse have the highest amounts of natural gas water heating and space heating.

Source: Navigant (now Guidehouse) analysis of California Public Utilities Commission *2018 Potential & Goals Study and 2006 Commercial End-Use Survey*

Residential Versus Commercial

Barriers and opportunities for the residential and commercial sectors vary significantly because of the differences in decision-making, equipment, infrastructure requirements, construction process, and codes and standards. Even though the end uses in residential and commercial constructions are the same, technical applications tend to pose larger barriers for the commercial sector. For example, the commercial heating, ventilation, and air-conditioning (HVAC) systems are far more complex than residential systems, requiring more contractor training and experience.

The residential and commercial sectors typically have different requirements because the capacity of the equipment is scaled to meet larger loads for commercial systems. Commercial buildings require mechanical equipment to scale while meeting space allocation constraints (in the case of a retrofit), requiring technical knowledge from contractors and technicians when designing such systems for either new construction or retrofit projects. The electric technologies required for space and water heating throughout large commercial buildings have higher price points compared to the residential sector due to prematurity in economies of scale and many building professionals’ unfamiliarity with such systems. This unfamiliarity requires additional time and capital to retrain staff. In contrast to residential, commercial markets have much lower market penetration of electric systems such as ductless heat pumps and heat pump water heaters because of the higher costs and lack of an adequate supply chain to support players that will stimulate market competition in the United States.

New Construction Versus Retrofit

Retrofit applications are complicated by existing conditions such as space constraints and adequate electrical service for new equipment installation. Existing state policies and utility rates further complicate retrofit installations, with barriers to offering incentives for fuel substitution (as of September 2019) and retail rates that make gas technologies more economically favorable in many service territories. In addition, customer awareness of the value, familiarity of the technologies by building professionals, and contractor skills and acceptance are low, inhibiting the retrofit potential of electric technologies.

End-User Barriers and Needs

The research team relied on other studies, especially when addressing barriers. California legislation, including Senate Bill 1477 and Assembly Bill 3232, has led to increased documentation of the residential and commercial sectors adopting fuel substitution opportunities.

Table 1 lists end-user needs and barriers to fuel substitution for the residential and commercial sectors. The barriers facing fuel substitution echo those for energy efficiency.

Table 1: Residential and Commercial End-User Needs and Barriers

Category	Barriers	Needs
Knowledge and Awareness	• Lack of knowledge by all stakeholders — end users and supply side such as contractors. • No messaging or trainings providing information on fuel substitution opportunities. • New challenges and uncertainty in fuel substitution requirements.	• **Training and education:** End users and suppliers will need to learn about the types of technologies available and ways to install them. • **Marketing and outreach:** Specific messages and campaigns are needed to promote the benefits of fuel substitution, dispelling any myths and addressing any potential concerns or pitfalls associated with fuel substitution replacements. • **Developing case studies**: Utility or state agency funding of testbed sites or information on the success and satisfaction of peer installations.

Category	Barriers	Needs
Financial	- Upfront cost and effort to replace equipment that still works. - Demand charges within the rate structure increase focus to reduce peak demand and diminish the attention given to reduce energy consumption. - Preference for short payback and return on investment (ROI).	- **More rebates:** The rebates are often critical to provide messaging of the benefits and lower the ROI. - **Financing options:** To compensate for high initial costs, utilities or other parties should offer favorable financing options to encourage adoption and offset risk. - **Price signals:** Either through carbon tax or utility rates, the price signals should align to allow flexible demand management[44] for the end user.
Reliable Equipment and Technical Applicability	- Lack of demand for electric equipment in the United States has stunted technical development and innovation to accommodate lower amperage service and climate constraints. - Insufficient electrical panel capacity at the building level and datasets differentiating between buildings requiring circuit, panel, or service upgrades. - Lack of knowledge of cost-effective system options, equipment performance data, and design guidance for central heating and water-heating systems for high-rise multifamily buildings. - Lack of knowledge of systems options for high-rise residential and commercial buildings to accommodate multiple all-electric outdoor units when many thermal zones are needed.	- **More rebates:** More utility-offered programs to subsidize panel upgrades, specifically in retrofit projects. - **Better building stock data:** Access and identification of building stock data documenting panel service, recent panel upgrades, and associated electrical permits can help inform incentive programs. - **Low-cost or low-power retrofit-ready products:** Use less power than available systems, allowing retrofits to be completed in buildings with constrained budgets or constrained electrical capacity. - **Technology availability:** Researchers are developing and testing cold climate-rated heat pumps to address reliability and generate datasets. Ductless heat pumps can help reduce spatial constraints by replacing the indoor wall-mounted units one-for-one.

Source: Guidehouse

The following subsections explore the barriers from policy, technical, and cost perspectives and discuss possible solutions and opportunities.

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[44] Flexible demand management can shift electric use to periods of low grid load and low GHG emissions.

Policy Barriers and Solutions

The existing policy barriers and potential solutions are discussed in the following sections. The table at the beginning of each section indicates the relevant sectors for the topic (indicated with an X in the applicable column).

Barriers

Fuel Substitution and the Three-Prong Test

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
–	–	X	X

The CPUC refers to fuel switching as "using a CPUC-regulated fuel to replace a fuel outside CPUC jurisdiction" (for example, gasoline-powered vehicle to electric-powered vehicle). Fuel substitution is defined as the "replacing of one type of CPUC-regulated fuel with another" (for example, natural gas-burning stove to an electric stove). IOU programs could fund fuel substitution through energy efficiency, but the fuel substitution project must meet the requirements historically set by the CPUC's three-prong test. The three-prong test, established in 1992, focuses solely on energy reduction, not GHG emissions, and is used to determine whether energy efficiency funding can be allocated for fuel substitution. Because of the ambiguity of the requirements to pass the three-prong test, most utilities did not pursue fuel substitution under the three-prong test.

In August 2019, the CPUC replaced the three-prong test with the fuel substitution test, which emphasizes fuel use and GHG emissions reductions. Because the fuel substitution test removes cost-effectiveness and aligns with state policies and CPUC technical guidance, fuel substitution may emerge within the IOU program portfolios.

Building Energy Standards (Title 24)

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	X	X	X

The Building Energy Efficiency Standards (Title 24) are an essential policy tool to help California achieve fuel substitution. For the 2019 cycle, the CEC made significant progress toward achieving a building decarbonization goal by increasing energy efficiency requirements, addressing barriers for all-electric single-family and low-rise family homes, and becoming the first building code to require new homes to be designed to zero-net-energy standards.

Hurdles remain for high-rise residential and commercial buildings. The main barriers are in the compliance software and the 2019 Alternative Calculation Manuals (which explain how the proposed and standard building designs are determined including the procedure for performance calculations) critical components of the implementation of the standards. The 2019 Alternative Calculation Manuals now aligns with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1-2016 baseline system mapping for domestic hot water and HVAC, which uses gas systems. Using the time-dependent valuation[45] metric with this baseline makes it difficult for efficient buildings with efficient electric systems to comply with the 2019 standards. The time-dependent valuation metric sets the compliance bar higher for electric systems despite the lower-source energy and GHG emissions, such that a typical efficient all-electric design would have to implement additional energy efficiency measures to achieve equivalent time-dependent valuation as a mixed fuel design and comply with Title 24.

Title 24 requirements for existing building alterations also are a barrier to fuel substitution. For example, the 2016 Title 24 requirements for home alterations specify that new or complete replacement space conditioning systems shall be limited to natural gas, liquified petroleum gas, or the existing fuel type. This issue is addressed in the 2019 Title 24 code by allowing a space-conditioning system to be a heat pump even if the fuel type of the replaced heating system was natural gas or liquefied petroleum gas.

Appropriate Baseline for Fuel Substitution

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
–	–	X	X

A challenge for fuel substitution (as with many other retrofit strategies) is what the savings claims are for an IOU program. When a code requires fuel substitution, the allowable program savings for an IOU is the difference in energy use of the proposed appliance and a minimally code-compliant appliance — in other words, savings beyond code for the proposed measure. The codes and standards program has typically claimed the difference between the existing condition and the code-minimum efficiency appliance (to-code savings) at the time the code-minimum efficiency was proposed (if the code minimum is set at the state or local level). The savings analysis for a code baseline is relatively straightforward to account for and is equitable.

The challenge is if the fuel substitution is not driven by code, but rather through a utility program or another market transformation initiative. Measure retrofit rules require a code baseline for end-of-measure-life retrofits, but they allow existing conditions baseline in limited circumstances such as early appliance retirement. With fuel substitution, the CPUC needs to revise and develop new rules that align with the fuel substitution test.[46] Draft CPUC guidance

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[45] More on time-dependent valuation can be found here: p. 67, Joint Appendix J:A3. The time-dependent valuation of energy is a participant cost-effectiveness metric to evaluate whether a Title 24 measure will save consumers money on their utility bill over the life of a new building.

[46] California Public Utilities Commission. 2019. *Decision Modifying The Energy Efficiency Three-Prong Test Related to Fuel Substitution.*

is leaning toward using the measure application type (replace on burnout vs. accelerated replacement)[47] to define the comparison (baseline) technology of the original fuel.[48]

Appropriate Metrics for Fuel Substitution

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	X	X	X

Because fuel substitution increases the target energy source (that is, electricity) and reduces the existing energy source (that is, natural gas), the typical energy and demand savings metrics based on a single fuel source between existing and retrofit do not work. For example, energy efficiency program savings for an electric utility assume electricity savings compared to code or existing electricity use. However, in a fuel substitution scenario, the electric utility would see a net increase in electricity use, whereas the natural gas utility would see a net decrease in natural gas use. This shift makes program savings claims difficult under the existing framework for a single fuel CPUC-regulated utility.[49] The CPUC needs to develop and promote alternate metrics that capture the inherent GHG emissions savings that result from beneficial fuel substitution. The changes in metrics need a CPUC rulemaking for IOUs to address effectively and send a clear signal to the market.

Another metric-related issue is whether annual benefits (for example, annual kilowatt-hour savings) are appropriate for all fuel substitution measures. Current rules for energy efficiency and DR value annual energy savings and peak energy demand, respectively. With the increased use of renewables, a need is emerging to redefine when and how demand should be curtailed. For example, there is a long history of HVAC programs supporting demand reductions between 12 p.m. and 4 p.m., whereas the current system peaks are from 4 p.m. to 9 p.m. These peaks may eventually vary with potential new winter peak periods. New metrics to address grid impacts and time-of-use aspects of fuel substitution are needed.

Natural Gas Ratemaking

As decarbonization and electrification efforts increase and market uptake grows, the cost of the natural gas infrastructure may be borne by an increasingly smaller number of customers (a disproportionate number of which may be in low-income and disadvantaged communities) unless regulatory and other mechanisms keep the gas rates in check. A recent report by Gridworks[50] summarizes this challenge:

> "Since most of the capital and ongoing maintenance costs of the gas delivery system do not vary much with changes in the volume of gas consumed, a decline

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[47] Replace-on-burnout baseline uses code or industry standard practice. Accelerated replacement is early retirement, where the existing conditions baseline is used for calculating savings through the remaining useful life; the second baseline for energy savings calculation for the remaining EUL of the replacement is code or industry standard practice.

[48] California Public Utilities Commission. October 2019. *Fuel Substitution Technical Guidance for Energy Efficiency*, Version 1.0.

[49] Building electrification programs operated by POUs do not have such constraints.

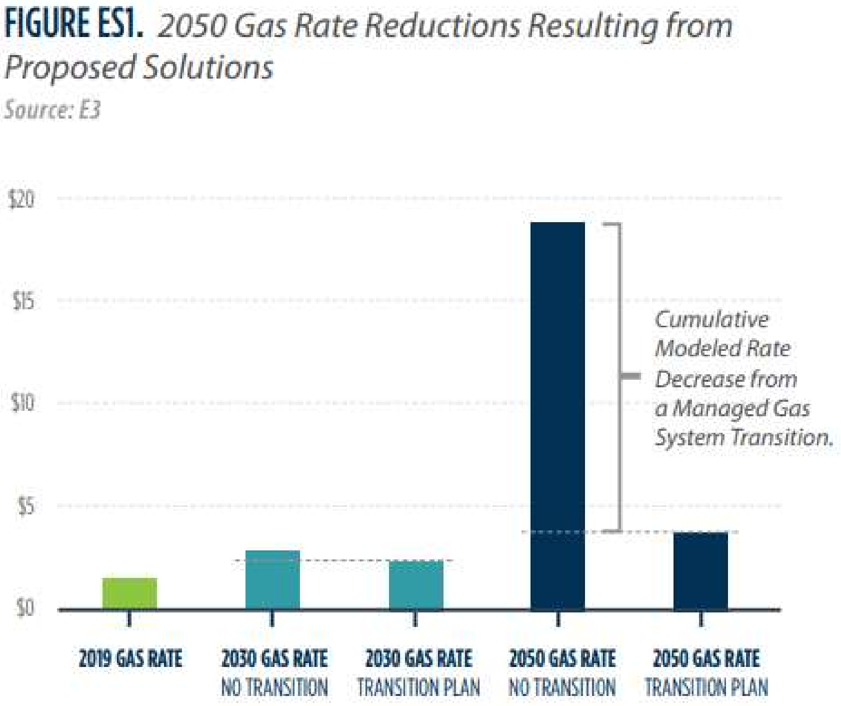
[50] Gridworks. 2019. *California's Gas System in Transition – Equitable, Affordable, Decarbonized and Smaller.*

> in gas demand will typically lead directly to higher rates and potentially higher gas bills for those who continue to use gas if the gas delivery system footprint remains static."

Any form of fuel substitution needs to consider the longer-term consequences of the natural gas infrastructure and ways to allocate costs for the remaining participants. The Gridworks report outlines several strategies to avoid such a scenario and presents two paths to California regulators:

- One path is a "smart, managed path that maximizes benefits and minimizes costs for everyone" and the other is one "uncontrolled path that is reactive and costly." The report continues to say that a "smart, managed path must consider equity and protect customers from unaffordable gas bills by enabling them to electrify."
- The reactive path is most likely to hurt those least likely to afford the transition: low-income residents. Figure 8 (from the report) shows the potential impact that "a smart, managed path" can have on gas rates.

Figure 8: Impacts of a No-Transition Plan Versus a Transition Plan on Natural Gas Rates in 2030 and 2050



Bar graph showing the effects on natural gas rates with no transition plan and with a transition plan. With no transition plan, gas rates will increase more than four times in 2050. Source: Gridworks, *California's Gas System in Transition – Equitable, Affordable, Decarbonized and Smaller*, 2019.

Solutions

This section discusses California initiatives and programs that provide possible solutions to the above-described policy barriers. These programs help promote the adoption and implementation of fuel substitution technologies by providing supporting documentation to streamline the ordinances and permitting associated with fuel substitution adoption.

To shift the market and increase penetration of all-electric appliances, this section provides policy solutions to accelerate fuel substitution:

- Orient energy efficiency goals, incentives, and savings with GHG savings options.
    - A CPUC decision modified the energy efficiency three-prong test to the fuel substitution test by simplifying the requirements. The new test is now policy.
    - Redesign method for assessing cost-effectiveness so time-dependent valuation fully values GHG emissions savings (metrics for valuing fuel substitution).
- Focus on new construction provides a higher life-cycle savings to customers and will quicken market penetration.
    - Update the building code – Title 24.
    - Develop programs to offer incentives for all-electric new construction buildings.
        - Reach code recommendations – Reach codes are local jurisdiction codes that encourage above Title 24 compliance for new buildings or major renovation
        - City council initiatives
- Develop a building fuel substitution market transformation initiative.
    - Utility programs like Advanced Energy Rebuild and SMUD’s fuel substitution initiative
    - Statewide program like those mandated by SB 1477: BUILD/TECH programs

CPUC Decision Modifying the Three-Prong Test

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
–	–	X	X

On August 1, 2019, the CPUC provided a decision to modify the three-prong test, which included renaming it the “fuel substitution test.” The decision upholds the requirements that fuel substitution offer “resource value and environmental benefits, while reducing the need for energy supply” and specifically relate to the eligibility requirements. Measures can be deemed (unit energy savings on a per-widget basis) or custom (savings calculated on a site-specific basis) incentive types and be included in custom projects. To be considered for a retrofit measure, the CPUC states the following conditions must be met:[51]

a. The measure must not increase total source energy consumption when compared with the baseline comparison measure available utilizing the original fuel, as currently defined by the baseline policies in D.16-08-019 and Resolution E-4939, Attachment A, and as may be revised by the Commission.

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[51] Energy and Environmental Economics, Inc. April 2019. *Residential Building Electrification in California Consumer Economics, Greenhouse Gases and Grid Impacts.*

b. The measure must not adversely impact the environment. This means that the use or operation of the measure must not increase forecasted CO_2-equivalent emissions impacts as compared to the comparison measure utilizing the original fuel.

The comparison measure using the original fuel, against which the fuel substitution measures is compared, must be the same for both items a and b above.

The fuel substitution test does not apply to new construction applications, but it does apply to renovations of existing buildings. The test had a few major decisions that may affect immediate program implementation:

- The test defined the applicable costs and benefits of the fuel substitution measure — for example, if a panel upgrade is required, this cost is not allocated to the measure.[52]
- Programs are reflected in the cost-effectiveness analysis of the total portfolio of the program administrator sponsoring the measures rather than on a measure-by-measure basis. The default net-to-gross ratio for fuel substitution measures should be 1.0 because there is little-to-no uptake in fuel substitution measures in the market so far.
- Pending any CPUC updates, the decision allows program administrators and implementers to use the current cost-effectiveness tool[53] to evaluate annual cost-effectiveness.
- The baseline against which a fuel substitution measure is compared should be determined in the same manner for other measures in the energy efficiency portfolio (namely, using code baseline, industry standard practice, or existing conditions depending on the circumstances of the measure installation).

The fuel substitution test requires that the measure save energy and not harm the environment (as measured by GHG emissions). According to the existing decision and the September 16, 2019, guidance, the test does not include any considerations on refrigerant use and potential leakage or fugitive emissions from methane.

The draft guidance document provides the data sources and analysis algorithm for source energy and emissions calculations over the lifetime of the measure savings. For example, renewable energy sources such as wind and solar have zero source energy. Depending on the load shape of the fuel substitution measure, the measure will add more or less emissions or source energy. Like the energy efficiency portfolio, the GHG adder[54] values may change if the GHG emissions intensity changes. Furthermore, the cost-effectiveness calculation values a kilowatt-hour GHG ton reduction higher than the same reduction in therms (favoring gasification over electrification instead of being neutral). Per CPUC Decision 19-08-009

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[52] The decision authors did not want to burden the potential benefits of fuel substitution with the full cost of a panel upgrade. End-user decisions for a panel upgrade are not limited to the fuel substitution measure.

[53] "Cost-effectiveness," Consumer Energy Resources, California Public Utilities Commission, accessed September 2019.

[54] The "GHG adder" is the valuation of the GHG emissions reduction within the avoided cost calculation. The GHG adder value depends on the quantification of the abatement cost savings, integration costs, and low-value emissions.

(modifying the three-prong test), the CPUC will address this issue in future updates to the avoided cost calculator.[55]

The decision for modifying the three-prong test requires that new fuel ratepayers fund the proposed fuel substitution measures and that energy savings accrue to those ratepayers; the fuel savings will otherwise become unavailable to the original fuel utility. The test specifies that the utility that provides the new fuel can claim the savings expressed in terms of source energy (Btu) and the equivalent reduction in energy savings goals due to the fuel substitution activities. Further, the decision instructs that the savings calculation should consider the life-cycle avoided source energy consumption of a fuel substitution measure rather than just the first-year source energy consumption. The decision acknowledges that, to be accurate, the calculation should use a forecast of the hourly marginal heat rates of the electric grid over the effective useful life (EUL) of the measure. However, the decision allows use of the annual system average heat rate (a simplified approach) because it might be more practical in the short term.

Building Energy Standard (Title 24)

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	X	–	–

As Title 24 evolves toward zero-net-energy buildings and decarbonization, each iteration addresses improvements and removed barriers. The 2019 Title 24 update took a major step toward supporting fuel substitution in new construction by allowing prescriptive and performance baselines for electric water heating and space heating in residential buildings (single-family and multifamily). The CEC can make similar efforts for high-rise residential and commercial buildings in the 2022 and subsequent Title 24 updates.

Researchers and advocates have proposed creating new baseline systems for all-electric design.[56] Two scenarios are being proposed:

- Create an all-electric baseline such that the baseline system fuel type would be electricity regardless of the fuel type of the end uses in the proposed design.
- Develop an alternate pathway for the proposed all-electric design such that the baseline system fuel type is the same as the proposed design.

A future Title 24 update could provide alternate compliance metrics to replace the time-dependent valuation metric — for example, a metric based on GHG emissions or source energy (which closely mimics GHG emissions). This change would provide an equitable path for all-electric designs compared to mixed-fuel designs. The CEC is exploring options to redefine cost-effectiveness and energy budgeting to better account for emissions reductions.

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[55] California Public Utilities Commission. October 2019. *Fuel Substitution Technical Guidance for Energy Efficiency*, Version 1.0.

[56] NRDC. 2019. Docket Number 19-BSTD-01: *NRDC comments on the Draft 2019 ACM Reference Manuals and Compliance Software Tools.* TRC Companies, Inc. 2019. *2022 CASE Initiative Workplan: Multifamily All-Electric Compliance Pathway*.

To align with the net zero energy goal, Part 6 of 2019 Title 24 – Building Energy Efficiency Code (Section 110.10) outlines "Mandatory Requirements for Solar Ready Buildings." These requirements are for the residential and commercial sectors (new construction and retrofits) and require the "main electrical service panel have a minimum busbar rating of 200 amps." [57] These requirements are intended to meet the needs for solar generation while indirectly paving a pathway to provide capacity for buildings to accommodate all-electric loads.

Reach Code Recommendations

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	X	–	–

Reach codes are a type of local ordinance that set or exceed minimum building code requirements, as outlined in 2019 Title 24. Such reach codes can take the form of energy efficiency measures or construction codes. Local jurisdictions adopting local ordinances for buildings to exceed statewide standards must apply to the CEC and document the cost-effectiveness of the ordinance before being cleared through the California Building Standards Commission and put into effect.[58]

TRC Companies, Inc. conducted an electrification measure study for the City of Palo Alto and made the following recommendations:[59]

- Encourage or require policies for all-electric residential and commercial new construction.
- Examine policies that require higher-capacity electrical requirements for residential buildings through amendments to the city's electrical codes.
- Identify targeted electrification areas of greatest need by surveying the percentage and location of the California building stock that requires panel upgrades.

This study also suggests that, for small commercial buildings, packaged rooftop air-conditioning units require equivalent electrical service as packaged heat pumps. This requirement would make small office commercial buildings capable of accommodating heat pump retrofit measures without additional electrical upgrade costs.

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[57] Additional code requirements available in Sections 110.10(b) through 110.10(e) of *2019 Title 24 – Building Energy Efficiency Standards*: CEC-400-2018-020-CMF-T24; California Utilities Statewide Codes and Standards Team. September 2011. *Solar Ready Homes and Solar Oriented Development.*

[58] Retrieved from California Energy Codes and Standards, A Statewide Utility Program: https://localenergycodes.com/.

[59] TRC Companies, Inc. September 2018. *City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT.*

Valuing Fuel Substitution

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	X	X	X

Different considerations are needed to value fuel substitution than the standard kWh or therms reduction in energy efficiency. The fuel substitution test provides guidance on qualifying the measure in the context of reducing emissions and fuel use but does not provide guidance for cost-effectiveness neutral of fuel and utility provider.

SMUD developed a metric to value fuel substitution that it presented at a CEC workshop on August 27, 2019. The metric uses carbon to maximize local benefits for planning and is based on calculating marginal carbon savings instead of first-year kilowatt-hour or therm savings. SMUD adopted in January 2020 to use carbon as the metric to value benefits from energy efficiency and fuel substitution.[60] Its analysis uses:

- Hourly marginal carbon emissions from the grid.
- Hourly load/savings profiles of efficiency and electrification measures.
- Carbon reduction from fossil fuels eliminated by the customer.

SMUD is also reviewing how to calculate a programmatic carbon reduction by shifting the annual stream of carbon reductions to the first year as part of program optimization planning. This stream includes changing the electricity grid fuel mix and emissions.[61]

Another option to consider is a method to assess cost-effectiveness so time-dependent valuation fully values GHG emissions savings (metrics for valuing fuel substitution). A cost-effectiveness analysis must incorporate an hourly valuation over the lifetime of the measure to properly value the benefits. As the bulk electricity grid decarbonizes, hourly GHG emissions from the grid will decrease over time as well. Forecasting or assuming how much the bulk grid decarbonizes involves some uncertainty. A publicly vetted singular forecast of hourly GHG emissions factors to use in such analysis will address this uncertainty.

Furthermore, the valuing of energy efficiency-DR potential integration assumes added significance in electrification. Fuel substitution will increase the electric system load, increasing the need for DR to provide grid services. Representation of DR impacts from these technologies and the interactive effects between energy efficiency and DR from these technologies would assume increasing importance as the portfolio of electrification technologies grows over time.

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[60] SMUD. "SMUD first in US to change efficiency metric to 'avoided carbon," news release, February 3, 2020.

[61] SMUD, "SMUD – Using Carbon as an EE Metric," presented August 27, 2019.

Utility Program Incentives and Fuel Substitution Initiatives

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	–	X	X

With the push to eliminate natural gas and the updated fuel substitution test, new IOU electrification incentives are expected to surface (and have been rolled out). CCAs, POUs, and regional energy networks have started delivering programs before the change to the CPUC policies.

A variety of program models and approaches encourage early and aggressive adoption of fuel substitution technologies. These approaches include market transformation programs, rebate programs, and other initiatives. Some of the most successful heat pump and heat pump hot water heater programs focused on promoting the equipment switch through upstream or midstream[62] incentive programs. These programs and the subsequent evaluation reports provide insightful data to improve these types of programs over time. The most prevalent residential retrofit projects have been in Massachusetts, Maine, Vermont, and the northwestern regions of the United States.[63] Specific examples in California of programmatic solutions are outlined in the following sections.

Advanced Energy Rebuild

This PG&E-funded incentive is part of the utility's larger Respond, Rebuild, Resilience commitment, which the utility established in response to extreme weather onset from climate change. The program specifically allocates more funds toward energy efficiency practices for new residential construction. Upon pulling a permit for new construction, persons who lost houses during the 2017 and 2018 Carr, Camp, and Tubbs fires are eligible for these incentives, no matter the location of their reconstruction.[64]

Marin Clean Energy, a CCA in Northern California, teamed up with PG&E, the Bay Area Air Quality Management District, the Bay Area Regional Network, and Napa County to extend the Advanced Energy Rebuild program to Napa County residents. A Bay Area Air Quality Management District grant and California utility customers fund this program; PG&E and Marin Clean Energy administer it with authorization through the CPUC. Funding is provided on a first-come, first-served basis for projects meeting eligibility requirements. The deadline to reserve funds was December 31, 2019, or once all funds are allocated. Table 2 summarizes the incentive offerings; Appendix B provides a more detailed list.[65]

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[62] "Upstream" refers to manufacturer incentives. "Midstream" programs offer incentives to distributors and retailers to buy down the costs for end users.

[63] Additional information available on p. v of the American Council for an Energy-Efficient Economy's *Energy Savings, Consumer Economics, and Greenhouse Gas Emissions Reductions from Replacing Oil and Propane Furnaces, Boilers, and Water Heaters with Air-Source Heat Pumps* report.

[64] Additional information and program application details available on the program website.

[65] Additional incentive information, case studies, and application details available at the Advanced Energy Rebuild website.

Table 2: Summary of Advanced Energy Rebuild Incentive Offerings

Options	Incentive	Incentive Overview
Above-Code Home	$2,200 (starting)	Marin Clean Energy add-on available (up to $7,640), including solar
Advanced Energy Home	$7,500	Mixed fuel with $3,000-$5,000 available for solar with storage
All-Electric Home	$12,500	All-electric with $3,000-$5,000 available for solar with storage
Solar Option	$5,000	Designed to offset annual electric usage with a 7.5 kWh battery energy storage system coupled with the PV array

Source: California Advanced Homes Initiative, accessed August 2019

SMUD Fuel Substitution Initiative

SMUD initiated a program to replace gas equipment with electric options and a separate rebate to pursue defined steps toward achieving an all-electric home.[66] The Home Performance Program provides an avenue for SMUD customers to pursue whole-house bundled energy efficiency upgrades, including a Go-Electric Bonus Package. This package includes a rebate up to $13,500, broken into the following steps:[67]

- $2,500 for a gas furnace replacement with a heat pump HVAC system.
- $3,000 for a gas water heater replacement with a heat pump water heater.
- $2,500 to make the home all-electric-ready by wiring for an EV charger and all-electric appliances.
    - This rebate provides $500 for each new electric circuit, up to $2,500 if a panel upgrade is required.
    - EV charger, cooktop/range, and clothes dryer circuits are eligible.

SMUD is structuring a rebate offering for new construction all-electric homes and an additional rebate for electric-ready homes that have enough electric infrastructure such as wiring, breakers, service panels, and plugs; this infrastructure allows an easier transition to all-electric equipment and appliances.

SB 1477: BUILD/TECH Programs

Rules at the CPUC separate funding streams into energy efficiency, DR, renewables, and storage. These funding streams are independent and generally not allowed to be intermingled at the project level. It is hard to have an integrated DER program that encourages efficiency, renewables, and storage under one funding source.

To address this barrier, the California Legislature passed SB 1477 to develop two clean-building pilot programs focused on GHG emissions from buildings:

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[66] Nadel, Steven. August 1, 2018. "New Programs Nudge Homeowners to Switch to Electric Heat Pumps." *ACEEE Blog.*

[67] More information available on SMUD's website.

- **Building Initiative for Low-Emissions Development (BUILD) program:** Offers incentives for buildings (specifically new construction) to "build clean from the start" via high-efficiency heat pumps, solar thermal storage, energy efficiency, battery storage, and home energy management systems.
- **Technology and Equipment for Clean Heating (TECH) program:** Aims to spur the state's market for low-emissions space and water heating technologies in new and existing homes by offering incentives to distributors and retailers to stock the equipment. It also provides consumer, contractor, and vendor training to support these technologies.[68]

Other Examples

Some electrification programs have already been developed*,* and implementers are prepared to incorporate upon CPUC approval. The Bay Area Regional Network's multifamily building energy efficiency programs have program rules in place for retrofit packages; these rules require that at least three measures cumulatively reduce consumption by no less than 10 to 15 percent. After meeting this requirement, the program offers a $750 rebate per dwelling to eligible property owners. Programs such as this promote fuel substitution by electrifying appliances that yield energy savings through the higher efficiency appliances (for example, washers and heat pump dryers); the savings from these appliances count toward the 10 to 15 percent savings mark required to receive rebates. These rebates could also help customers maintain the all-electric appliance when replaced on burnout or accelerated replacement instances arise.

City Council Initiatives

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	–	X	–

Cities and other California jurisdictions have added building decarbonization (electrification) into their local ordinances. In a new ordinance taking effect January 1, 2020, Berkeley (via its city council) is banning natural gas hookups for new low-rise multifamily buildings. San Luis Obispo and San Jose City Council put a similar measure in motion. This phasing-out of gas is also being pursued by U.S. and European governments — California's aggressive GHG reduction goals have been a catalyst to these initiatives to meet the 100 percent zero-carbon-energy goal by 2045.[69]

Other jurisdictions are moving to either ban new gas connections, promoting electrification, reducing emissions, or a combination in their local legislature. Table 3 provides an overview of cities and counties' progress toward these initiatives.

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64 More information available at SMUD Residential Programs, accessed August 2019, and Building Decarbonization Pilots.

69 Gerdes, Justin. August 23, 2019. "2020 Looks Like the Breakout Year for Building Decarbonization in California," *Greentech Media.*

Table 3: Status of California Jurisdictions Adoption of Legislation Regarding Fuel Substitution (as of August 2019)

Jurisdiction	Status	Ban	All-Electric Reach	Electric-Preferred
Berkeley	Approved	X		
Carlsbad	Approved		X	
Davis	Second Reading			X
Marin County	Second Reading			X
Menlo Park	Approved	X	X	
San Jose	Second Reading			X
San Luis Obispo	Second Reading			X
San Mateo	Approved			X
Santa Monica	Approved			X
Windsor	Second Reading		X	

Source: TRC Companies, Inc., Reach Code Update Tracking on behalf of Peninsula Clean Energy, Silicon Valley Clean Energy, East Bay Community Energy, City of San Luis Obispo and the Statewide IOU Codes and Standards Team

Technical Barriers and Solutions

Technical barriers to electrification and decarbonization exist for various parties, including the utility, customer, contractor, and policy-governing agencies. This section discusses the residential and commercial sector-specific equipment, infrastructure upgrade, and consumer-based barriers to implementing and dispatching electric equipment and appliances for retrofit and new construction projects.

One of the major barriers within the residential sector is the capacity of the electrical panel and the upgrades needed to address fuel substitution in older homes. This technical barrier stems from older homes having 100 A or lower panel capacities; retrofit electric technologies, such as heat pump dryers and hot water heaters, are not available in lower wattage/amperage options in the United States. Moreover, when it is time for a replacement (typically under replace-on-burnout situations), there is no time to wait for planning and construction, which may be needed when changing fuels. Therefore, most replacement technologies operate on the same fuel as the removed technology.

Based on current incentive offerings and policies, the Energy and Environmental Economics study expects new construction all-electric homes to be at lower cost than gas or mixed-fuel new construction homes. New construction electrification offers a short-term payback and life-cycle savings compared to retrofit projects.[70] When comparing life-cycle savings of a retrofit to new construction, retrofit homes see less cost savings, which is because of the required 200 A

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[70] Energy and Environmental Economics, Inc. April 2019. *Residential Building Electrification in California: Consumer Economics, Greenhouse Gases and Grid Impacts.*

panel upgrade and potential wiring, distribution line, and circuit upgrade costs needed for older homes.

For high-rise residential units and commercial buildings, the main technical barriers are lack of cost-effective system options, equipment performance data, and design guidance for central heating and water heating systems. Existing cost-effectiveness studies for electrification have not directly addressed high-rise multifamily buildings with central systems because of limitations of the compliance software and lack of data on system design options, costs, and feasibility. The statewide codes and standards program is working on the 2022 Title 24 case studies to address this knowledge gap for the 2022 Title 24 code cycle.

Barriers

Electricity Service Upgrades

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
–	–	X	X

Required electricity service affects retrofit projects more heavily than new construction projects because new construction projects can be proactive in prepping their sites with adequate panel capacity to meet future anticipated electric loads. Most homes would need 200 A service panels, which are typical in older homes. Before an owner of an older home replaces his or her existing gas equipment with all-electric, the owner will need his or her electricity service assessed to determine if a service upgrade to a higher amperage is required. For retrofits, the contractor must obtain building plans and any documentation required to assess the baseline service infrastructure of the building; this requires a case-by-case approach.

There is no statistically valid dataset showing what percentage of existing buildings have adequate panel capacity and other electrical upgrades to meet fuel substitution needs. An overall lack of data documenting the cost to upgrade these infrastructures does not allow indirect estimates or historical tracking of cost-to-upgrade trends. Typically, this one-time upgrade can be expensive and a deterrent to the customer seeking to pursue an all-electric building. This added cost, on top of an already higher capital cost of the all-electric equipment, generates a need for greater offerings with incentives for such equipment and upgrade services.[71]

Panel Upgrades

The 2019 Palo Alto Electrification Study, compiled by TRC Companies, Inc., identified a 200 A panel as able to meet a 2,700-square-foot all-electric single-family home load for new

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[71] 2016 Title 24 Nonresidential Alterations Reach Code Recommendations Report Cost Effectiveness Analysis for California Climate, CALGreen Cost Effectiveness Study.

construction and retrofits.[72] The 200 A panels are the market standard for panel replacement given typical heat pump, heat pump water heater, and all-electric appliance loads.[73]

New construction homes, specifically those with EV charging and PV systems incorporated into the building design and construction, do not typically require electrical infrastructure upgrades. However, homes with sub-200 A panels or larger existing homes that are approaching or exceeding capacity on existing 200 A panels may need options to upgrade a branch circuit to serve a new heat pump water heater.[74] This option decreases the investment required but caters to consumers who may already have most all-electric appliances and only wish to add an electric or heat pump hot water heater.

It is hard to determine what stock of homes would need a simple branch circuit upgrade versus the full panel upgrade. California electrical code requirements for electrical panel capacity are updated regularly. New homes constructed in the past decade-plus would have 200 A panels based on the electrical code requirements. Older homes are unlikely to have 200 A panels solely due to code requirements; however, some fraction of those older homes may have upgraded to a 200 A panel during home remodels, electrical upgrades to the house, or reconstruction after natural disasters and other events. Therefore, code vintages do not directly correlate with what fraction of existing homes have 200 A panels.

Electrical Wiring

Electrical wiring requirements and standards have changed over time and require large appliances such as dryers, heaters, and water heaters to be on dedicated circuits. Further, these larger appliances typically require larger capacity circuit breakers (30 A – 50 A) than typical for lighting and general plug-in fixtures (typically 20 A). For most new construction homes, adding separate circuits and wiring for fuel substitution is not costly. Title 24, Part 6 requires water heaters to be electric-ready by having a dedicated circuit and outlet next to a gas water heater so that a replacement can be an electrical water heater.

In older homes, the type, gauge, and quality of the electrical wiring vary significantly. Homes built before 1950 commonly have knob-and-tube wiring, which uses single insulated copper conductors encased in porcelain tubes and supported by porcelain knob insulators. Building codes now prohibit knob-and-tube wiring from new construction because of concerns about safety, fire, and lack of adequate capacity. Several generations of power cables have replaced knob and tube, each iteration safer and higher capacity than the previous version. As with panel sizes, no one-to-one correlation among house vintage, location, and type of wiring exists. It is not uncommon to have different generations of wires within an existing building based on repairs, additions, and partial upgrades to the electrical wiring.

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72 According to California Title 24, Part 6, Section 110.10 (b)1: for solar, "the main electrical service panel shall have a minimum busbar rating of 200 A." This is assuming that new construction single-family homes will have solar, as per California's Title 24 mandate for 2020.

73 TRC Companies, Inc., *City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT*, September 2018.

74 Navigant Consulting, Inc. 2018. *Impacts of Residential Appliance Electrification*. California Building Industry Association.

Underground Feeder Lines

Another issue related to service upgrades is that the main service drop to the building may be underground (electrical supply cables buried directly in the ground instead of buried in a conduit in the ground). This situation is likely more prevalent in commercial buildings, though there are instances of underground electrical service in older neighborhoods — either due to the utility preference or aesthetic considerations by the building owner.

HVAC Space Heating

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	X	X	X

Industry practitioners have recommended heat pump technologies as the solution to achieving fuel substitution for space heating. While there are still some minor technical barriers in low-rise and midrise residential units, the main barriers are in high-rise residential units and commercial buildings, both retrofit and new construction.

The list below contains key technical barriers; some that overlap with fuel substitution are noted in a decarbonization memo to the CPUC:[75]

- Standard heat pump equipment has less reliable performance in colder climates because of a lack of real-world demonstrations. This challenge is being addressed through an effort led by the Northwest Energy Efficiency Alliance, which has developed and tested cold climate-rated heat pumps that address reliability and performance data issues.
- Consumers are concerned with the aesthetics of heat pump systems. The common air-source heat pump systems include packaged terminal system, mini ductless split systems, ducted split systems, and packaged heat pumps. All systems consist of an outdoor unit that usually hangs on exterior walls or is installed on the roof or ground. For large buildings, there could be hundreds of outdoor units, resulting in aesthetic concerns.
- Contractors lack knowledge of the technology and are unable to communicate the value proposition to the consumer.
- Building layouts may not be conducive, especially for high-rise residential buildings and large commercial buildings. Manufacturers limits refrigerant piping length, such that the outdoor unit of a heat pump system cannot be too far away from the associated indoor unit, which is installed in the space it is serving. In addition, when there are too many thermal zones in a large building, it becomes a challenge to find space to locate all the outdoor units.
- Ground-source heat pumps require extensive excavation engineering, higher upfront costs, and long-term returns on investment (ROIs).

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[75] Opinion Dynamics memo to the CPUC, *SB 1477 BUILD and TECH Programs Thought Paper,* April 22, 2019.

When retrofitting heat pumps or other electrical systems in existing low-rise homes, the contractor needs to address technical constraints such as electrical circuits and electrical panel sizes, as well as practical problems such as available space. When switching from a gas furnace/split air-conditioner combination (common in many California homes), the heat pump system can be easily retrofitted within existing locations for the indoor and outdoor units. However, homes with wall furnaces or furnaces located in closets present spatial and technical challenges to retrofitting heat pumps. Ductless heat pumps could be one solution, but they need to be located on external walls rather than in the closets, where furnaces are typically installed.

For high-rise residential and large commercial buildings, several HVAC all-electric alternatives exist, but each has challenges:

- Variable-refrigerant-flow air-source heat pumps have been more prevalent in the commercial than residential sector and are still considered an emerging and costly technology in the United States compared to the global commercial sectors. Variable-refrigerant-flow systems present higher environmental costs because of the large volume of refrigerant required by the system design.[76]
- Large-scale heat pumps for commercial buildings are not affordable at scale and have not reached the desired efficiencies considering the system size needed to serve space loads.
- Electric-resistance heating cannot achieve compliance without other energy efficiency measures (such as improved envelope efficiency) because of the current Title 24 compliance time-dependent valuation metric. Because of the heating inefficiency, Title 24 prescriptively prohibits electric-resistance heating for commercial constructions.

Retrofits for high-rise residential and commercial buildings using gas systems for space heating present some unique technical challenges for fuel substitution opportunities. Because the central hydronic system using a gas boiler as the heating source is the leading HVAC space-heating approach for large commercial buildings,[77] several all-electric alternatives are available.

- The best fit option to retrofit an existing gas boiler system is to replace it with a heat pump hot water boiler. Some challenges with this approach include the following:
    - The existing hot water pipe and terminal heating coil are sized for high temperatures, while commercial size heat pump hot water boilers provide significantly lower hot water temperature, between 110°F and 130°F. Lowered hot water temperature may result in degraded heat capacity.
    - When switching from high hot water temperature to low temperature, pipes may leak.

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[76] Synapse Energy Economics, Inc. October 2018. *Decarbonization of Heating Energy Use in California Buildings: Technology, Markets, Impacts, and Policy Solutions.*

[77] Additional details available in the Itron report (CEC-400-2006-005).

- Electric-resistance heating is a viable option to replacing the existing hot water coil in a terminal unit, such as the fan coil and variable air volume terminal unit. However, as mentioned above, this option cannot easily achieve compliance.

Domestic Hot Water

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	X	X	X

Alternative-fuel-source water heating options are electric hot water heaters, tankless electric hot water heaters, heat pump hot water heaters, and CO_2 heat pump water heaters, which typically have the highest installed cost.

Commercial-scale heat pump water heaters are a relatively new design approach to decarbonize domestic water heating; no design guidelines exist to ensure appropriate design.[78] Industry modeling software, such as CBECC-Res,[79] lacks the product design specifications to model central heat pump water heaters.[80] With a lack of uniform design guidelines within the technician community, market penetration is stunted by the more common plumbing skillset of natural gas system technicians. With the relatively new introduction of these systems in the market, the National Appliance Energy Conservation Act has not published standards, which is a barrier to the residential and commercial sectors. Overall, researchers identified the following barriers to entry for heat pump water heaters:[81]

- For residential:
    - Customers may be unfamiliar with the technologies.
    - There is a misconception that heat pump water heaters are noisy
    - Retrofits can involve electric panel upgrades for larger volume units if other wiring upgrades and additional service delivery upgrades are also required.
- For commercial:
    - For new constructions and retrofits, contractors may not be accustomed to designing large storage tanks for central heat pump water heaters and identifying adequate footprint spaces for wall-mounted and roof-mounted tanks.
    - There is a lack of case studies and pilot projects associated with central heat pump water heater savings.
    - Disagreement about system sizing, configuration, or application of the central heat pump water heater.

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[78] California Energy Commission and CPUC. July 2019. *California Public Utilities Commission and California Energy Commission Staff Proposal for Building Decarbonization Pilots – Draft*.

[79] This is the standard Title 24 code-compliance software for residential. It models individual heat pump water heaters, and the CEC is developing central heat pump water heater capabilities.

[80] Statewide CASE Team, Work Plan: Central Heat Pump Water Heater: 2022 CASE Initiative, https://title24stakeholders.com/measures/cycle-2022/multifamily-domestic-hot-water/.

[81] Synapse Energy Economics, Inc. October 2018. *Decarbonization of Heating Energy Use in California Buildings: Technology, Markets, Impacts, and Policy Solutions.*

  - Insufficient products available on the market.
  - Code compliance simulation software not properly configured for this technology analysis.

Technicians, contractors, and tradesperson jobs will be affected by switching gas to electric — for example, where a plumber was required to perform gas water heater repairs, now an electrician is also needed to fix an electric water heater or heat pump water heater.

Technical Solutions

Technical solutions include:

- Supporting research efforts to improve the understanding of the technologies.
- Developing design guidelines and tools to enable technology adoption for retrofit and new construction applications.
- Providing workforce training.
- Collaborating with manufacturers to bring emerging technologies to the U.S. market.

Low-Power Heat Pump Water Heater/Retrofit-Ready Products

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
–	–	X	X

Many studies refer to the integration of heat pump water heaters in new construction buildings as the easiest adoption for fuel substitution.[82] In new construction, the constraints that retrofits face are typically not present due to 200 A panels, higher capacity service being standard in new building code construction, and the ability to design around such electric appliance requirements. Program design catered to the existing building market in California is needed. The New Buildings Institute for the Building Decarbonization Coalition suggests a 12-step design and implementation program for IOUs to adopt.[83]

The retrofit upgrades for homes with 60 A or 100 A services can be expensive for residents. The CPUC is working on programs, incentives, and policies that will assist low-income California residents and those in disadvantaged communities with these changes; the CPUC has not defined the details of these programs.[84] Another solution is developing a 120 V heat pump water heater that can be installed in electrically constrained and space-constrained locations. While an electric-resistance water heater would not have enough capacity with a standard 110 V circuit, the technical potential for a heat pump water heater could meet this constraint. To date, manufacturers have expressed some interest, but most have not publicly communicated any plans to invest — presumably because of the still small market share for the 220 V heat pump water heaters. The introduction of the 15 A Rheem heat pump water

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82 New Buildings Institute for the Building Decarbonization Coalition. March 2019. *California Retrofit-Ready Heat Pump Water Heater Program Elements Framework*, Version 4.

83 New Buildings Institute for the Building Decarbonization Coalition. *California Retrofit-Ready Heat Pump Water Heater Program Elements Framework*.

84 California Energy Commission and CPUC. July 2019. *California Public Utilities Commission and California Energy Commission Staff Proposal for Building Decarbonization Pilots – Draft*.

heater in 2018 may mean electrification is possible without upgrading the panel.[85] Increasing market availability and awareness of these systems should help programmatic efforts gain more participation.

Heat Pump Water Heater Design Guidelines and Tools

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	X	X	X

Centralized heat pump water heating is a key design strategy to fuel substitution for water heating for residential and commercial buildings. Designers have implemented several successful field demonstrations in Washington and California. System performance and efficiency depend highly on design and are not guaranteed. No design guidelines exist to ensure appropriate design, but several efforts are ongoing to address this issue:

- IOU-sponsored laboratory testing of heat pump products and system design configurations to develop heat pump water heating system models to include in compliance software. Based on the testing results, stakeholders can develop installation criteria for heat pump water heating systems.
- 2022 Title 24 Statewide Utility Codes and Standards Enhancement effort to develop a prescriptive compliance pathway for central heat pump water heater systems. This work involves market assessment, cost-effectiveness analysis, data collection from demonstration projects, and real-world projects to understand system performance and integrate best practices into code language.

Efforts for demonstration projects and design guide development would also improve the technology adoption rate.

Variable Capacity Heat Pump for Space Heating Demonstration Projects

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	X	X	X

Like heat pumps for water heating, there is no well-established design guideline to support applications of large-scale air-to-water heat pumps. Case studies and technology demonstration studies could support guideline development. The CEC sponsored a study of all-electric technologies for water heating and HVAC in four zero-net-energy demonstration projects in California.[86] Two of the demonstration projects used large-scale air-to-water heat pump systems that produce hot water for space heating and cooling. The study offers opportunities to investigate the technologies in-depth and provides lessons learned.

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[85] Redwood Energy. 2019. *A Zero Emissions All-Electric Multifamily Construction Guide*;
Rheem Water Heating. July 2019. "Product Guide: Rheem Hybrid Electric Water Heaters."

[86] Build It Green. August 31, 2016. "Build It Green Wins Research Grant to Advance Multifamily Zero Net Energy."

For the variable-capacity air-to-air heat pumps, one major barrier is a lack of proof-of-concept performance data. This issue could be addressed by demonstration research, development of quality specifications accompanied by design, and installation and verification protocol:

- IOU-sponsored demonstration projects — Central Valley Research Homes Variable Capacity Heat Pumps, Evaluation of Ducted and Ductless Configurations 2016 – 2017, PGE 2018_3 — explicitly and intentionally test systems relative to the proposed prescriptive measure requirements and proposed performance modeling benefits.[87]
- The research team suggests creating and using a heat pump quality specification, a qualifying product list, and an accompanying design, installation, and verification protocol across incentive programs to ensure performance of variable-capacity heat pumps. The quality specifications could also support energy code calculations used within Title 24, Part 6.

Workforce Training and Education

Residential New Construction	Commercial New Construction	Residential Retrofits	Commercial Retrofits
X	X	X	X

Several reports have suggested the need for workforce training to promote electrification.[88]Poorly installed heat pumps and heat pump water heaters could create customer backlash against the technology. Workforce training, combined with a voluntary certification program for building electrification, could provide quality assurance to customers interested in switching to electric HVAC or water heating. Similarly, with CPUC guidance, utilities could consider direct install and midstream programs to ensure fuel substitution technologies are readily available by retailers, distributors, and contractors so that the equipment can be installed immediately.

Market Barriers and Solutions

Even if the above-described technical barriers are resolved, significant market barriers still stand in the way of fuel substitution. This section discusses barriers and solutions specific to individual sectors and end uses.

Market Barriers

A study by Synapse Energy Economics identifies customer and contractor unfamiliarity with heat pump technologies as a primary market barrier.[89] This unfamiliarity makes it difficult for residential customers to break the trend of replacing heating systems with the same fuel type and equipment previously installed, specifically in replace-on-burnout situations. A lack of

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[87] California Energy Commission, *Central Valley Research Homes Project*, November 2018.

[88] Energy and Environmental Economics, Inc, *Residential Building Electrification in California Consumer economics, greenhouse gases and grid impacts*, April 2019. New Buildings Institute for the Building Decarbonization Coalition, *California Retrofit-Ready Heat Pump Water Heater Program Elements Framework*, Version 4, March 2019.

[89] Synapse Energy Economics, Inc., *Decarbonization of Heating Energy Use in California Buildings: Technology, Markets, Impacts, and Policy Solutions*, October 2018.

knowledge transfer from contractors to customers can also deter customers interested in but not familiar with these technologies.

Commercial HVAC

Like the residential sector, high installed costs and capital constraints, along with the lack of consumer awareness and staff training, pose major barriers to electrification. A lack of case studies associated with the electrification of larger HVAC systems presents a data validation and overall reassurance gap for prospective customers to use as a knowledge base to support the higher capital investment such systems generally require.

Regarding retrofit projects, the commercial sector also faces limitations associated with building owners and operators pursuing lower upfront cost options, opting to use existing ductwork infrastructure rather than transitioning to ductless, ground, or variable-refrigerant-flow[90] systems typical of larger commercial building HVAC loads. Even with a lack of data and the present apprehension toward higher-sticker-price electric systems, variable-refrigerant-flow systems require much less space for new construction projects because of the substitution of large duct runs for refrigerant lines.

Residential Domestic Hot Water

Immediate replacement on burnout is a major barrier because consumers typically have an urgent need for hot water service. Due to unfamiliarity with all-electric units, purchasing a one-for-one natural gas unit replacement is most common for users. Two reasons for low penetration are most typical:

- Higher capital cost for heat pump water heaters or electric-resistance units makes these units unappealing.
- For existing homes, an adequate electrical panel or building circuit capacity to accommodate the electric water heater may not be present.[91]

Adoption of electric water heaters may increase with more end-user education and outreach about the cost- and non-cost-related benefits. Such benefits include incentives to shift usage to cheaper times of day, which may provide savings to the customer; DR program enrollment options that can increase grid reliability; and participant incentives in some IOU territories.

Commercial Domestic Hot Water

Due to the low market penetration data, case studies are scarce, and the U.S. Department of Energy[92] excluded heat pump water heaters because the number of consumers adopting heat pump water heaters has been low.[93] There is a gap in the best practices for sizing such electric

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[90] Variable refrigerant flow or VRF systems vary the flow of the refrigerant to the indoor units providing cooling to a space.

[91] Additional variable refrigerant flow market penetration available on p. 80 of the National Renewable Energy Laboratory's, *Proven Energy -Saving Technologies for Commercial Properties* (2015) report.

[92] U.S. Department of Energy. April 2016. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Water Heating Equipment*.

[93] Additional information on existing commercial heat pump water heaters is available in the National Renewable Energy Laboratory's *Electrification Futures Study*.

systems for commercial applications because no code or guidelines reference is uniformly adopted. This barrier again is marked by the lack of penetration of these products in the commercial sector, an issue that utilities can begin to address through incentives, rebates, and programs to promote consumer adoption of such electric-resistance or heat pump water heater units.

Appliances

Aside from costs, electric stoves and heat pump dryers[94] are faced with heavy consumer preference and usage modification requirements. In general, because cooking is considered a lifestyle choice, purchasing is mostly driven by performance and cost, while energy consumption is considered secondary. For example, consumers may prefer the quick heating and controllability of natural gas, while electric induction heating is just as fast, if not faster, but requires different cooking habits.[95] Changing consumer preference and allowing them time to accept modifications to his or her cooking habits could slow all-electric cooktop and oven adoption. Though electric stoves have been prevalent in the market and serve as a great alternative to gas stoves, induction stoves provide a greater efficiency benefit overall. Because induction stoves use the electromagnetic field to heat the pot (rather than radiant heat), some additional hurdles exist for this technology. Researchers identified the following market barriers for induction stoves and dryers:[96]

- Customer bias toward gas stoves due to tradeoffs associated with cooking habits, recipes, and new cookware, including transitioning to equipment that behaves differently.
- These cooktops do not have actual flames that can char foods, which is a preference for some customers; the magnetic field can interfere with digital thermometers and other digital kitchen equipment.
- For heat pump dryers, costs are higher than typical ENERGY STAR®-rated gas dryers, and drying times can be greater than those of traditional electric or gas dryers.

Market availability for heat pump dryers is limited due to the introduction of the technology to the market. Given this entry, manufacturers are uncertain about the ability for the U.S. market infrastructure to accommodate these products and turn a profit.[97]

Market Solutions

Residential and Commercial HVAC

The major hurdles to be cleared are ways to funnel information effectively to potential consumers on these newer electric-based technologies, the long-term payback of the

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[94] A "heat pump dryer" uses a refrigerant system that can be heated and cooled.

[95] Northeast Energy Efficiency Partnership. December 2018. *Developing a Pathway to Decarbonize Existing Buildings.*

[96] Synapse Energy Economics, Inc. October 2018. *Decarbonization of Heating Energy Use in California Buildings: Technology, Markets, Impacts, and Policy Solutions.*

[97] More information available in Appendix C: Customer Barriers Analysis of EMI Consulting's, *Pacific Gas & Electric ENERGY STAR Retail Product Platform (ESRPP) Program Pilot Early Evaluation* (January 2019).

technologies, and associated environmental benefits to adoption.[98] To address the lack of technical knowledge transfer of heat pump benefits to customers, utilities could bear a portion of this responsibility by providing educational materials on these products; these materials can translate the technical information associated with heat pumps to promote informed decisions regarding technology adoption.

For commercial HVAC, variable-refrigerant-flow systems are considered innovative and yield project-specific energy savings, which qualify these measures for custom financial energy efficiency measure incentives. With the newly available funds for electrification because of the changes to the fuel substitution test, funding and programs for such will likely increase.

Residential and Commercial Domestic Hot Water

Solutions to promote the adoption of the heat pump water-heater technologies come in a few forms. Early retirement programs offered by utilities help customers make more informed decisions by providing information regarding electric water heaters when they are deciding on a replacement unit. These programs reduce the stress and urgency that replace-on-burnout situations place on the ratepayer.

Utility-offered discounts for customers enrolling in grid-control or demand response programs are one of the most basic solutions and help reduce the effects of the installation and operating costs. Applying control systems to electric-resistance and heat pump hot water heaters enables these units to be used as grid management components, which is becoming increasingly important as electric usage grows. The control systems allow customers, grid operators, and third parties to control the state of charge[99] of the water heater and employ DR signals and load shifting, which can decrease customer bills and increase grid reliability by alleviating load during peak usage periods.[100] To promote higher penetration of these electric-resistance and heat pump hot water heater units into the market, utility incentives by way of DR programs are a prime entry point.[101]

A potential pathway and major incentive to the adoption of heat pump water heaters in commercial buildings are the dual service these units provide. Heat pump water heaters produce hot water and cool air, which have the potential to significantly offset capital costs in service spaces such as laundries, hotels, restaurants, and other building types where simultaneous demand for hot water and space conditioning is needed.

Cost Barriers and Solutions

Balancing the costs and benefits of fuel substitution opportunities is a challenge because many benefits are associated with longer-term GHG emissions reductions and not necessarily short-

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[98] Lawrence Berkeley National Laboratory. March 2018. *Electrification of Buildings and industry in the United States: Drivers, Barriers, Prospects, and Policy Approaches*.

[99] The state of charge for a water heater is the equivalent to the level of charge an electric battery as a percentage of capacity. To use water heaters as a DR-enabled device, the water must be heated (state of charge) to be available for DR signals.

[100] The Regulatory Assistance Project. January 2019. *Beneficial Electrification of Water Heating.*

[101] Additional information of existing commercial heat pump water heaters is available in the National Renewable Energy Laboratory's Electrification Futures Study.

term customer bill savings. Many studies conducted on fuel substitution to reduce GHG emissions in residential and commercial markets suggest that low-rise residential all-electric new construction options provide the most promising capital cost, bill, and life-cycle potential savings — specifically those savings associated with near-term emissions reductions. This conclusion indirectly highlights retrofit options and commercial sector projects as not being as promising for consumer cost savings.[102]

The industry will need to continue developing fuel substitution technologies for buildings. Contractors will need to abide by best practices during project scoping and electric equipment installations to reduce overall costs. The lack of retrofit-ready heat pump unit options in the United States means a barrier to entry as well as an opportunity in the market. Furthermore, an overall lack of lower-cost electrical panel upgrade packages in the market bars owners of older homes in lower income brackets to transition to electric equipment and appliances to safely accommodate the added loads of electric heat pumps, water heaters, and appliances.

A Navigant (now Guidehouse) study notes that required electrical infrastructure upgrades to existing homes pursuing fuel substitution could experience total cost increases from $4,600 to $7,300 and $5,000 to $8,500 for 2020 and 2030, respectively. These costs include appliance and infrastructure upgrades. Homes that have the electrical infrastructure capacity to meet the additional load because of electrification are estimated to experience total cost increases from $250 to $3,000 in 2020 and $400 to $2,700 in 2030.[103] The electrical system upgrades range from $2,000 to $4,000 in added capital costs and are one of the only options given the industry standard amperage of heat pump options in the United States.

Total construction costs for new mixed fuel homes include the cost associated with electric and gas utility connections. Historically, gas utilities have subsided a portion of the gas connection cost (as high as 50 percent). Energy and Environmental Economics points out that as the population of gas consumers decreases, gas utilities may choose to adjust these subsidies, which could affect the cost borne by the builder and ultimately be passed on to the consumers that still opt for mixed-fuel homes.[104]

Costs Barriers

This section covers the costs associated with fuel substitution for the customer and the utility. Some of these costs have been discussed as part of the Technical and Market Barriers sections.

Customer-Side Electrical Upgrades

For electrical upgrade costs, customers are responsible for behind-the-meter costs such as panel upgrades. For existing homes, one study estimates the cost of upgrading from a 100 A capacity panel to 200 A capacity panel to be around $2,000-$4,000, while branch circuit

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[102] Energy and Environmental Economics, Inc. April 2019. *Residential Building Electrification In California Consumer Economics, Greenhouse Gases and Grid Impacts.*

[103] Navigant Consulting, Inc. 2018. *Impacts of Residential Appliance Electrification*, for California Building Industry Association.

[104] Merchant, Emma. June 18, 2018. "Electric Heating Accelerates the Push for Deep Decarbonization, but Cost Remains an Issue." *Greentech Media*.

upgrades for heat pump water heaters going from a 15 A circuit to 20 A circuit were estimated at $600-$700.[105] One study estimates utility service fees for residential new construction to be about $800-$900.[106] A detailed breakdown of associated electrical costs for customers can be found in Appendix A, which details the cost findings of reach code studies.

Utility-Side Infrastructure Upgrades

Increased electricity usage will lead to costs on the utility side in the form of electrical infrastructure upgrades and grid modifications to accommodate the increased electrification loading. The literature available covering the utility cost barriers to fuel substitution that addresses the increased electricity load is oriented primarily around distributed generation. While this scenario is not directly reflective of fuel substitution, the research team considers these findings and recommendations enough to address the increased capacity of the electric grid. The utility costs are typically low or negligible when changes in load are below 20 percent of the peak load on the distribution feeder. If the newly connected devices are managed to minimize use during peak hours, there will be a lower need for utility-side upgrades.

A distributed generation integration cost study conducted by Navigant (now Guidehouse)[107] evaluated three location scenarios and summarized the cost findings:

- The cost depends highly on locational factors for necessary upgrades for the feeder, distribution and transmission systems a.
- Integration impacts and costs are lower when distributed generation is installed in urban areas, where feeders are shorter and often equipped with larger conductor or cable along the entire length of the circuit.
- Integration costs increase significantly as greater amounts are clustered or installed near the end of distribution lines.
- Policies that encourage implementing fuel substitution opportunities (beneficial or targeted electrification) in areas with fewer impacts would minimize grid integration costs; however, the lowest total cost solutions would need to factor in procurement costs of the systems.

The integration costs range along an urban-to-rural deployment spectrum, where lower integration costs occurred toward the highly urban deployment and higher integration costs fell toward the highly rural deployment. The total integration costs range from $190/kW to $270/kW for the distribution system,[108] following the same trend of increasing costs with decreased urban locational classification. Location can greatly affect integration costs and updating electrical equipment to increase the load from accompanying electrification will follow a similar trend.

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105 Navigant Consulting, Inc. 2018. *Impacts of Residential Appliance Electrification*, for California Building Industry Association.

106 Cost assumes a need to upgrade the wire from the utility to the home; source: TRC Companies, Inc. September 2018. *City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT*.

107 Navigant Consulting, Inc. November 2013. *Distributed Generation Integration Cost Study*.

108 Typically, interconnection costs are borne by the customer, not the utility.

The National Renewable Energy Laboratory (NREL) studied the cost of electric distribution system upgrades with a focus on distribution feeder systems. Feeder upgrade costs pose a barrier in terms of executing the required electrical system upgrades to accommodate new load. Appendix A provides two case studies.

While these studies provide reference for utility pricing upgrades on a dollar-per-watt basis, the unknowns associated with electricity demand market trends and specific needs to update feeders and distribution systems make it difficult to ascertain exact systemwide deployment costs. The variability in increased electrification load adoption creates high uncertainty, and this uncertainty is a major fuel substitution cost barrier.

HVAC Costs

A wider range of high-efficiency electric technologies, available in Europe and Japan, need to penetrate the U.S. market to enable new construction, and specifically retrofit fuel substitution projects, to succeed at scale. When owners of older homes without air conditioning would like to pursue switching to an electric heat pump, they encounter a cost barrier because there is a notably higher incremental upfront capital cost for fuel substitution. This increased cost is because the prescribed heat pump provides heating and cooling, while the baseline did not include cooling equipment. Further, utility costs increase because the house can now provide cooling in addition to heating, so the heat pump can run longer than in a heating-only scenario. For example, homes on the north coast of California typically do not have air-conditioning units because of temperate coast climates, so they face a higher cost for the heat pump versus a gas furnace replacement.

Residential

The Rocky Mountain Institute[109] performed a detailed assessment of electrification upgrades in the residential sector, with case studies completed in multiple locations. This cost comparison showed that cost barriers still exist for retrofit heat pumps compared to natural gas alternatives in extremely hot climates. The Oakland, California, example indicates that natural gas with existing air conditioning is cheaper on the 15-year net-present cost scale[110] for retrofits compared to standard and high efficiency heat pumps. New construction does not present the same cost barriers because heat pump installations are cheaper than natural gas with air conditioning on the same 15-year net-present cost scale in both scenarios. Appendix A contains a figure showing the cost comparison from this study, which also pertains to hot water heating.

Specific factors affect these costs:

- If electric rates are higher than gas based on energy content, the economics of switching to a heat pump are less favorable for the customer, specifically for replace-on-burnout situations.
- An appropriate adjustment to end-user behavior and time-of-use rates must be made.

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[109] Rocky Mountain Institute. 2018. *The Economics of Electrifying Buildings*.

[110] "Net-present costs" values the cash flow of the difference between the benefits and costs in current year dollars.

Commercial

The 2020 projections for commercial technologies indicate a higher capital cost for heat pumps and electric appliances relative to the gas counterparts.[111] In models using the economics of current heat pump technologies, projections through 2050 for space heating in warm and cool climates show air-source heat pumps reaching the lowest cost in warm and moderate climates. These findings suggest larger barriers to adoption for commercial all-electric HVAC will be prevalent in cooler climates.

An additional barrier will be the demand charges associated with the commercial rate tariffs. Baseline and peak demand of commercial customers switching to all-electric heating and water heating loads will increase along with the customer's electric bill, which was considerably lower with gas-fueled equipment.

Domestic Hot Water

A standalone replacement of an existing gas storage or tankless gas water heater with a heat pump water heater does not generate life-cycle cost savings. Rather, life-cycle savings are seen when heat pump water heater and heat pump HVAC retrofits are combined, which may not be conducive to the consumer's remaining useful life on either of the current gas-consuming units. The two major financial barriers specific to heat pump hot waters heaters are:[112]

- The space constraints needed to provide enough air volume for the heat pump (that is, large rooms, basements, garages, or laundry rooms). In the event the baseline gas or electric water heater is not placed in a space with adequate air volume, installation costs will increase or require more costly solutions compared to a standard water heater.
- Life-cycle costs vary from effective to ineffective depending on climate zone, utility rate, and equipment efficiency.

Figure 9 compares the projected life-cycle costs for various California residential water heating appliances under different inflation scenarios. The first inflation scenario compares the life-cycle costs of water heating technologies with a price increase of 2 percent per year for both fuel types. The second scenario varies the fuel price increase, comparing life-cycle costs for fuel price increase of 4 percent for natural gas and 2 percent for electricity. The different scenarios highlight the dynamic nature of energy prices and the profound influence they have on equipment life-cycle costs.

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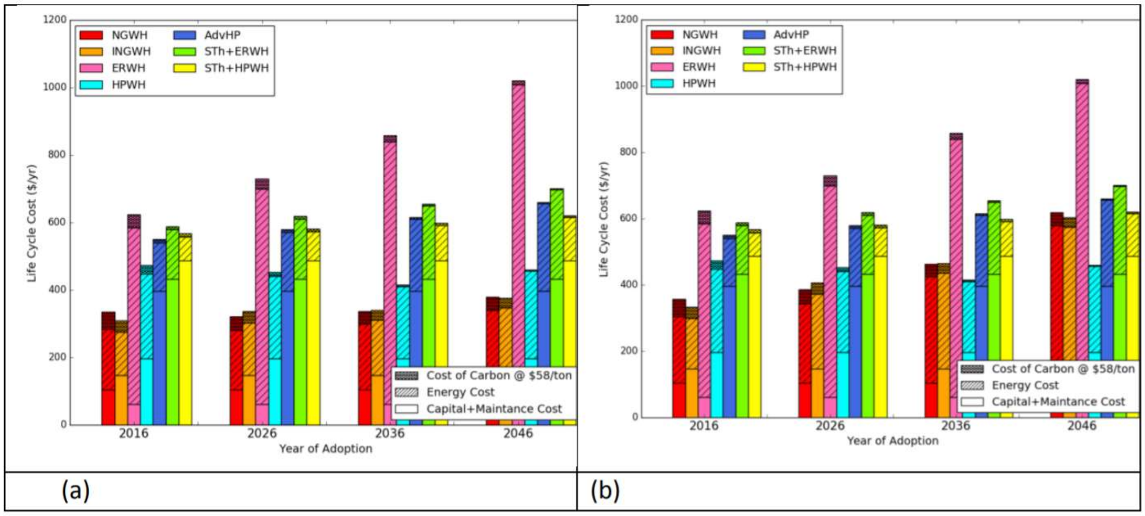
111 Lawrence Berkeley National Laboratory. March 2018. *Electrification Of Buildings And Industry In The United States – Drivers, Barriers, Prospects, and Policy Approaches*.

112 Ibid.

Figure 9: Annual Estimated Life-Cycle Cost for Various Water Heating Technologies



The bar charts indicate that the cost barrier associated with the price of natural gas versus electricity depends highly on future fuel pricing.
(a) Annual Estimated Life-Cycle Cost ($/yr.) for Various Water Heating Technologies for Natural Gas and Electricity Price Increases of 2 Percent per Year
(b) Annual Estimated Life Cycle Cost ($/yr.) for Various Water Heating Technologies for Natural Gas Price Increases of 4 Percent per Year and Electricity Price Increases of 2 Percent per Year
Abbreviations mean the following: NGWH = Natural Gas Water Heater, INGWH = Instant (tankless) Natura Gas Water Heater, ERWH = Electric Resistance Water Heater, HPWH = Heat Pump Water Heater, AdvHP = Advanced Heat Pump Water Heater, STh = Solar Thermal Water Heater.
Source: Berkeley Lab, Electrification of Buildings and Industry in the United States, 2018.

Figure 9 demonstrates the following cost findings:[113]

- In the instance of more efficient technologies, capital costs make up a larger portion of the levelized costs, but increased costs are offset by long-run fuel savings.
- Relative to electric resistance technologies[114], heat pumps for space and water heating in the residential and commercial sectors show a cost-of-service advantage. In other words, if electricity is being used for space and water heating, the high upfront cost of heat pumps is more than offset by savings in electricity costs when compared to traditional resistance-based technologies.
- Current (or near future expected) residential air-source heat pumps and heat pump water heaters are approaching cost parity with incumbent natural gas technologies in moderate-to-warm climates. In cold climates, however, incumbent gas technologies continue to exhibit an advantage relative to cold-climate air-source heat pumps. As a result, with modest improvements in the cost and performance of

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[113] Lawrence Berkeley National Laboratory. March 2018. *Electrification Of Buildings And Industry In The United States – Drivers, Barriers, Prospects, and Policy Approaches*.

[114] "Electric resistance technologies" are heating sources when an electric current passes through a material that preferable has high resistance creating losses of energy and converting the electrical energy into heat.

residential air-source heat pumps, the adoption of these technologies over natural gas technologies could be driven by pure cost advantages in moderate-to-warm climates, but greater improvements would likely be needed for adoption in cold climates.

Appliances

Under current utility rates, electric stoves, convection ovens, and dryers have not yielded life-cycle cost savings relative to the gas counterparts because of the initial cost. Many customers are unfamiliar with these technologies, and the appeal of the lifetime savings of these technologies is typically shadowed by the upfront capital cost. With initial installation costs typically higher than convention gas appliances to install, consumers are more inclined to stick with a gas appliance repair or replacement when faced with a failing gas appliance. Due to low turnover and the high capital investments for stoves and clothes dryers, the most cost-effective time to switch to electric appliances is during new construction and replace-on-burnout projects or home renovations. A study by Synapse Energy Economics identifies the following market barriers:[115]

- Additional costs for the required magnetic cookware, which contain steel or iron, used to transmit the magnetic field and subsequently the heat.
- Capital costs — induction cooktops are more expensive then electric units using glass-ceramic surfaces; the switch from gas to electric units can require panel upgrades for higher-amperage capacities.
- Upfront costs for convection ovens are typically higher than traditional ovens.
- Consumer expectations require users to adjust recipes and approach to account for changes in cooking time.

Cost Solutions

Several potential solutions address the cost barriers:

- Industry advances in technology and research and development to create economies of scale to drive electric appliances and HVAC costs down. For example, residential heat pump water heater initiatives can drive down the cost of systems by creating greater market demand, thus reducing the cost premium for the technology.
- Potential IOU, POU, and CCA emerging program incentives to reduce financial barriers to consumers. As identified in the Solutions section, a few programmatic efforts are already underway.
- Emerging technology options for heat pump water heaters, heat pump space heating, induction cooking, and heat pump dryers that run on lower wattages. These are typically smaller capacity but are perfectly suited for smaller residential applications, including multifamily. These could reduce panel upgrade costs and design constraints.
- Demand flexibility optimized for typical time-of-use rates that can reduce energy costs. However, it is not usually significant enough to tip the scales in favor of fuel

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115 Synapse Energy Economics, Inc. October 2018. *Decarbonization of Heating Energy Use in California Buildings: Technology, Markets, Impacts, and Policy Solutions.*

substitution. Different pricing structures that capture more of the flexible capability of these devices could provide greater value and improve customer economics.[116]

- New programs supporting systematic electrification of blocks or neighborhoods to deenergize segments of the gas distribution system, such as panel box upgrades. These programs could result in more cost-efficient retrofits than one-off projects with a local electrician.
- Studies that review the cost barriers, similar to the U.S. Department of Energy's Solar Energy Technologies Office review of the soft costs of solar installations. These studies could help reduce fuel substitution implementation costs.[117]

Data Gaps

The following summarizes the data gaps researchers identified when evaluating the policy, technical, and cost barriers and solutions in residential and commercial sectors:

- **General:** Efforts are underway to identify appropriate systems for central water heating using heat pumps. Limited data on the performance of various system choices exist, and no standardized methods for design, specification, and installation enable these technologies to have wider applications.
- **Electrical service upgrades**: No statistically valid dataset showing what percentage of existing buildings have adequate panel capacity and other electrical upgrades to meet fuel substitution needs exists. Moreover, an overall lack of data documenting costs to upgrade these infrastructures does not allow indirect estimates or historical tracking of cost-to-upgrade trends. For retrofits, the main service to the building may have inadequate capacity to serve the required wattage when electrifying major end uses in the building. There is no statistically sound dataset available to evaluate the prevalence of this issue. The CEC and CPUC are implementing the BUILD and TECH programs, which may present an opportunity to address this data gap through data collection and evaluation.
- **Commercial space heating**: The major gap is product availability and performance data for large-capacity heat pump systems. Limited options are available for upgrading existing variable-air-volume systems that use natural gas for reheating. Electric resistance retrofits are feasible, but there are cost implications in terms of first costs and operational costs. Case studies and technology demonstration studies that present a savings data validation for electrifying larger HVAC systems could provide overall reassurance for prospective customers to support the higher capital investment such systems generally require.
- **Multifamily water heating:** Especially for large residential buildings, case studies and technology demonstration studies are needed to provide lessons learned and improve customer confidence and acceptance of the technology. Efforts are underway to identify appropriate systems for central water heating using heat pumps.

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[116] Rocky Mountain Institute. 2018 *The Economics of Electrifying Buildings*.

[117] "Soft Costs," Solar Energy Technologies Office, U.S. Department of Energy, accessed August 2019.

- **Residential cooking:** Limited data on consumer acceptance of induction cooktops exist. Discussions and efforts to date have focused on getting the word out, but significant efforts are necessary to promote induction cooktops to address consumer apprehensions about the effect of the technology on cooking methods. Specific efforts are needed to address technology options for nonwestern cooking that rely on high heat or open flames.

CHAPTER 4:
Industrial and Agricultural Fuel Substitution

This section summarizes the market as well as the barriers and opportunities for fuel substitution in the industrial and agricultural sectors in three subsections:

- **Market and End-Use Characterization:** Overview of the fuel substitution opportunities in various end uses in the industrial and agricultural sectors.
- **End-Use Barriers and Needs:** Literature review findings for the policy, technical, and cost barriers for fuel substitution in the industrial and agricultural sectors and a description of associated solutions and opportunities for electrifying these sectors.
- **Data Gaps:** Existing data gaps to support future research plans.

Market and End-Use Characterization

The California industrial and agricultural sectors combined consume 24 percent of the state's electricity[118] and 35 percent of the state's natural gas.[119] The industrial sector is the leading consumer of natural gas in California. Furthermore, the industrial and agricultural sectors account for 23 percent and 8 percent of state CO_2 emissions,[120] respectively. These sectors include a diverse set of segments, representing different building or site types.

To understand these sectors, it is important to describe the makeup of the market by segment type. Table 4 and Table 5 represent the energy sales data from the *2017 Integrated Energy Policy Report (IEPR)* at the segment level.[121]

Table 4: Agricultural Electricity and Natural Gas Consumption by Segment: 2017

Segment	GWh	% Total	MM therms	% Total
Irrigated agriculture, vineyards, forestry, and greenhouses	4,301	72%	79	83%
Dairies, fishing, hunting	964	16%	16	17%
Water pumping	684	12%	0	0%
Total	**5,949**	**100%**	**95**	**100%**

Source: 2017 Ag-Com-Ind 6-digit North American Industry Classification System by IOU Quarterly Fuel and Energy Report data provided by the CEC

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[118] "California Energy Consumption by End-Use Sector, 2017," California State Profile and Energy Estimates, U.S. Energy Information Administration, accessed August 2019.

[119] "Table F18: Natural Gas Consumption Estimates, 2018," California State Profile and Energy Estimates, U.S. Energy Information Administration, accessed August 2019.

[120] "2019 GHG Inventory," Current GHG Inventory Data, California Air Resources Board, accessed November 2019.

[121] 2017 Ag-Com-Ind 6-digit North American Industry Classification System data by IOU from the CEC.

Table 5: Industrial Electricity and Natural Gas Consumption by Segment: 2017

Segment	**GWh**	**%**	**MM therms**	**%**
Chemicals	2,504	10%	382	11%
Electronics	3,811	14%	46	1%
Food	5,217	20%	634	18%
Lumber & Furniture	476	2%	9	0%
Industrial Machinery	883	3%	18	1%
Fabricated Metals	1,710	6%	89	3%
Primary Metals	1,043	4%	98	3%
All Other Industrial	707	3%	19	1%
Paper	771	3%	68	2%
Petroleum	1,841	7%	1,804	52%
Plastics	1,997	8%	21	1%
Printing & Publishing	377	1%	11	0%
Stone-Glass-Clay	2,498	9%	199	6%
Textiles	566	2%	48	1%
Transportation Equipment	1,956	7%	57	2%
Total	**26,357**	**100%**	**3,503**	**100%**

Note: Petroleum (Ptr) natural gas usage may go to both feedstock and process heating.
Source: 2017 Ag-Com-Ind 6 -digit North American Industry Classification System by IOU Quarterly Fuel and Energy Report data provided by the CEC

For this analysis, the research team focused its evaluation on the industrial sector rather than the agriculture sector. The agricultural sector's natural gas consumption is less than 3 percent of the industrial sector's consumption. Most GHG emissions associated with the agricultural sector are the result of biological processes, which are not subject to fuel substitution opportunities.

Table 6 lists the energy end uses in the industrial and agricultural sectors. Guidehouse focused on only natural gas end uses in this review because of the potential for fuel substitution.

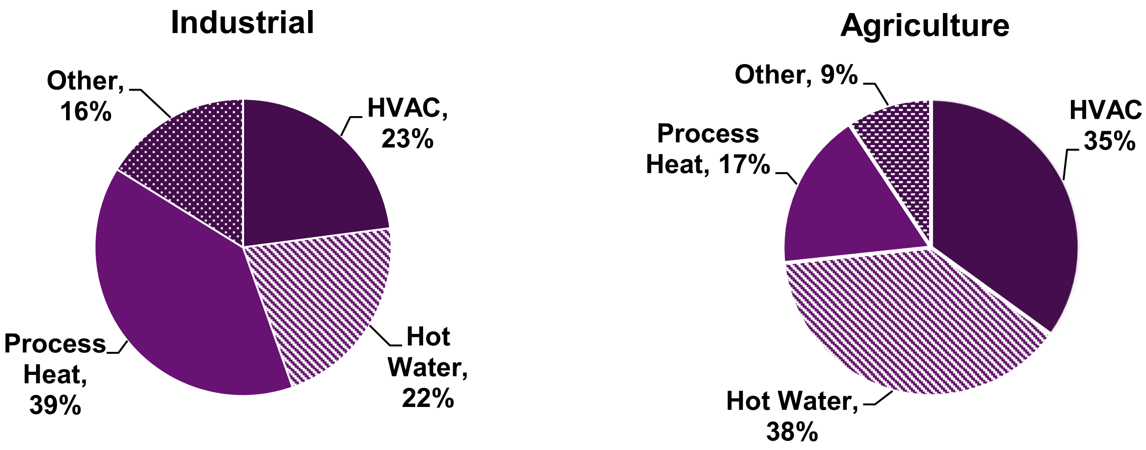
Table 6: Industrial and Agriculture Electricity and Natural Gas End Uses

Electricity	Natural Gas
Compressed Air	HVAC
HVAC	Process Heating
Lighting	Water Heating
Motors	Other
Other Process	
Process Cooling	
Process Heating	
Other	

Source: Guidehouse analysis

The charts in Figure 10 provide the breakdown of the natural gas end uses within each sector.

Figure 10: Natural Gas End Use by Sector



In the industrial sector, process heat is the largest consumer of natural gas, whereas hot water and HVAC consume the largest amount of natural gas in the agricultural sector.
Source: Industrial: Guidehouse analysis of Industrial Assessment Center data; Agriculture: Guidehouse analysis of multiple sources

Industrial fuel substitution opportunities vary by segment and the nature of the production process. The opportunities discussed in this report exclude natural gas as a feedstock used to produce a product such as plastics, fertilizers, and various chemicals. When natural gas is used for heating, the technological and economic potential is dictated by the operating parameters of the production process (for example, temperature, duration, and frequency of the heating cycle). Natural gas consumption is the main fuel source for conventional boiler use, combined heat and power (CHP) and cogeneration processes,[122] process heating, and HVAC. Consequently, these end uses provide the greatest opportunities for fuel substitution, though the economics of fuel substitution in CHP applications are complex.[123]

Within the agricultural sector, HVAC, water heating, and process heating provide the greatest opportunity for fuel substitution and GHG emissions reductions. The potential for these end uses is still minimal compared to the industrial sector.

This study focuses on process heating, which may be from furnaces, boilers, or waste heat from CHP applications. Process heating is the leading end use in industrial, whereas HVAC leads the agricultural sector. In agricultural, greenhouses use HVAC to heat conditions during the winter season, for example.[124]

End-Use Barriers and Needs

The research team relied on previous research, including results from the Measure, Application, Segment, Industry study,[125] and primary data collection to understand the overall needs and barriers for the industrial and agricultural sectors. The Measure, Application, Segment, Industry study documented barriers related to energy efficiency, which also apply to fuel substitution. Many of these barriers translate to specific needs that are unmet or challenges to facilities that prevent measure implementation. While the original Measure, Application, Segment, Industry work focused on the food processing segment, the research team used this work to draw conclusions to apply to other segments, even if each segment has unique characterizations. These generalizations work to address the industrial sector's needs and potential barriers to fuel substitution.

In general, any changes to facilities (including energy systems) must not negatively affect product quality. Facility managers mentioned a hesitance to adopt energy-efficient measures because they fear they may jeopardize the compliance of the facility with product safety and standards or affect operational efficiency.

Table 7 lists the overall barriers and end-user needs for fuel substitution for the industrial sector. The barriers facing fuel substitution are like the barrier for implementing energy efficiency retrofits.

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[122] This study does not include electrifying fossil fuel generation. Combined heat and power and cogeneration are synonymous words, meaning the production of electricity while producing useful heat for with water, space, or process heating.

[123] NREL, pg. 53 of the *Electrification of Industry: Summary of Electrifications Future Study Industrial Sector Analysis*, 2018

[124] Even though this section focuses on the industrial sector, there is crossover in the barriers and solutions with the agricultural sector. This information regarding the highest gas end use in the agricultural sector helps prioritize research and analysis going forward.

[125] The California IOUs commissioned Navigant to complete studies for certain large customer segments in 2015. One such study was the *Measure, Application, Segment, Industry: New Opportunities in the Food Processing Industry* study, which included detailed interviews with food processing customers; these interviews provided information regarding pain points and barriers.

Table 7: Industrial End-User Needs and Barriers

Category	Barriers	Needs
Knowledge and Awareness	• Lack of knowledge sharing across the industry. There is no platform for connecting with other similar facilities, whether that is via regular industry meetings or online discussion forums. • Lack of measure information and interaction from the energy utilities. • Lack of understanding of energy flows and savings potential. • New challenges and uncertainty in fuel substitution requirements	• **Energy management tools/ equipment:** Many sites would benefit from tools or equipment that could help them better understand where the associated energy is being consumed. • **Expert advice in energy audits and in planning stages of construction:** A comprehensive energy audit would identify potential opportunities. Moreover, receiving expert advice during the early stages of construction would allow the project to implement fuel substitution measures at a lower cost. • **Identifying existing industry resources (case studies):** The CEC could provide a central authoritative source on what tools and information are available. • **OEM engagements:** These engagements include equipment providers to identify the potential to convert processing equipment from natural gas to electricity and financial, technical, and market support to capture early adopters.
Financial	• Upfront cost and effort to replace equipment that still works. • High costs for critical energy management and monitoring systems to understand energy consumption at a more localized level. • Demand charges within the current rate structure increase focus on reducing peak demand and diminish the attention given to reduce energy consumption. • Preference for payback and ROI of 3 years or less.	• **More rebates:** The rebates are often critical to achieve a minimum internal ROI target. • **Financing options:** To compensate for high initial costs, utilities or other parties should offer favorable financing options to promote adoption and offset risk. • **Price signals:** Either through cap and trade, carbon tax, or utility rates, the price signals should align to allow flexible demand management for the end user.

Category	**Barriers**	**Needs**
Safety and Quality Standards	• Slow to adopt new technologies because some industries are heavily regulated by safety and sanitation standards. • Fuel substitution must not jeopardize the compliance of the facility with standards and product quality. • Existing programs are not specific to the various segment needs — for example a utility's auto-DR program could curtail energy consumption in the middle of a process, which could pose health and safety issues. • Many production processes that consume natural gas are highly customized to the product being produced, and options for electric equipment that maintain quality standards and production needs may be limited in technical availability and service capability by the vendors that stock, install, and service this equipment.	• **Information on compliance with safety standard:** Reports and case studies will help assure facilities that the new technologies are reliable and will not violate safety and sanitation requirements. • **Expert advice on installations:** Facilities would be more assured when installing upgrades if they had advice from an expert who is familiar with safety, sanitation, and quality standards and measure installation. • **Case studies:** New technologies or retrofits will not alter or reduce product quality.
Continuous Operation Cycles and Seasonality	• Refrigeration or heating for certain facilities is required continuously; therefore, downtime for upgrades is challenging. • Seasonality of product harvests[126] or other production limits opportunity and runtime hours.	• **Advanced planning:** Facilities with seasonal operations can install equipment during downtime if the facility conducts proper long-term planning. Partnering with external parties (utilities and financiers) requires those parties also align with the operational schedule of the facility and fiscal planning timeline for decision-making and installations. • **Backup power:** Continuous operation cycles require temporary power systems and parallel operations while upgrades are being installed on the main system. Fuel substitution also requires more backup power.

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[126] For example, tomato canning occurs during harvest months with nonstop operation. Between harvests, these plants sit idle. This fallow period means that energy savings occur only during the active times, which lengthens payback periods for replaced equipment compared to plants that operate year-round.

Category	Barriers	Needs
Organizational Barriers	• Without a clear company program, trained internal champion, or energy manager in place, opportunities to improve may not be promoted or implemented effectively, even if known. • Lack of communication among plants, a poor understanding of how to create support for an energy efficiency project, limited finances, poor accountability for measures, or organizational inertia to changes from the status quo. Even when energy is a significant cost, many companies still lack a strong commitment to improve energy management.	• **Strong commitment:** Companies can communicate a strong commitment to become energy-efficient. • **Training:** Program provide educational opportunities to industry professionals on the financial and energy savings opportunities available through fuel substitution • **Multiyear planning:** Consider budgeting and capital improvements over multiple years to meet organizational planning cycles; understanding the future energy landscape is critical.
Reliability	• Concerns about grid outages with natural gas as the heating unit still operates when there is a grid outage. • Maintaining temperature and pressure requirements for process heating loads.	• **Backup power source:** Companies need to know that if there is a grid outage, their critical systems will continue to operate, either with onsite generation or other grid-side resources. • **Case studies:** Facilities need to know that electric furnaces or boilers can maintain system requirements consistently like the equivalent natural gas systems.

Source: Guidehouse

The following subsections explore the barriers from policy, technical, and cost perspectives and discuss possible solutions and opportunities.

Policy Barriers and Solutions

Policy drivers creating pathways to fuel substitution in the industrial sector can contribute to achieving the ambitious SB 350 goals and GHG emissions reduction targets. This section addresses the policy barriers and potential solutions for this sector.

Barriers

Unlike the residential and commercial sectors,[127] limited targeted policy exists to motivate the industrial sector to participate in fuel substitution. This situation is partly because industrial electric technologies do not have high profiles like technologies in other sectors, such as EVs in the transportation sector. Adoption rate is also an issue — as highlighted earlier in Table 7, industry resists changing the way it operates. Industry fuel substitution policy progression is

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[127] For example, the SB 1477 pilot programs: the BUILD program and the TECH program.

further hindered because "researchers and policymakers face significant gaps in data (for example, energy use, cost) and analysis tools."[128]

Barriers for fuel substitution vary by customer type and size. For example, larger operations know what to do but do not feel supported by policies and utilities, while smaller plants may have limited staff (for example, a mechanic on staff stretched too thin with no energy manager). A better understanding, including data that segments the market at the facility-size level, would help policy makers address the diverse needs of the industrial segment. Furthermore, policy and program designers need more segment-specific studies on the requirements of each industrial type to increase fuel substitution. Some segment-level documentation exists for food processing and oil refineries, but other facility types have minimal information, inhibiting meaningful policy that addresses the segment level respective needs.

Program funding and planning cycles are another policy barrier. Often there can be a mismatch between industrial planning cycles and utility and state energy program cycles. Consequently, cyclical issues can keep industry from moving forward with an energy project.[129]

Solutions

State Regulation

Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006) and Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016), California's major initiatives to reduce GHG emissions, contain policy that supports fuel substitution in the industrial sector:

- **AB 32:** Also known as the California Global Warming Solutions Act of 2006, this bill aims to cut emissions to 1990 levels by 2020. It also aspires to cut emissions below 1990 levels by 2050, although this target was not explicitly marked in this bill.
- **SB 32:** In 2016, the governor signed SB 32, which succeeds and expands on AB 32 to reduce statewide emissions to 40 percent below 1990 levels by 2030.[130]

In addition, through these bills, the California Air Resources Board (CARB) implements mandatory GHG reporting regulation. To fund this emissions regulation and other emissions agencies funded under this bill, CARB collects an annual fee from large sources of GHG emissions, including industrial sources.[131] In 2010, 250 sources paid fees when they exceeded their emissions target; in the latest report, this number has increased to 265.[132] Industrial plants are often large sources of emissions incurring these annual fees, which encourages the

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128 National Renewable Energy Laboratory. 2018. *Electrification of Industry: Summary of Electrifications Future Study Industrial Sector Analysis*.

129 U.S. Department of Energy. June 2015. *Barriers to Industrial Energy Efficiency.*

130 Senate Bill No. 32. Pavley, California Global Warming Solutions Act of 2006: emissions limit, Chapter 249, Statues of 2016,

131 "Assembly Bill 32 Overview," Climate Change Programs, California Air Resources Board, accessed August 2019.

132 California Air Resources Board. August 2019. "AB 32 Cost of Implementation Fee Regulation Fact Sheet."

sector to pursue fuel substitution opportunities. While these bills focus on emissions reduction targets, their targets support the adoption of fuel substitution in the industrial sector.

Consequently, the industrial sector is affected most by emissions regulations because of the high GHG emissions levels that accompany this consumption. Fuel substitution is a viable alternative that provides ample opportunity to reduce emissions and decrease the financial fees incurred as a result of these bills. In this way, policy encourages the adoption fuel substitution in the industrial sector.

In the 2018 *Electrification of Buildings and Industry in the United States* report, Berkeley Lab provides insights on the GHG regulatory policies driving the effect of fuel substitution on air quality. Attaining existing air quality standards could encourage greater use of electrified equipment. Targeted policies and incentives to improve air quality and public health in disadvantaged communities would also promote fuel substitution, as air quality tends to be poor in such communities.[133]

Rate Design

Electricity rate design presents another opportunity to encourage the fuel substitution of the industrial sector. Specifically, demand charges and time-varying pricing offer potential savings:

- **Demand charges:** Electricity users can be flexible about usage and manage it to avoid creating large peaks. Those users may experience lower electric bills in the presence of demand charges than they would without them, encouraging fuel substitution.
- **Time-varying pricing:** Given the diversity of industrial loads, industrial peaks vary. Some industrial processes can shift runtimes with relative ease, allowing industrial facilities to take advantage of times with lower electricity prices. To the extent that newly electrified end uses would face below-average prices on time-varying rates, their economic prospects would improve.[134]

Adapt European Framework

California could adapt the European Union’s recommended policy agenda framework (below) for fuel substitution to create its own framework:[135]

1. Recognize heat electrification from renewable energy sources.
2. Contribute to energy savings in the framework of the Energy Efficiency Directive.[136]
3. Include explicit focus on possibilities for substituting fossil fuels with renewable electricity, primarily in high temperature industrial processes applied to furnace technologies

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[133] Lawrence Berkeley National Laboratory. March 2018. *Electrification of Buildings and Industry in the United States – Drivers, Barriers, Prospects, and Policy Approaches*.

[134] Ibid.

[135] Navigant Consulting, Inc. (Ecofys). March 2018. *Opportunities for Electrification of Industry in the European Union.*

[136] The Energy Efficiency Directive mandates that certain facilities must implement energy efficiency improvements.

4. Define guidance on electrification of heat in best available technologies reference documents.[137]
5. Facilitate development of innovative electrification processes through research.
6. Support knowledge sharing by establishing a competence network.
7. Demonstrate the potential of novel electrification technologies through pilot and demonstration projects.

Additional Policy Adjustments

California can consider opportunities that mostly adapt or leverage existing policies and programs from the residential and commercial sectors. These approaches may include:

- Using the new fuel substitution test. (See the CPUC Decision Modifying the Three-Prong Test section for a description of this test.)
- Providing program incentives and financing support via utility programs and streamlined pathways through custom analysis or normalized meter energy consumption.
- Expanding the energy as a service market into the industrial sector for a comprehensive DER outlook, which should encourage fuel substitution.
- Developing utility or state agency programs (like BUILD and TECH) for the industrial and agricultural sectors that:
    - Engage over multiple years for long lead times before a facility investment.
    - Employ trusted technical experts.
    - Provide a strategic energy managementlike support network.[138]
- Altering the CPUC cost-effectiveness tool[139] to conduct hourly analysis to more accurately calculate the GHG benefit, including DR (or flexible load) benefits.
- Developing additional codes and standards for the industrial and agricultural sectors. The only standard is based on limiting carbon emissions for larger emitters.
- Encouraging additional load shifting capabilities frameworks through the CPUC, independent system operator, or other markets.

Technical Barriers and Solutions

Limited opportunities are available for electric technologies to replace gas equipment across the industrial and agricultural sectors. The technology solutions exist, but there are technical barriers for market adoption. Some of these technology solutions are provided in Appendix C.

Many of the technical barriers and solutions relate to the highly customized nature of the production processes that consume natural gas. These processes are customized to the product being produced; options for electric equipment that maintain quality standards and

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[137] The best available technology for each building type is outlined in the reference documents developed under the directive.

[138] The CPUC designed a program that includes objectives to have peers talking to one another. Sergio Dias Consulting. February 2017. *California Industrial SEM Design Guide*.

[139] "Cost-effectiveness," Consumer Energy Resources, California Public Utilities Commission, accessed August 2019.

production needs may be limited in technical availability and service capability by the vendors that stock, install, and service this equipment.

Barriers

The most prevalent technical barriers for the industrial sector are the availability and feasibility of electrifying processes. Many industrial processes are not designed to use electricity, or electrically based alternatives are not available. For example, some higher-temperature processes like those found in cement manufacturing[140] do not have many electrified alternatives but are good targets for hydrogen alternatives (a topic this study does not cover). Fuel substitution alternatives that do exist for high-temperature processes can be difficult to implement, and the overall transition is intensive.

When electric alternatives are available, they cannot always replace the nonelectrified process because of the intended purpose and design of the equipment. For example, an electric motor cannot always directly replace a steam-turbine motor (driven by steam generated with carbon fuel combustion) because steam-driven motors serve different purposes than electric-drive motors. Steam-driven turbines, typically pumps, are used for specific applications such as pumping material of varying viscosity, and the turbines are built to accommodate specific material viscosity ranges. Generally, steam turbines are built to handle denser, more viscose materials relative to electric turbines because it is more efficient due to the different fuel sources. In most cases, the applications limit the replacement of these steam-driven turbines with electric motors.

Another industry fuel substitution complication is best described by Berkeley Lab:

> "…the intensive degree of integrated process design including extensive use of CHP in several sectors and in the oil and gas refining and chemicals/petrochemical sectors… [The] oil refining industry has extensive 'own-use' fuel consumption where by-products of the oil refining process (e.g., refinery or still gases obtained during the distillation of crude oil) are used as fuel in upstream or downstream processes. Attempting to substitute the fuel for these processes would complicate the design and increase the energy cost over and above a sector that does not have this type of extensive process integration and own-use energy consumption."[141]

The lack of information on electric alternatives to gas is an additional technical barrier. The lack of information exists at the end user level and the delivery agent to the end user. The end user may have concerns that the electric alternative could not provide the same level of service, may affect product quality, and reduce productivity. Furthermore, the vendors and service providers do not have information or experience with the alternatives.

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140 Lawrence Berkeley National Laboratory. March 2018. *Electrification of Buildings and Industry in the United States – Drivers, Barriers, Prospects, and Policy Approaches*.

141 Ibid.

Solutions

The technical opportunities that exist depend on the industrial building type because of the variable processing of each building type. The solutions include:

- Using existing technologies.
- Funding research, development, and demonstration.
- Providing education and training.

Using Existing Technologies

Many alternative technologies provide fuel substitution solutions. For example, mature electroheating technologies such as induction, resistance, infrared, electric-arc and radio frequency, and microwave heating could be used in high-temperature processes. The applicability of these technological opportunities is segment-specific.

In addition to process heating fuel substitution solutions, electrified process alternatives for boiler systems, CHP, process heat, and facility HVAC exist for a variety of segments. Researchers found overlap among the segment type-specific fuel substitution suggestions across a variety of references, indicating that some end uses are more feasible to electrify. The research team reviewed several data tables (shown in Appendix C), which showed that process heat was the most prevalent end use for fuel substitution. Process heat provides the largest opportunity for fuel substitution across segments, and specific fuel substitution strategies can be matched to the requirements of the specific process.

Funding Research, Development, and Demonstration

An NREL study found that the primary drivers of new technology adoption are productivity and profitability benefits rather than simple payback. These benefits can be observed in terms of improved product quality, higher throughput, and reduced scrap and labor costs.[142] In most cases, the solution to a technology barrier is research, development, and demonstration funding/initiatives. One potential solution is to use the CEC's Energy Research and Development Division and the Electric Program Investment Charge program to advance industrial fuel substitution technologies.

The Sustainable Gas Institute is developing an industrial modeling software to provide a stimulatory approach to whole energy systems. The institute can use the ModUlar energy system Simulation Environment model to evaluate processes and technologies suitable for increasing fuel substitution of the industrial sector and to analyze the effect of a portfolio of technologies on energy and emissions reductions.[143] This software is a potential resource for industrial fuel substitution modeling in the future.

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[142] National Renewable Energy Laboratory. 2018. *Electrification of Industry: Summary of Electrifications Future Study Industrial Sector Analysis*.

[143] Sustainable Gas Institute. "Finding Ways to Electrify the Industrial Sector." Imperial College London, accessed August 2019.

Providing Education and Training

Many industrial and agricultural customers are knowledgeable about their operations and cost savings opportunities. However, they are weary of doing something different from the status quo. There is an opportunity to offer education and training services through:

- Case studies.
- Training sessions.
- Utility or government programs.
- Collaborative forms such as strategic energy management.[144]

Through education, facilities may embrace focusing more on design than technologies, like industrial heat pumps via process re-engineering. Facility owners may be hesitant because it is changing what they are used to. One solution is encouraging plants and companies to employ an energy manager who can disseminate knowledge about fuel substitution opportunities. The energy manager can dispel myths about certain changes to fuel types disrupting plant operations.

Cost Barriers and Solutions

Decision-making in these sectors is tied to the costs: financial, time needed to implement a solution, and energy. It is important to consider the operational and first costs. Many industrial and agricultural facilities have limited funding for capital improvements. For the funding that is available, it is prioritized toward improvements in production efficiencies. If there are unknowns on how to improve production or what the benefits are for the technology in question (such as fuel substitution), then the facility decision makers move on to what is known and has a with a quantifiable, favorable ROI.

Barriers

The low cost of natural gas presents a major cost barrier to industry fuel substitution, leading to unfavorable economics. In California, the average retail price of electricity for the industrial sector in the IOU territories is \$0.124/kWh, and the price of commercial natural gas is \$0.70/therm.[145] However, "[on] an energy basis, the price of natural gas is four times cheaper than for electricity, so an electric heating application would need to be four times more efficient than its natural gas counterpart to have the same energy costs."[146] Thus, converting the price of electricity to an equivalent natural gas basis because of this differing energy content results in the equivalent price to be \$3.63/therm of natural gas.[147] From a cost-per-energy unit perspective, this pricing difference profoundly affects operating costs and presents a cost barrier. This cost calculation does not take into consideration the cost of carbon or the

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[144] Sergio Dias Consulting LLC. February 2017. *California Industrial SEM Design Guide*.

[145] California Energy Commission, *2017 IEPR Update* and Demand Forecast Forms. Adopted Feb. 2017. Excel Demand Forecast Forms available at http://www.energy.ca.gov/2017_energypolicy/documents and *California Energy Consumption Database (ECDMS)*, accessed Oct. 2018.

[146] Lawrence Berkeley National Laboratory. March 2018. *Electrification of Buildings and Industry in the United States – Drivers, Barriers, Prospects, and Policy Approaches.*

[147] Conversion based on ratio of 29.3 kWh = 1 therms of natural gas.

potential ability to provide grid resources via flexible loads. Most industrial customers use retail energy rates when making financial decisions related to energy use.

This energy cost disadvantage that persists in fuel costs is affected greatly by equipment efficiency. Two varying examples of this equipment cost comparison are as follows:

- "For an electric boiler with 100 percent end use efficiency versus a gas-fired boiler with 80 percent efficiency, the cost of energy is 4.2 times higher for the electric boiler."[148]
- For an electric heat pump water heater with a coefficient of performance (COP) of 4.0[149] in the commercial and industrial sector versus a gas-fired heater at 0.8 COP,[150] the cost of energy is 1.04 times higher for the electric case. This cost differential used to be greater, but efficiency advancements in heat pump technologies have closed the gap.

Further cost barriers exist related to the capital costs associated with the equipment transition. While capital costs are sometimes lower for electrical machinery, replacing an operational nonelectric machine in favor of an electrified alternative adds capital costs to transition fuel sources. These added costs mean that plants will be incurring nonessential capital costs for machinery that will cost more to operate. Additional costs may exist if the end user exceeds the local grid capacity availability. Additional cost burdens exist for some large end users that own their substations and may exceed the substation capacity when electrifying processes.

The U.S. Department of Energy provides some additional cost barriers applicable to industry fuel substitution:

- Infrastructure manipulation costly: High capital costs to transition machinery fuel from fossil fuel over to electric, often losing efficiency
- Internal competition for capital: Manufacturers often have limited capital available for end-use projects and frequently require very short payback periods (one to three years).
- Energy price trends: Volatile energy prices can create uncertainty in investment returns, leading to delayed decisions on energy efficiency projects.
- Split incentives: Companies often split costs and benefits for energy projects among business units, which complicates decision-making
- Corporate tax structures: U.S. tax policies, such as depreciation periods, the treatment of energy bills, and other provisions, can be a deterrent.[151]

Solutions

While industrial users participate in a competitive industry and have an incentive for cost-minimization, solutions to these cost barriers still depend heavily on policy and technical

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[148] Lawrence Berkeley National Laboratory. March 2018. *Electrification of Buildings and Industry in the United States – Drivers, Barriers, Prospects, and Policy Approaches*.

[149] Navigant Consulting, Inc. July 2018. *Analysis of the Role of Gas for a Low-Carbon California Future.*

[150] Lawrence Berkeley National Laboratory. March 2018. *Electrification of Buildings and Industry in the United States – Drivers, Barriers, Prospects, and Policy Approaches.*

[151] U.S. Department of Energy. June 2015. *Barriers to Industrial Energy Efficiency.*

drivers. Policy changes provide cost solutions in the form of monetary incentives for fuel substitution. On the technical side, advancements that increase the efficiency or transitional feasibility of electrical equipment provide additional cost solutions. These solutions include addressing the overall costs (first and operational costs). In most cases, there is not a capital expenditure barrier (even though end users bring it up in surveys); there is a need to provide a high ROI to engage decision makers in an investment.

Possible solutions to the first cost barrier include:

- Engaging energy as a service companies to help provide the financing streams to pursue retrofits that reduce initial costs via the service model.
- Supporting the development of financing products specifically targeting this market, like how the property assessed clean energy and commercial property assessed clean energy[152] programs have addressed access to financing for energy savings solutions.
- Encouraging and supporting utility programs for technical support, decision-maker engagement, and monetary incentives.
- Encouraging sites to quantify nonenergy benefits to fully incorporate the benefits into analysis. Some benefits may include reduced risk (safety due to natural gas usage), health benefits (less combustion), improved productivity, and improved product quality.

Possible solutions to the operating cost barrier include:

- Informing and encouraging industrial and agricultural facilities to participate in ancillary services and be a demand-side resource via flexible load (that is, demand management).
- Promoting ongoing decreases in renewable generation costs; this has the potential to reduce energy supply costs and provide price stability, which is key to most manufacturers.
- Fostering the emergence of carbon markets that might allow GHG reductions to be more fully monetized, improving the economics of the fuel substitution in larger-scale industrial applications.

Data Gaps

When attempting to evaluate fuel substitution for the industrial sector, significant data gaps exist in terms of energy, use, cost, and analysis tools. There is little publicly available cost data for electrotechnologies, and most available data are anecdotal. "Although some data are available for certain industries, end uses, and technologies, the lack of consistent metrics limits their use for developing projections."[153] Furthermore, available literature is often old and cannot be easily generalized for analysis.

Further research in the industry needed, including:

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[152] Property assessed clean energy, https://pacenation.us/.

[153] National Renewable Energy Laboratory. 2017. *Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050*.

- Data for analysts/modelers and tools to estimate results and to identify opportunities for fuel substitution.
    - Hourly load shapes to fully quantify the benefits of carbon abatement and grid-level impacts related to potential feeder upgrade requirements for electric process heating for targeted segments.
    - Data for policy makers to supplement the incomplete picture of opportunities and effects from analysts/modelers.
- More exploration on emerging technologies and fuel substitution technology research, development, and demonstration for the sectors:[154]
    - Applicability and expansion of induction and other forms of electric heating.
    - Comparisons of costs and benefits of direct versus indirect (via hydrogen production) fuel substitution.[155]
- Industrial process improvements effect on productivity and product quality:
    - Further process-level analysis and modeling to identify which segments or processes to prioritize for fuel substitution.
    - Development of direct fuel substitution process designs, equipment costs, and demonstrations.
    - Studies to understand potential effects to product quality.
    - Case studies and technology demonstration studies exploring and documenting successful industrial fuel substitution.

The general data trends appear to be that industry data are not widely or consistently collected for public use. Moreover, any data that are collected lack the granularity necessary to evaluate effectively the industry based on specific segments and end uses.

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[154] Global Efficiency Intelligence. April 9, 2018. Infographic: Deep Electrification of Manufacturing Industries."

[155] Lawrence Berkeley National Laboratory. March 2018. *Electrification of Buildings and Industry in the United States – Drivers, Barriers, Prospects, and Policy Approaches*.

CHAPTER 5:
Fuel Substitution Scenario Analysis Tool

The FSSAT functions as a flexible analysis tool that provides the CEC user with the data and framework necessary to understand the effects of fuel substitution in California at the technology level. The tool functionality allows users to update input data and scenarios and provides granular control of technology replacement.

Tool Description

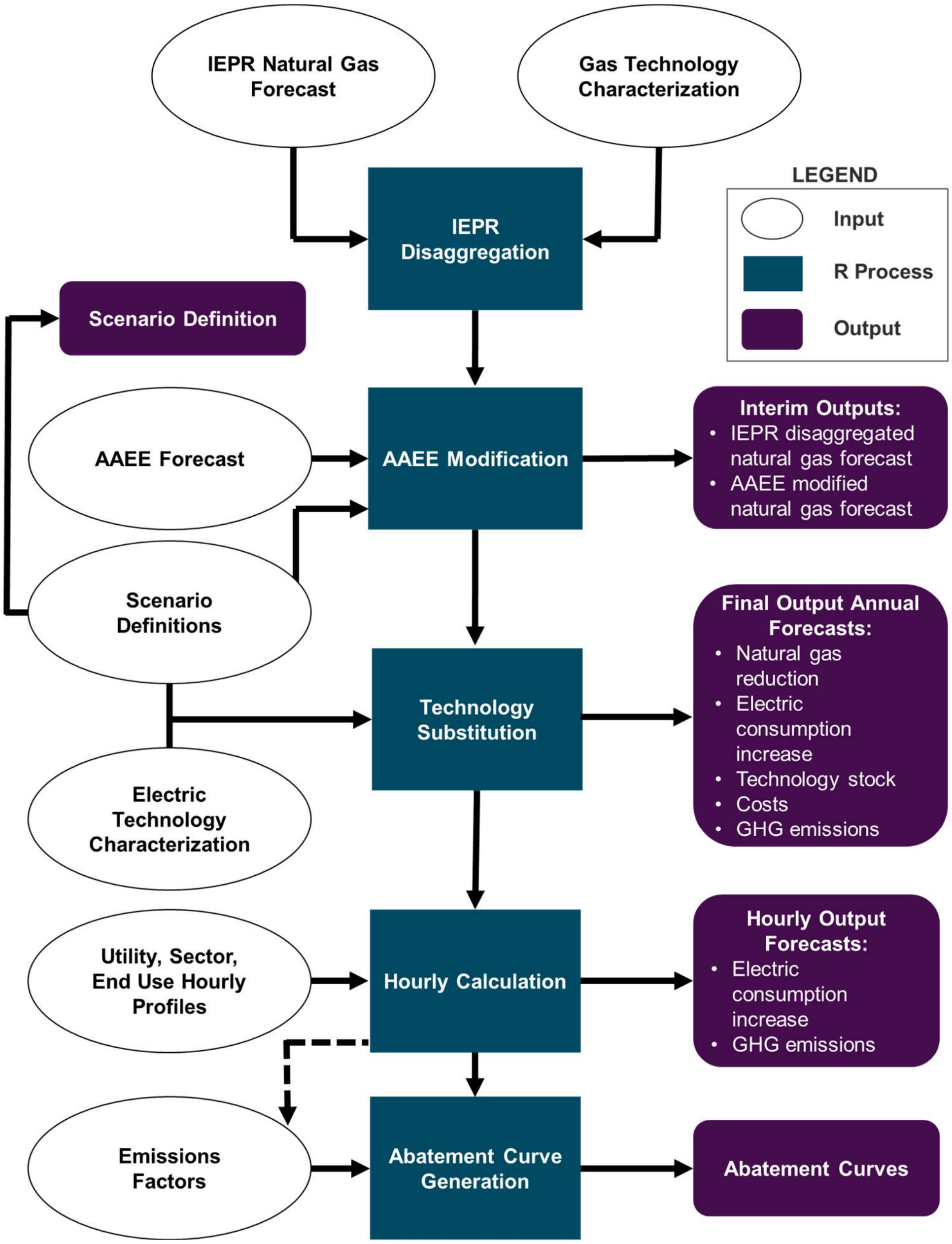
The objective of the FSSAT is to determine the change in GHG emissions in the residential, commercial, agricultural, and industrial sectors based on user inputs, focused on 2030 in accordance with AB 3232. The FSSAT outputs include annual forecasts of the natural gas displaced and additional electric energy consumed at the end-use level, electric technology stock, and consumer costs at the technology level. Where appropriate, these outputs are also given at the hourly level to determine hourly GHG emissions impacts. Combined, the FSSAT tool outputs are used to determine the resulting change in overall GHG emissions.

The FSSAT completes five tasks for a given scenario:

1. **IEPR disaggregation**. Disaggregation of the IEPR natural gas forecast from the end-use level to the technology level.
2. **Additional achievable energy efficiency (AAEE) modification.** Modification of the IEPR natural gas forecast to incorporate the natural gas energy efficiency planned savings accounted for in the AAEE forecast disaggregated to the technology level.
3. **Technology substitution.** Substitution as specified in the user-defined inputs. Fuel substitution targets are defined by the user specifically for calendar year 2030. Years prior to 2030 are populated using static adoption curves defined by the user. Technology substitution results in the following calculated forecasts:
    a. Annual reduction of natural gas at the end-use level.
    b. Annual change in electric technology stock and increase in electric consumption at the technology level.
    c. Overall costs associated with the defined fuel substitution scheme including technology, installation, fuel, and ancillary costs.
    d. Overall annual GHG emissions reduction at the end-use level based on natural gas consumption reduction, electric generation addition, additional refrigerant leakage, and natural gas leakage emissions reduction.
4. **Hourly calculation.** Calculation uses hourly normalized load shapes specific to the utility, sector, and end-use level to disaggregate the annual electric load increase and GHG emissions reduction forecast to the hourly level.
5. **Abatement curve generation.** Development of supply curves based on calculations for GHG emissions reductions and overall costs.

The research team built the FSSAT using two linked platforms: Microsoft Excel® and R scripts. Excel input files are imported into the R script, which contains the core analysis algorithms. The R script generates output files into Excel workbooks. Figure 11 illustrates the FSSAT tasks and distinguishes each item as an input, R process, or output.

Figure 11: Fuel Substitution Scenario Analysis Tool Description



Flow chart depicting the inputs, outputs, and R processes of the FSSAT. Inputs include IEPR natural gas forecast, gas technology characterization, AAEE forecast, scenario definitions, electric technology characterization, hourly profiles, and emissions factors. Annual outputs include interim and final natural gas reduction, electric consumption increase, electric technology stock, costs, and emissions. Hourly outputs include electric consumption increase and GHG emissions reductions. Output analysis includes abatement curves. The R processes include IEPR disaggregation, AAEE modification, technology substitution, hourly calculation, and abatement curve generation.

Source: Guidehouse

Tool Objectives and Scope

The FSSAT objectives, as directed by CEC staff, were to calculate fuel substitution scenarios to achieve various policy objectives. The FSSAT has several functions:

- Calculate and output natural gas reduction and electric energy increase based on replacement scenario inputs at the utility,[156] sector, end-use, building-type, and replacement type (replace-on-burnout, new construction, or retrofit) levels.[157]
- Calculate and output electric stock added due to fuel substitution at the utility, sector, end-use, building type, and replacement type levels.
- Calculate and output an emissions forecast for substitution based on natural gas removed, electric load added, refrigerant leaks, and natural gas leaks.
- Calculate and output the costs associated with a fuel substitution scenario (technology, fuel, and panel upgrade costs).
- Modify the IEPR forecast baseline according to a specific AAEE savings scenario (described in "Modify Forecast Based on AAEE" section).
- Allow the user to modify input data, as needed.

The tool allows only for the substitution of natural gas to electricity technologies. It does not allow for substitution of natural gas to high-efficiency natural gas technologies or electricity to natural gas technologies. The tool does account for expected energy efficiency replacements as prescribed in the Scenario 1 of the AAEE forecast.[158]

The tool features allow users to vary existing baselines and scenarios at the technology, end-use, building-type, sector, and utility levels. The user can configure technology adjustments by the new construction, accelerated replacement, and replace-on-burnout replacement (or measure application) types.

The emissions calculated in this study are from electricity generation carbon emissions, methane leakage, or refrigerant leakages. The reported values are quantified in kilograms of carbon equivalent (kg CO_2e).

Scope of FSSAT Capabilities

The FSSAT uses customizable baseline data combined with user-specified input parameters to define fuel substitution and the resulting effects to statewide natural gas consumption, electric consumption, GHG emissions, and customer costs in 2030, which are extrapolated over the forecast period.

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156 Specific utility disaggregation is provided in Table 15.

157 The added electric load also incorporates added load from residential space cooling due to heat pump installation where there was no space-cooling load. For example, in the case where a household replaces a natural gas furnace and no air conditioning with a heat pump, there may additional load (and subsequent electric generation emissions) from space cooling. The tool analysis assumes no new commercial space cooling consumption.

158 Users may update the FSSAT AAEE inputs to examine the impacts of different forecasts of energy efficiency, some of which in AAEE are more aggressive than Scenario 1.

Measure Characterization

The tool characterized technologies at the building-type level and leveraged existing data sources, if available. The building-type level characterization means that it is not at the facility/building level. Therefore, any analysis of per household or per 1,000 square feet (units used to define the commercial building stock) is based on market average equipment density assumptions per unit of building stock. The results represent the entire population of buildings of that type in a given segment rather than a single building of that type. In future work, assumptions could be made about electric technology adoption to approximate building-level results. An analysis at this level would require data that define customer behavior in adopting multiple electric technologies. This limitation also affects reporting costs at the end-use level because the panel costs are allocated on an installed-heat pump basis, not at the building level.

In leveraging existing data sources, the electric technologies performance and cost characterizations are based on best available data. In many cases, data regarding performance and costs in California available from thorough and well-vetted program evaluation or market research are limited. As better data become available, the tool user should update the technology characterization accordingly.

Technology Adoption

The tool does not complete any adoption modeling based on customer behavior or market conditions. Instead, the FSSAT uses static user-defined adoption curves to determine adoption of technologies by the 2030 target year. As utility rates and the cost of technology change over time, the user must modify the adoption curve to reflect changes in the market as an input to the tool. Default values in the FSSAT for adoption do not represent any program designs that would provide a basis for shaping adoption through subpopulation targeting and incentives, nor any consumer behavior that would inform organic transition from natural gas to electric appliances.

Nonfuel Substitution Building Emissions

The tool does not incorporate refrigerant emissions from the installed air-conditioning and refrigeration equipment throughout the forecast period. As detailed in the Refrigerant Emissions section, the FSSAT calculates refrigerant emissions for additional heat pumps and relies on user inputs to account for any additional non-heat pump refrigerant leakage through the forecast period. The tool does correct for refrigerant emissions when heat pumps replace air conditioners and natural gas furnaces because this technology replacement assumes no new refrigerant emissions when the baseline technology had refrigerant (for the residential sector only). Using the tool for Senate Bill 1383 (Lara, Chapter 395, Statutes of 2016) analysis will be limited to only the effects of heat pumps and heat pump water heaters, not refrigerant-type changes when retrofitting other technologies. The tool requires user assumptions on the mix of refrigerants used per technology.

Analysis Framework

The research team chose a combination of Excel workbooks and R scripts to host the tool. The FSSAT Inputs and FSSAT Outputs sections describe the Excel input and output workbooks from the FSSAT. The R Processes section describes all data manipulation and calculations that occur in the R environment.

FSSAT Inputs

There are two sets of inputs to the model: global inputs and user-defined inputs. The global inputs are defined by a variety of California-based data sources and studies. The user defines the user inputs during the fuel substitution scenario building process. The research team designed the FSSAT for maximum user flexibility to modify inputs, global or user-defined, as better or more updated data become available.

Table 8 describes the global inputs. The research team obtained most of the global inputs from CEC sources. The CEC typically updates these sources biennially. The global inputs Excel workbook provides specific sources and instructions on how to update each dataset.

Table 8: FSSAT Global Inputs

Dataset	Data Description
Building Stock Forecast	Building forecast and demolition rate at the utility and IEPR-defined building-type level* through 2030 (demolition rate included).
Utility Rates Forecast	Electricity and natural gas retail rates by sector and utility through 2030 used to calculate user technology fuel costs.
IEPR Natural Gas Demand Forecast	Natural gas consumption at the utility, sector, and end-use level through 2030.
Utility To Climate Zone Mappings	Mapping between gas utility, electric utility, forecast climate zone (FCZ), and building climate zone (BCZ).
AAEE Forecast	Energy efficiency savings at the FCZ, sector, and end-use level through 2030.

***Appendix E lists the defined building types. Building types are segmented based on geography and building function. There is no differentiation for building vintage.**
Source: Guidehouse

The technology-level characterization inputs are predefined and based on best available data. The technology characterization, described in Appendix F, has parameters that users can define. As needed, the user may modify the natural gas and fuel substitution technology environments in the scenario building process. For example, the user may choose to modify the COP and costs unique to a specific scenario in the fuel substitution characterization environment or the saturation and densities specific to a utility in the natural gas technology characterization environment.

Like the global inputs, the user should update this dataset as more and/or better data becomes available. The original source for most of the technology characterization is the CPUC 2019 Potential and Goals study.[159] The Potential and Goals study relies on the CPUC's Database for Energy Efficient Resources[160] and measure workpapers. Alternate sources may

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[159] Navigant Consulting, Inc. 2019. *2019 Energy Efficiency Potential and Goals Study*. California Public Utilities Commission.

[160] DEER can be found at http://www.deeresources.com/.

provide more up-to-date data such as for POU programs.[161] The research team recommends reviewing the top technologies regularly for updates to technology characterization inputs. During the update, users may add more natural gas and fuel substitution technologies. Table 9 describes the technology characterization inputs.

Table 9: FSSAT Technology Characterization Inputs

Name	Description
Natural Gas Technology Characterization	Technology-level consumption, costs, saturation, and density by utility, sector, end-use, building-type, BCZ, and efficiency level.
Fuel Substitution Technology Characterization	Technology level efficiency and cost characterization.

Source: Guidehouse

The natural gas technology characterization includes assumptions for the existing residential and commercial stock for gas space heating, water heating, appliances, and cooking. The characterization, described in Appendix F, includes costs, technology-level consumption, efficiency-level distribution (saturation), and capacity of system or quantity of technologies in a given technology group (density) at the building stock level.

Density and saturation are two essential natural gas technology characterization metrics.

- Density is the number of technology units per building scaling basis (per household for residential and per square foot for commercial). The density is used in the FSSAT framework to scale the technology stock to the sector/segment level. Each individual technology group has a defined density. Examples of density are units/home, kBtuh/home, water heaters/1,000 square feet, and tons of cooling/1,000 square feet.
- Saturation is the share of a specific technology within a technology group such that the sum of the saturations across a technology group always sums to 100 percent.[162] For residential and commercial, technology characterization is disaggregated to the building-type and climate-zone levels.

The existing data source is the 2019 Potential and Goals study. The user may update the data points, as needed. Appendix F has more details.

The COP is also an important metric in the fuel substitution technology characterization. The COP represents the ratio of the useful heating value produced by the technology to the heat value of the fuel supplied to the technology. In the FSSAT framework, this value is used to convert natural gas heating consumption to electric heating consumption. In heat pumps, the dominant electric heating resource, operation is sensitive to ambient air temperature.

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[161] SMUD is implementing a program that subsidizes fuel substitution, including the costs of the panel upgrade. Collecting actual project costs can supplement the technology characterization inputs.

[162] Users may calculate stock using this data. Most technology densities are at a per-stock value. The analysis uses Equation 1 without the consumption.

Increasing the COP values in the characterization (indicating a more efficient heating system) results in reduced energy consumption and more GHG emissions abated. Appendix G describes the analysis conducted to address variations in COP by technology and climate zone.

The tool user defines the user-defined inputs and modifies each scenario in the user inputs Excel workbook. Table 10 describes each user-defined input type.

Table 10: FSSAT User-Defined Inputs

Name	Description
Scenario Definition	Set the scenario names, AAEE scenario, cost year, discount rates, emissions factors, and input/output workbook file locations.
Scenario Parameters	Set the target for 2030 fuel substitution activity for calculating adoption by replacement type, efficiency level, sector, and utility.
Replacement Map	Map existing (gas) technology to one or more electric replacement technologies.
Adoption Scheme	Map adoption curves defined in adoption curves input tab to replacement technologies.
Adoption Curves	Input the rate of technology change from gas to electric year-over-year. The researchers provided general assumptions for current values.
R Input	Input sheet that feeds into the FSSAT R script. Any changes made in the other input tabs (for example, scenario parameters, replacement map, adoption scheme, and adoption curves) feed into here. The user may override inputs line by line on this tab.
Refrigerant Inputs	Input for refrigerant emissions analysis, which includes percentage leakage and charge size by electric technology.
Natural Gas Leakage Emissions Inputs	Inputs for natural gas leakage emissions analysis, which includes percentage leakage as a function of natural gas consumption.
Panel Costs	Input facility-level cost inputs — for example, an electrical panel upgrade.
Effective Useful Life Distribution	Input the EUL and stock turnover decay by electric technology.
Buildings With AC Proportions	Input for proportion of residential buildings with air conditioning units at the gas utility, BCZ, building type, and sector levels.

Source: Guidehouse

FSSAT Outputs

The tool provides output workbooks by scenario:

- Residential/commercial interim outputs
- Agricultural/industrial interim outputs
- Residential/commercial final outputs (emissions)
- Residential/commercial final outputs (costs)
- Agricultural/industrial final outputs
- All sector hourly outputs

Table 11 describes the contents of interim output workbook. The interim outputs provide the adjustments to the baseline natural gas forecast for FSSAT use. The tool calculation relies on the IEPR forecast disaggregated to the technology level, which is then adjusted to reflect planned energy efficiency (AAEE).

Table 11: FSSAT Interim Output Data

Name	Units	Description
IEPR Natural Gas Forecast	MM therms	The IEPR natural gas forecast at the BCZ and FCZ levels disaggregated to the technology level.
AAEE Modified Natural Gas Forecast	MM therms	IEPR NG* forecast worksheet data modified based on expected energy efficiency over the forecast period.

***NG is used as an abbreviation for natural gas in the workbook.**
Source: Guidehouse

Table 12 describes the final annual consumption and emissions output data of FSSAT.

Table 12: FSSAT Final Output Data – Annual Consumption and Emissions

Workbook Tab Name	Units	Description
Revised NG Forecast*	MM therms	AAEE modified NG forecast worksheet with natural gas reduction due to fuel substitution included.
Added Stock	Unit Basis	Electric technology stock added due to fuel substitution.
Added Electric Cons. (From Replaced Gas)	kWh	Electric consumption increases due to fuel substitution (without additional space cooling loads).
Added Electric Cons. (Added Heat Pump Cooling Load)	kWh	Electric consumption increases due to fuel substitution (additional space cooling only).
HFC Emissions (HP)*	kg CO_2e	HFC emissions from heat pump refrigerant leakage.

Workbook Tab Name	**Units**	**Description**
HFC Emissions (Non-HP)	$mTCO_2e$*	HFC emissions from non-heat pump refrigerant leakage.
NG Leakage Emissions	kg CO_2e	Emissions from natural gas leaks downstream of the commercial and residential meter.
NG Emissions Added*	kg CO_2e	Direct emissions from additional natural gas consumption due to fuel substitution.
Electric Emissions Added	kg CO_2e	Indirect generation emissions from additional electric consumption due to fuel substitution.
Total Emissions Added	kg CO_2e	The net aggregate emissions added due to fuel substitution.
Emissions Reduction Cost	Various	This tab includes cumulative avoided emissions, cumulative net present cost incremental to the gas technology, and cumulative cost per metric ton avoided ($/$mTCO_2e$).

***NG = natural gas, AC = air conditioning, mT = metric tonne, HFC = hydrofluorocarbon, HP = heat pump**

Source: Guidehouse

Table 13 describes the final cost output data of FSSAT.

Table 13: FSSAT Final Output Data – Costs

Workbook Tab Name	**Description**
Added Tech. Cost (Split)	Fuel substitution technology cost expected due to fuel substitution split by cost type: • Equipment cost • Installation cost • Overhead and profit cost
Added Tech. Cost (Total)	Total (not including electric or gas supply-side infrastructure costs) technology cost expected due to fuel substitution.
Added Tech. Cost (Inc Total)	Total (not including electric or gas supply-side infrastructure costs) technology incremental cost expected due to fuel substitution.
Fuel Costs (Split)	Fuel costs split into natural gas costs mitigated and electric costs added due to fuel substitution.
Fuel Costs (Net)	Net fuel costs of added electricity and reduced natural gas.
Panel Costs	Aggregate costs of panel upgrades at the utility, sector, building type, and BCZ levels.

Source: Guidehouse

Table 14 describes the final hourly analysis output data of FSSAT.

Table 14: FSSAT Final Output Data – Hourly Analysis (Detailed)

Workbook Tab Name	Description
FS Hourly Impacts Out (MW)	The hourly electric load impacts for the input utility or utility group at the sector level.
FS Hourly Impacts Out (GHG)	The hourly electric emissions impacts for the input utility or utility group at the sector level.
FS Hourly Impacts Scenario Out	The statewide hourly electric load impacts for the input utility or utility group.
Hourly Impacts Compare	The annualized summary of hourly emissions factors to be compared against the user input annual emissions factors.
Load shape Map Input	A record of the load shape mappings defined in the master map.
Transmission Inputs	A record of the transmission inputs defined in the master map.
Distribution Inputs	A record of the distribution inputs defined in the master map.
Residential End Use Output	The hourly electric load impacts for the input utility or utility group at the end use level in the residential sector.
Commercial End Use Output	The hourly electric load impacts for the input utility or utility group at the end use level in the commercial sector.
Agricultural End Use Output	The hourly electric load impacts for the input utility or utility group at the end use level in the agricultural sector.
Industrial End Use Output	The hourly electric load impacts for the input utility or utility group at the end-use level in the industrial sector.

Source: Guidehouse

Data outputs are provided at the utility (Table 15) including mapping to FCZ, sector, and end-use levels (Table 16). Not all end uses are included in the outputs because the tool addresses only electricity end uses substituting natural gas. Some data outputs are available at the FCZ and building type level. Appendix D provides the BCZ to FCZ mapping.

Table 15: Utility Disaggregation

Forecasting Climate Zone	Electricity	Natural Gas
1	PG&E	PG&E
2	PG&E	PG&E
3	PG&E	PG&E
4	PG&E	PG&E
5	PG&E	PG&E
6	PG&E	PG&E*
6	PG&E	SCG*

Forecasting Climate Zone	Electricity	Natural Gas
7	SCE	SCG
8	SCE	SCG
9	SCE	SCG
10	SCE	SCG
11	SCE	SCG
12	SDG&E	SDG&E
13	SMUD	PG&E
14	Other	PG&E
15	Other	PG&E
16	LADWP	SCG
17	LADWP	SCG
18	Other	SCG
19	Other	SCG
20	Other	SCG

*** Forecasting Climate Zone 6 is the only climate zone that contains two gas utilities (PG&E and SCG).**

Source: Guidehouse

Table 16: Fuel Substitution End-Use Description

Sector	End Use*	Description
Residential	HVAC	Heating and ventilation heat loss for space conditioning.
Residential	WaterHeat	Energy for heating domestic hot water.
Residential	AppPlug	Residential appliances including oven, cooktop, clothes dryer.
Commercial	HVAC	Heating and ventilation heat loss for space conditioning.
Commercial	WaterHeat	Energy for heating domestic hot water.
Commercial	FoodServ	Appliances used for food service including fryer, griddle, and oven.
Commercial	AppPlug	Clothes dryers.
Agricultural	HVAC	Building heating and cooling, including heating for greenhouses.
Agricultural	WaterHeat	Energy for heating hot water.
Industrial	ProcHeat	Generalized process heating in industrial processes.

***The miscellaneous end use included in the IEPR forecast does not have a corresponding electric fuel substitution as delivered in the FSSAT. The miscellaneous end use is characterized in the IEPR study and represents niche end uses like spa heating and gas fireplaces. The abbreviated spelling matches the tool end use nomenclature.**

Source: Guidehouse

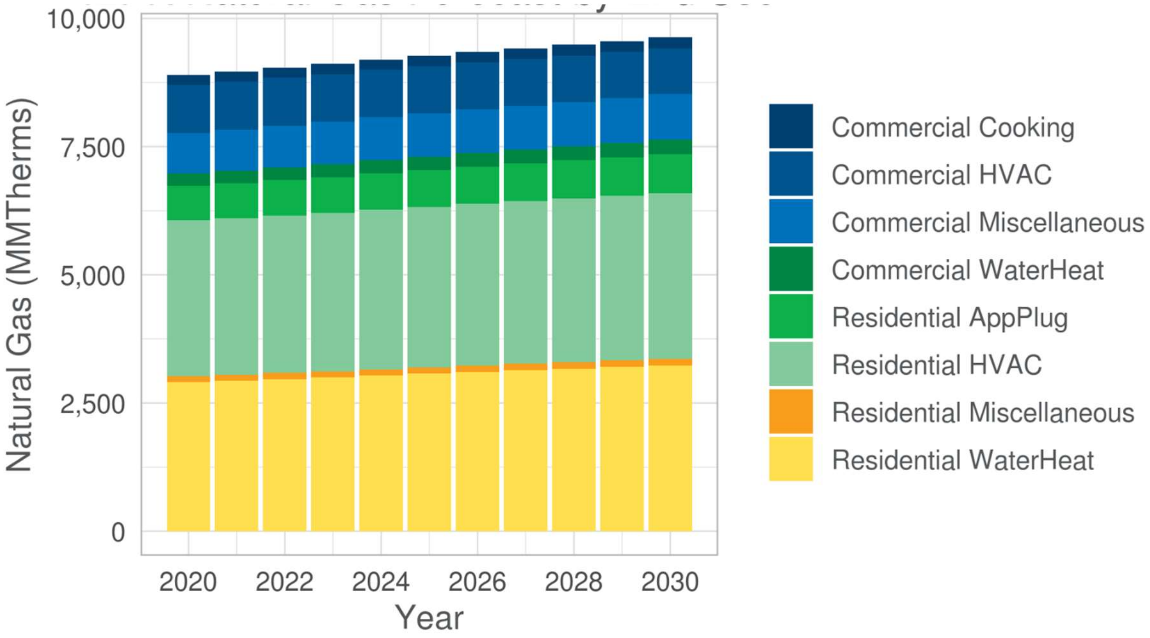
R Processes

Five main analysis processes occur with the R script in FSSAT, each with specific functionalities. This section describes each process.

Disaggregate IEPR Forecast to Technology Level

The CEC develops, adopts, and reports a natural gas forecast every two years through the IEPR process. The research team used the *IEPR 2017* mid case as the starting baseline gas demand in the FSSAT framework.[163] Figure 12 shows the mid case IEPR natural gas demand forecast at the sector and end-use levels.

Figure 12: IEPR Natural Gas Forecast by Sector and End Use



Stacked bar chart showing annual sector and end-use allocation of the natural gas forecast. Industrial and residential HVAC have the largest end-use consumption. The miscellaneous end use includes niche energy users such as spa heating and pool heating. No fuel substitution takes place in miscellaneous end uses.

Source: *IEPR 2017*

The first R process uses the IEPR natural gas demand forecast and data from the 2019 California Potential and Goals study natural gas technology characterization to approximate the relative proportion of consumption that can be attributed to unique technologies across all residential and commercial end uses. This R process does not affect industrial and agricultural sector data.

The overall gas consumption of a given technology as shown in Equation 1 relies on the characterized unit consumption, saturation, density, and building stock. The technology-level gas consumption varies by year with changing stock levels. Equation 1 also shows the

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[163] California Energy Commission. January 2020. CED 2019 - AAEE Savings by Planning Area and End Use.

calculation for disaggregating the IEPR end-use consumption to the technology level according to the saturations and densities documented in the gas measure characterization.

Equation 1: End-Use Disaggregation to Technology Level Consumption Characterization

$$Gas\ Consumption_{yr=2030,technology=j,end\ use=}$$

$$= \quad Gas\ Consumption\ IEPR_{j,k} \times \frac{Unit\ Energy\ Consumption_j \times\ Saturation_{j,2030} \times Density_j \times Stock_{j,2030}}{\sum_k (Unit\ Energy\ Consumption_j \times\ Saturation_{j,2030} \times Density_j \times Stock_{j,2030})}$$

$Where$:

$Gas\ Consumption\ IEPR_{i,k}$ = Gas consumption forecast in IEPR for technology, j, and end use, k
$Unit\ Energy\ Consumption_j$ = Characterized annual unit energy consumption for technology, j
$Saturation_{j,2030}$ = Characterized saturation of technology, j, in year 2030
$Density_j$ = Characterized density of technology, j
$Stock_j$ = Characterized building stock of technology, j, in 2030

The research team used the Potential and Goals study forecasted 2030 disaggregation across the efficiency levels and technologies by end use to assign the IEPR 2030 end-use level to each characterized technology. Table 17 summarizes the key inputs, outputs, and assumptions of the IEPR disaggregation R process.

Table 17: IEPR Disaggregation Forecast Inputs, Outputs, and Assumptions

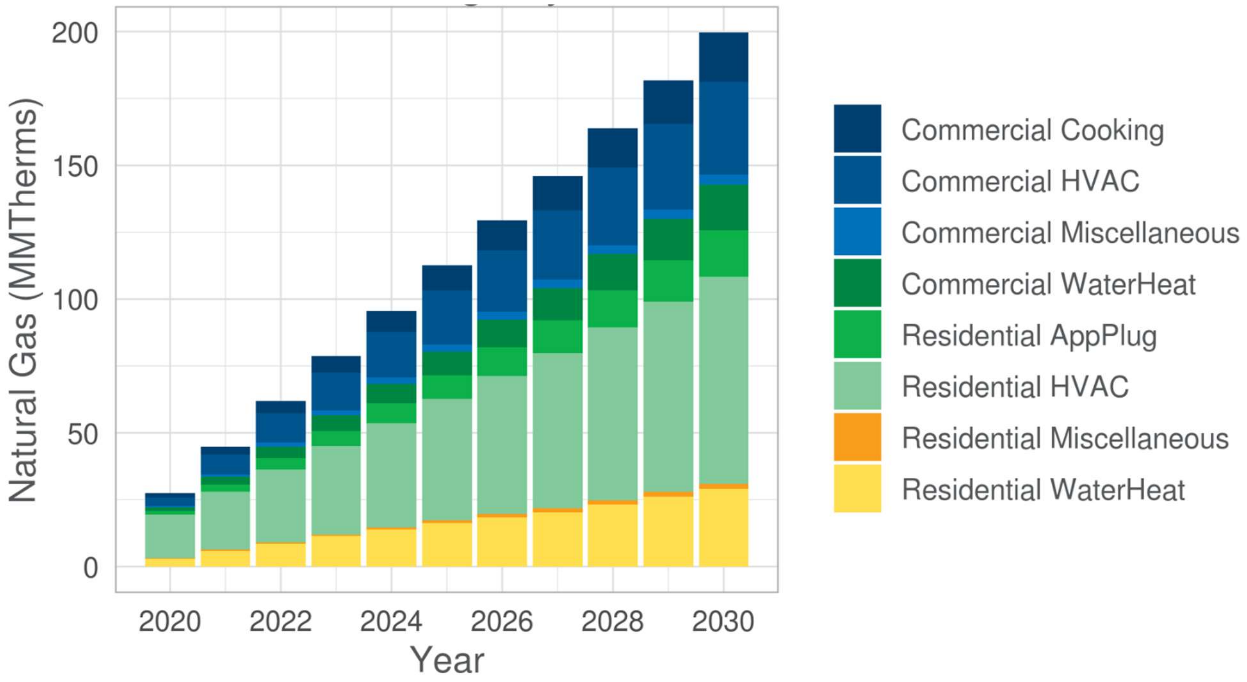
Inputs	Outputs	Assumptions
• 2017 IEPR end-use natural gas demand forecast • Technology characterization (consumption, saturation, and density data)	• IEPR natural gas technology disaggregated forecast 2030	• Consumption at the technology level is assumed to remain constant over the technology life (no decay in efficiency). • Any increase in the forecast of gas consumption is attributed to new construction, not new gas technologies in existing building stock. • No agriculture and industrial sector natural gas forecasts disaggregated to the technology level.

Source: Guidehouse

Modify Forecast Based on AAEE

The CEC develops the AAEE forecast to represent the savings that are reasonably expected to occur from planned or funded initiatives. The AAEE forecast consists of multiple scenarios. The IEPR natural gas forecast does not include AAEE savings. Effects of AAEE must be added to fully understand how the natural gas demand forecast is expected to change in the future because of energy efficiency programs. As such, the scenario parameters tab allows users to select which AAEE scenario to use in the analysis.[164] For this report, all figures and tables are based on the reference scenario, AAEE Scenario 1. Figure 13 shows the breakout of expected AAEE savings at the sector and end-use levels.

Figure 13: AAEE Scenario 1 Natural Gas Savings at the Sector and End-Use Levels



Stacked bar chart showing the forecast 2017 AAEE natural gas savings at the sector and end-use levels. The miscellaneous end use includes niche energy users such as spa heating and pool heating.
Source: Guidehouse analysis of AAEE data

Considering how AAEE savings might be affected by fuel substitution scenarios adds another layer of complexity. As fuel substitution is applied at higher penetrations, interactive effects may exist between gas energy efficiency and fuel substitution, affecting the potential for each. As shown in Figure 14 (left), AAEE assumes that density, or the overall amount of gas technologies in operation, remains constant through the forecast period. As fuel substitution is applied, the density of a given gas technology decreases and may disrupt the assumptions made by AAEE. Therefore, the team assumed a threshold value that will result in a degradation on potential natural gas energy efficiency opportunities.

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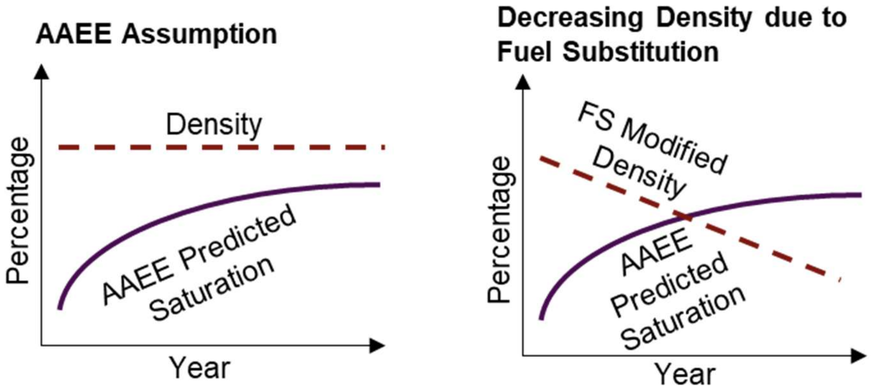
[164] California Energy Commission. January 2020. CED 2019 - AAEE Savings by Planning Area and End Use.

Figure 14: AAEE Forecast Modification



Graphs demonstrate how fuel substitution will change the overall gas technology density over time. The change in density of existing gas technology will affect the available potential for energy efficiency.
Source: Guidehouse

Gas end uses that have high AAEE savings forecasted may begin to have interactive effects with fuel substitution in that end use (shown in the right side of Figure 14). The analysis assumes that beyond a threshold of AAEE savings, AAEE savings proportionately scale down as fuel substitution scales up, as described in Equation 2.

Equation 2: AAEE Modified Savings Calculation Above Threshold

$$AAEE_{Modified\ Savings} = \frac{(NG_{Forecast,IEPR} - NG_{Substituted})}{NG_{Forecast,IEPR}} (AAEE_{Savings})$$

$Where$:
$AAEE_{Modified\ Savings}$ = Energy efficiency savings adjustment based on natural gas substitution.
$NG_{Forecast,IEPR}$ = Disaggregated IEPR natural gas consumption at the technology level.
$NG_{Substituted}$ = Gas consumption avoided due to fuel substitution.
$AAEE_{Savings}$ = Total amount of energy efficiency savings reported by the CEC.

The research team implemented the following method to account for interactive effects at the end-use level only if energy efficiency exceeds the assumed threshold where it will make a significant impact. The assumed threshold is 15 percent of the IEPR forecast:

- AAEE savings of 15 percent or less of the IEPR forecast are not adjusted before subtracting from the natural gas forecast.
- AAEE savings above 15 percent are proportionally degraded by the amount of natural gas remaining after electrification (based on the user inputs), as described in Equation 2.

The R process uses the inputs, outputs, and assumptions in Table 18 to compute the modified natural gas forecast.

Table 18: Modify AAEE Forecast Inputs, Outputs, and Assumptions

Key Inputs	Key Outputs	Key Assumptions
• Disaggregated IEPR technology-level natural gas demand forecast • AAEE savings (reference case)*	• AAEE modified technology-level natural gas forecast	• Beyond a threshold of 15 percent savings, AAEE savings proportionately scale down as fuel substitution scales up per Equation 2.

***Actual AAEE scenario is user input and may vary.**

Source: Guidehouse

Substitute Technologies

The main objective of the substitute technologies R process is to determine the gas reduction and the electric load increase as well as the cost impacts of fuel substitution. A key assumption for this process is that the electric technology consumption is a function of the existing gas consumption. In addition, this R process also calculates the associated GHG emissions reductions and ancillary costs.

The user input workbook has a scenario parameters tab (Table 10). This tab allows the user to set parameters to define the tool calculations for fuel substitution scenarios. The tab also provides a high-level adjustment to all technologies by sector and utility. However, users can override these options at a more granular level (at the building type and BCZ level) in the R input-substitution map tab. The adjustable parameters include the following:

Replacement Percentage Parameters

- **Percentage replacement-on-burnout electric replacement parameter:** This parameter defines the cumulative replace-on-burnout replacement of a gas technology with an electric technology over the forecast period for a given sector and end-use combination.
- **Percentage accelerated retrofit electric replacement parameter:** This parameter defines the cumulative accelerated retrofit replacement of a gas technology with an electric technology over the forecast period for a given sector and end-use combination.
- **Percentage new construction electric installation parameter:** This parameter defines the cumulative proportion of electric technology installed in newly constructed buildings over the forecast period for a given sector and end-use combination.

Replacement Technology Parameters

- **Maximum allowable measure cost per savings percentile parameter:** This percentile parameter defines the maximum allowable $/(therm saved) that the analysis framework will consider. Only technologies that meet the $/(therm saved) percentile defined are included in replacements unless overridden in the R inputs worksheet.
- **Replacement efficiency weighting parameter:** The replacement efficiency is assigned one of three values:

  - High-efficiency weighted: With this selection, the highest-efficiency technology is weighted most heavily, and then weightings decrease linearly in order of decreasing efficiency.
  - Evenly weighted: All technologies are weighted evenly.
  - Low-efficiency weighted: With this selection, the lowest-efficiency technology is weighted most heavily, and then weightings decrease linearly in order of increasing efficiency.

Before substitution takes place, the tool segments the IEPR-forecasted gas consumption into new construction consumption, replace-on-burnout eligible consumption, and acceleration retrofit eligible consumption using the following three steps:

1. The IEPR 2030 forecasted natural gas consumption is segmented into existing consumption and new construction consumption based on the IEPR-predicted increase in natural gas consumption over the forecast period. This segmentation is based on two main assumptions:
   a. All new natural gas consumption over the forecast period is attributable to newly constructed buildings.
   b. Existing natural gas consumption at the beginning of the forecast period decreases at the same rate as the building demolition rate.
2. The existing stock developed in step 1 is further segmented based on the proportion of technologies that are expected to expire during the forecast period based on the associated EUL. These technologies become eligible for replace-on-burnout replacement. The FSSAT framework assumes annual burnout rate is constant through the forecast period by technology.
3. The makeup of technologies in the existing stock that are not expected to expire over the forecast period become eligible for accelerated retrofit replacement.

Natural Gas Reduction

Per the scenario description, the user assigns the maximum cumulative percentage substitution for natural gas consumption by 2030 for new construction, replace-on-burnout, and accelerated replacement. Replacement is carried out for existing stock (replace on burnout and accelerated retrofit) and new stock (new construction) according to the scenario parameter inputs. The simplest user entry is to assign percentages by utility, sector, and end use. However, a user may provide fine tuning of all inputs for a given scenario at the technology, building-type, and BCZ level (on the R input-substitution map tab). The tool applies the percentage at the technology level to the disaggregated forecast in 2030 developed in the disaggregate IEPR forecast R process. The tool calculates the natural gas consumption reduction for prior years (2020–2029) based on the user-defined adoption curves mapped in the user inputs. Equation 3 describes this calculation.

Equation 3: Avoided Gas Consumption by Year by Technology

$$
\begin{aligned}
&Gas\ Avoided_{i,j,k} \\
&\qquad = Gas\ Consumption_{2030,j} * Replacement\ \%_{j} * Elec\ Tech\ Substitution\ Share\ \%_{k} \\
&\qquad * Adoption\ Curve_{i,k}
\end{aligned}
$$

$Where:$

$Gas\ Avoided_{yr=\ ,gastech=j,electech=k}$ = Gas consumption avoided by substituting gas technology, j, with electric technology type and efficiency, k, in year i, for a given gas and electric utility territory, sector, climate zone, and building type.

$Gas\ Consumption_{2030,j}$ = Business-as-usual technology-level gas consumption in 2030 for gas technology, j, for a given gas and electric utility territory, sector, climate zone, and building type.

$Replacement\ \%_{j}$ = User-defined percentage of gas technology, j, which will be replaced with an electric technology by 2030 (may vary by utility, sector, end use, and replacement type).[165]

$Elec\ Tech\ Substitution\ Share\ \%_{k}$ = Proportion of gas technology consumption substituted with electric technology, k, by 2030.

$Adoption\ Curve_{i,k}$ = Percentage of adoption defined in user inputs for electric technology, k in year, i, with the cumulative adoption percentage at 100 percent over the forecast period.

Natural Gas Reduction — Agricultural and Industrial

The industrial and agricultural sectors use a different calculation of the avoided gas consumption compared to the residential and commercial sectors. Before this study, characterizing these sectors for energy efficiency potential has been on a consumption basis versus a widget or square footage basis. The load intensity varies greatly across building types within the agricultural and industrial sector. The fuel substitution end-use characterization is based on a percentage of consumption estimate, as described in Equation 4.

Equation 4: Avoided Gas Consumption for Agricultural and Industrial

$$
\begin{aligned}
&Gas\ Avoided_{yr\ =\ i,End\ Use} \\
&\qquad = (Gas\ Consumption_{2020,Sector} - AAEE\ Gas\ Savings_{2020,Sector}) \\
&\qquad * Yearly\ Gas\ Consumption\ Change\ \%_{i,End\ Use} * User\ Input\ Substitution\ \%_{End\ Use}
\end{aligned}
$$

$Where:$

$Gas\ Avoided_{yr=i,End\ Use}$ = Gas consumption avoided due to fuel substitution at the end-use level in year, i.

$Gas\ Consumption_{2020,Sector}$ = Gas consumption in the baseline year (2020) at the sector level.

$AAEE\ Gas\ Savings_{2020,Sector}$ = Energy efficiency savings in the baseline year (2020) at the sector level.

$Yearly\ Gas\ Consumption\ Change\ \%_{i,End\ Use}$ = Proportion of gas consumption substituted with electric technologies at the end-use level in year, i.[166]

$User\ Input\ Substitution\ \%_{End\ Use}$ = Percentage of the total technical potential of fuel substitution that is likely to occur at the end-use level in year, i, over the forecast period.

---

[165] Replacement type is either replace on burnout, accelerated replacement, or new construction.

[166] The yearly gas consumption change percentage is defined by the technology characterization of industrial and agricultural fuel substitution, as defined in Appendix F.

Electric Load Increase — Electrification of Gas Load

The key assumption is that the tool calculates the electric load using the gas consumption of the baseline technology. Equation 5 provides the calculation of electric consumption increase using the baseline technology gas decrease.

Equation 5: Added Electricity Consumption – Electrification of Gas Load

$$Elec\ Consumption_{i,k} = Gas\ Avoided_{i,j,k} * \frac{Gas\ Tech\ Eff_j}{Elec\ Tech\ COP_k} * \frac{29.3\ kWh}{1\ therm}$$

$Where$:

$Elec\ Consumption_{yr=i,electech=k}$ = Electric consumption by electric technology, k, in year, i.

$Gas\ Avoided_{i,j,k}$ = Gas consumption avoided by substituting gas technology, j, with electric technology, k, in year, i.

$Gas\ Tech\ Eff_j$ = Fuel efficiency of gas technology, j.

$Elec\ Tech\ COP_k$ = COP of electric technology, k.

As an example, Table 19 shows the simplified process of calculating the resulting electric consumption from substituting one small gas water heater with a heat pump water heater. The FSSAT runs this calculation for the entire population of water heaters and the entire set of possible replacement technologies.

Table 19: Example Electric Load Increase From Fuel Substitution – Electrification of Gas Load

Step	Example
1) Identify gas technology	Residential small gas water heater
2) Identify replacement electric technology	Residential heat pump water heater
3) Characterize annual unit energy consumption of replaced gas technology	403 therms
4) Determine COP of electrification technology	COP = 3.0
5) Electrify replaced gas technology based on COP and furnace efficiency	$\text{Unit energy consumption (kWh)} = \frac{\left[(403\text{ therms})\left(29.3\frac{\text{kWh}}{\text{therms}}\right)(0.8\text{ EF})\right]}{3.0\text{ COP}} = 3{,}149\text{ kWh}$

Source: Guidehouse

Electric Load Increase – Agricultural and Industrial

For the industrial and agricultural sectors, calculating the added electricity consumption is similar to the avoided gas consumption (shown in Equation 4). Equation 6 provides the added electricity consumption for the agricultural and industrial sectors. The characterization of these sectors is on the end-use level rather the technology level. The added load is based on a percentage of consumption to estimate the impacts of fuel substitution by end use.

Equation 6: Added Electricity Consumption for Agricultural and Industrial

$$Elec\ Consumption_{yr\,=\,i,End\ Use}$$

$$= (Elec\ Consumption_{2020,Sector} - AAEE\ Elec\ Savings_{2020,Sector})$$

$$\times Yearly\ Elec\ Consumption\ Change\ \%_{i,End\ Use} \times User\ Input\ Substitution\ \%_{End\ Use}$$

$Where$:

$Elec\ Consumption_{yr=i,End\ Use}$ = Added electricity consumption due to fuel substitution at the end-use level in year, i.

$Elec\ Consumption_{2020,Sector}$ = Electricity consumption in the baseline year (2020) at the sector level.

$AAEE\ Elec\ Savings_{2020,Sector}$ = Energy efficiency savings in the baseline year (2020) at the sector level.

$Yearly\ Elec\ Consumption\ Change\ \%_{i,End\ Use}$ = Increased proportion of electricity consumption due to fuel substitution at the end-use level in year, i.[167]

$User\ Input\ Substitution\ \%_{End\ Use}$ = Percentage of the total technical potential of fuel substitution that is likely to occur at the end-use level in year, i, over the forecast period.

Electric Load Increase – Additional Cooling

The electric load added by new electric technologies is not limited to the consumption introduced by the electrification of gas technologies load. In the case of heat pump technologies capable of providing heating and cooling, the tool must account for the added electric consumption resulting from the introduction of cooling to buildings that previously lacked space cooling.

Equation 7: Added Electricity Consumption – Added Cooling

$$Added\ Cooling\ Electric\ Consumption_{i,k}$$

$$= Heat\ Pump\ Stock_{i,k} \times Elec\ Consumption, AC_k \times (1 - \%\ Buildings\ with\ AC)$$

$Where$:

$Added\ Cooling\ Electric\ Consumption_{yr=i,electech=k}$ = Added electric cooling consumption by electric technology, k, in year, i.

$Heat\ Pump\ Stock\ (k)_i$ = Cumulative number of heat pumps of type and efficiency, k, installed by year, i.

$Elec\ Consumption, AC_k$ = Electric consumption of air conditioning with equivalent use case and efficiency level of heat pump, k.

$\%\ Buildings\ with\ AC$= Percentage of buildings with air conditioning given a gas utility territory, BCZ, and building type.

The buildings with AC proportions tab allows the user to input the proportion of buildings with air conditioning at the building type, gas utility, and BCZ levels.

The buildings with AC proportions worksheet has air conditioning densities characterized at the gas utility level, making the densities identical across BCZs.[168] However, the probability of a home having an air conditioner depends on the associated BCZ. Custom values are permitted

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[167] The yearly electric consumption change percentage is based on the adoption curve value for the specific year.

[168] The current dataset is based on the Potential and Goals study measure characterization.

in the buildings with AC proportions tab to allow the user to override these default percentages if data on existing saturation are available. The worksheet also characterizes only air-conditioning proportions for homes — all uncharacterized buildings (that is, commercial buildings) are assumed to have air conditioning. The user may add a characterization of the proportion of commercial buildings with air conditioning. Table 20 provides an example calculation of the electric load increase for when cooling capability due to heat pumps is added to buildings where air conditioning was not previously present.

Table 20: Example Electric Load Increase from Fuel Substitution – Added Cooling

Step	Example
1) Identify replacement electric technology	Packaged/split heat pump where SEER = 13
2) Identify equivalent air conditioning technology	Res packaged/split system AC (SEER 13)
3) Look up electricity consumption for equivalent air conditioning technology	583.8 kWh
4) Look up percentage of buildings with air conditioning	62.8%
5) Calculate added electricity consumption from additional cooling	$Added\ Cooling\ per\ Unit\ (kWh)$ $= (583.8\ kWh)(1 - 0.628)$ $= 217.2\ kWh$

Source: Guidehouse

Stock Forecast

The tool calculated the added electric technologies stock forecast by dividing the added electric forecast for each technology by the associated unit energy consumption (Equation 8).

Equation 8: Added Electric Technologies Stock

$$Stock_{i,k} = \frac{Elec\ Consumption_{i,k}}{Unit\ Energy\ Consumption_{k}}$$

$Where:$

$Stock_{yr=i,electech=}$ = Stock of added electric technologies, k, in year, i.

$Elec\ Consumption_{yr=i,electech=k}$ = Electric consumption by electric technology, k, in year, i.

$Unit\ Energy\ Consumption_{i,j,k}$ = Annual kWh consumed by electric technology, k.

Technology and Fuel Costs

Technology costs, described in Equation 9, use the forecast electric technology stock increase and the three characterized technology cost components (equipment, installation, and overhead and profit).

Equation 9: Added Technology Costs

$$Equipment\ Cost_{yr=i,electech=k} = Stock_{yr=i,electech=k} * Unit\ Equip.Cost_{electech=}$$

$$Installation\ Cost_{yr=i,electech=} = Stock_{yr=i,electech=} * Unit\ Install.Cost_{electech=k}$$

$$OH\&P\ Cost_{yr=i,electech=} = Stock_{yr=i,electech=k} * Unit\ OH\&P\ Cost_{electech=}$$

$$\begin{aligned} &Total\ Technology\ Cost_{yr=\ ,electech=} \\ &\qquad = (Equipment\ Cost + Installation\ Cost + OH\&P)_{yr=\ ,electech=} \end{aligned}$$

$Where$:

$Equipment\ Cost_{yr=i,electech=k}$ = Equipment costs of added electric technologies, k, in year, i.

$Stock_{yr=i,electech=}$ = Stock of added electric technologies, k, in year, i.

$Unit\ Equip.Cost_{electech=}$ = Unit equipment costs of electric technology, k.

$Installation\ Cost_{yr=i,electech=}$ = Installation costs of added electric technologies, k, in year, i.

$Unit\ Install.Cost_{electech=}$ = Unit installation costs of electric technology, k.

$OH\&P\ Cost_{yr=i,electech=k}$ = Installation costs of added electric technologies, k, in year, i.

$Unit\ OH\&P\ Cost_{electech=}$ = Unit overhead and profit costs of electric technology, k.

$Total\ Technology\ Cost_{yr=i,electech=}$ = Technology costs of added electric technologies, k, in year, i.

The tool calculates the fuel costs using the forecast electric load increase and natural gas reduction from the IEPR electric and gas price forecasts (Equation 10).

Equation 10: Added Fuel Costs

$$Added\ Electric\ Cost_{yr=i,electech=} = Elec\ Consumption_{yr=i,electech=k} * \frac{\$}{kWh_{yr=i}}$$

$$Reduced\ Gas\ Cost_{yr=i,electech=} = -Gas\ Avoided_{i,j,k} * \frac{\$}{therm_{yr=i}}$$

$Where$:

$Added\ Electric\ Cost_{yr=i,electech=}$ = Added annual electric cost by electric technology, k, in year, i.

$Elec\ Consumption_{yr=i,electech=}$ = Electric consumption by electric technology, k, in year, i.

$\frac{\$}{kWh_{yr=i}}$ = Cost per kWh in year, i.

$Reduced\ Gas\ Cost_{yr=i,electech=}$ = Added annual gas cost by electric technology, k, in year, i (note that this value is negative — the electric technology will avoid gas costs).

$Gas\ Avoided_{yr=i,gastech=j,electech=}$ = Gas consumption avoided by substituting gas technology, j, with electric technology, k, in year, i.

$\frac{\$}{therm_{yr=i}}$ = Cost per therm in year, i.

Natural Gas Consumption Emissions

Natural gas consumption emissions are the emissions resulting from the in-building combustion of natural gas. Equation 11 output quantifies the avoided natural gas GHG combustion emissions due to reduced natural gas demand.

Equation 11: Natural Gas Consumption Emissions Avoided

$$Avoided\ emissions_{yr=i} = Natural\ Gas\ Emissions\ Factor * Gas\ Avoided_i * \frac{907.186\,\frac{kg}{short\ ton}}{10^5\,\frac{MMBTU}{MMTherm}}$$

$Where:$

$Natural\ Gas\ Emissions\ Factor$ = Short tons of CO_2 equivalent released per MMBTU of natural gas = 0.0585

$Gas\ Avoided_i$ = Natural gas consumption avoided in year, i.

Natural Gas Leakage Emissions

Natural gas leakage emissions are the result of leaked natural gas, which occurs within the utility system (in front of the meter) and in buildings (behind the meter). This output quantifies the avoided natural gas GHG leakage emissions due to reduced natural gas demand.

This calculation assumes that the leakage rate depends on the total gas consumption by sector and gas utility. The research team assumed that the total natural gas leakage scales linearly with the total natural gas consumed (Equation 12).[169] The default tool input assumes an annual natural gas leakage rate of one percent independent of building type and technology included.

The existing data from a CARB study assume an annual leak rate of 2,539 grams of methane (CH_4) per household.[170] This datapoint is per household instead of per technology or per consumption, so the alternate assumption is used.

The tool does not include natural gas leakage emissions upstream, but this leakage rate can be included in the user input tab, Natural Gas Leakage Emissions Inputs, as a percentage of consumption basis.

Equation 12: Natural Gas Leakage Emissions Avoided

$$Avoided\ emissions_{yr=i} = Gas\ Avoided_i * \frac{Gas\ Leaked}{Gas\ Consumed} * \frac{GWP_{nat\ gas}}{MMTherm}$$

$Where:$

$Avoided\ emissions_{yr=i}$ = Avoided CO_2 equivalent emissions in year, i.

$Gas\ Avoided_i$ = Natural gas consumption avoided in year, i.

$\frac{Gas\ Leaked}{Gas\ Consumed}$ = Percentage of natural gas leakage compared to consumption in year, i.

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[169] Absent detailed data on natural gas emissions rates, the research team made this assumption as an initial estimate for emissions due to behind-the-meter natural gas leakage.

[170] California Air Resources Board. August 2019. *California's 2000-2017 Greenhouse Gas Emissions Inventory 2019 Edition – Inventory Updates Since the 2018 Edition of the Inventory*.

$\frac{GWP_{nat\ gas}}{MMThe}$ = Global warming potential in kg CO_2e per MM therm of natural gas.

Electricity Generation Emissions

Electricity generation emissions are the emissions resulting from the upstream generation of electricity. Equation 13 output quantifies the added electric load GHG emissions due to increased electricity demand. Annualized emissions factors are calculated from the hourly GHG analysis further described in the Hourly Analysis Results section.

Equation 13: Electricity Generation Emissions Added

$$\begin{aligned} & Added\ Eletricity\ Generation\ Emissions_{yr=i} \\ & \qquad = Electric\ Emissions\ Factor_i * Elec\ Consumption\ Added_i \end{aligned}$$

$Where$:
$Electric\ Emissions\ Factor_i$ = Kilograms of CO_2 equivalent per kWh of electricity consumption added in year, i.
$Elec\ Consumption\ Added_i$ = kWh of electricity consumption added in year, i.

Refrigerant Emissions

In addition to the GHG emissions reductions achieved through fuel substitution, the team assessed the GHG emissions resulting from the increased use of refrigerant, hydrofluorocarbon (HFC)-containing heat pumps.

The research team estimated refrigerant emissions on an annual basis per technology level, allowing the total footprint to scale with the number of heat pumps used in the selected scenario (Equation 14).

Equation 14: Heat Pump Refrigerant Emissions Added

$$\begin{aligned} & Refrigerant\ emissions_{year=i} \\ & \qquad = New\ Heat\ Pump\ Installations_i * Charge\ Size_{avg,i,k} * Annual\ \%\ Leakage_{avg,i} \\ & \qquad * GWP_{avg,i} * (1 - \%\ Buildings\ with\ AC) \\ & \qquad + \ New\ Heat\ Pump\ Installations_i * Charge\ Size_{avg,i,k} * (Charge\ Size\ Ratio - 1) \\ & \qquad * Annual\ \%\ Leakage_{avg,i} * GWP_{avg,i} * (\%\ Buildings\ with\ AC) \end{aligned}$$

$Where$:
$Refrigerant\ Emissions_{year=i}$ = CO_2 equivalent emissions avoided in the scenario in year, i.
$New\ Heat\ Pump\ Installations_{year=}$ = Number of technology installations, i.
$Charge\ Size_{avg,i}$ = Charge size of electric technology, k, in year, i.
$Annual\ \%\ Leakage_{avg,i}$ = Percentage of refrigerant leakage in year, i.
$GWP_{avg,i}$ = Average global warming potential for installed heat pump refrigerant in year, i.
$\%\ Buildings\ with\ AC$= Percentage of buildings with air conditioning for the BCZ, gas utility, and building type of the heat pump technology.
$Charge\ Size\ Ratio$ = Ratio of heat pump replacement refrigerant charge size to replaced AC refrigerant charge size.

Most existing refrigerants contribute to GHG emissions. Users may update the global warming potential of the refrigerant (GWP as measured in kg CO_2 equivalent per kg of gas). The added refrigerant emissions are multiplied by (1 – percentage of buildings with AC). This is because the added refrigerant emissions occur only in buildings that did not previously have air conditioning. According to the CARB, the ratio between heat pump replacement and replaced AC unit refrigerant charge sizes is about 1.1.

The preliminary values of the tool (Table 21) are intended to provide initial estimates with the expectation they will be reviewed and replaced with more accurate values as available.

Table 21: Default 100-Year Global Warming Potentials in FSSAT

Gas	Year(s)	GWP	Source
CO_2	All	1.0	Engineering constant
Natural Gas	All	25	California ARB 100-yr GWPs*
Average Refrigerant – HVAC	2020 – 2022	2,088	Assumption: GWP for a common heat pump refrigerant: R-410A (GWP = 2,088)**
Average Refrigerant – Heat Pump HVAC	2023 - 2030	675	Assumption: GWP for R-32 (GWP = 675) which will meet the proposed 750 GWP cap effective in 2023**
Average Refrigerant – Heat Pump Water Heater	2020 - 2030	1,430	Assumption: GWP for most common heat pump water heater refrigerant: R-134a (GWP = 1,430)**

***CARB. https://ww2.arb.ca.gov/ghg-gwps, accessed March 2020**

****CARB. December 2019. "Low-GWP Alternatives for Space and Water Heating CARB.docx" Draft – Deliberative and Confidential. Table 1: Low-GWP Refrigerants for Residential Heat Pump Technologies.**
R-410A, R-134a, and R-32 are refrigerant types
Source: Guidehouse

In parallel to AB 3232, Senate Bill 1383 (Lara, Chapter 395, Statutes of 2016)[171] has committed to reducing California's refrigerant emissions by 40 percent by 2030 (from 2013 levels). This reduction will be achieved largely by requiring that new refrigerant-containing technologies, such as supermarket refrigeration systems and air-conditioning units, use refrigerants with a lower GWP.

A central question is if the AB 3232 goal contributes to increasing refrigerant emissions because of the higher penetration of technologies using refrigerants. The research team included the increased refrigerant emissions from heat pump deployments with the simultaneous decrease in HFC emissions from the implementation of SB 1383.

The FSSAT has a toggle in the refrigerant user input worksheet that allows the user to select whether SB 1383 is reached.

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[171] Senate Bill No. 1383, *Short-Lived Climate Pollutants: Methane Emissions: Dairy and Livestock: Organic Waste: Landfills*.

Toggle Off: SB 1383 Not in Effect

If SB 1383 is not in effect (that is, the SB 1383 reached toggle is set to NO), then the tool will use the user input forecast of non-heat pump HFC emissions when calculating combined refrigerant emissions.

Toggle On: SB 1383 in Effect

If SB 1383 is in effect (that is, the SB 1383 reached toggle is set to YES), then the tool will assume total HFC emissions in 2030 will be 10 MMTCO$_2$e based on CARB estimates.[172]

The CARB estimate does not assume any amount of building electrification; estimated reductions will be achieved through other measures and applied to non-heat pump technologies.[173] This implies added heat pumps as a result of electrification will either increase GHG emissions from HFCs above 10 MMTCO$_2$e in 2030 or other savings measures will be required to offset the added emissions from electrification. With the SB 1383 toggle on, FSSAT assumes the latter: that overall HFC emissions in 2030 are fixed based on the assumption that the state will meet its SB 1383 target by developing additional measures to offset the impact of electrification. FSSAT calculates the amount of leakage from additional heat pumps to inform users of the magnitude of savings needed from additional measures. However, this study does not examine what specific measures can meet this additional need.

Ancillary Costs (Panel Upgrades)

Many existing households may require a panel upgrade because of the increased electric load from fuel substitution. Calculating the costs of aggregate panel upgrades across the fuel substitution population is challenging. A triggered panel upgrade is not directly related to a specific technology; rather, it relates to the number and type of electric technologies installed in a specific building. Further, panel upgrades may also be triggered by recharging electric vehicles, rooftop photovoltaic systems with or without storage, or combinations of these with fuel substitution changes.

There is a lack of primary data that detail the number of buildings that require a panel upgrade in California or how much additional electric load will trigger a need for panel upgrades.[174] To predict more accurately expected overall panel upgrade costs associated with fuel substitution, more data on the existing panel landscape need to be collected and processed.[175]

The research team calculated aggregate panel upgrade costs in the FSSAT by assuming when buildings will require a panel upgrade and how many panel upgrades are necessary each year. The team used the percentage of natural gas removed due to fuel substitution as an indicator to estimate when a panel upgrade is required. When the percentage of natural gas removed exceeds the user-defined inputted threshold, that year and all following years will incur a panel

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[172] California Air Resources Board. March 2017. *Short-Lived Climate Pollutant Reduction Strategy*.

[173] The reduction measures do not include an end-of-life decommissioning reduction of the refrigerant leak. Strategies to reduce end-of-life venting may lead to additional HFC emissions reductions.

[174] Building Decarbonization Coalition. January 2020. *Decoding Grid Integrated Buildings Report*.

[175] In some cases, older homes may require panel upgrades; however, it is unknown how many have upgraded because of other renovations or for other reasons.

upgrade cost. Any year before this threshold is met will not have any associated panel upgrade costs. Because HVAC is the largest added electric load to a home and the most likely to trigger a panel upgrade, the research team associates a panel upgrade with the addition of every HVAC unit installed after meeting the threshold. Equation 15 details the calculation.

Equation 15: Approximation of Combined Panel Upgrade Costs

$$Aggregate\ Panel\ Costs_{yr=i} = Upgrade\ Cost * \frac{Stock\ of\ Added\ HVAC_i}{Average\ HVAC\ Size} * Panel\ Cost\ Decision_i$$

$$Panel\ Cost\ Decision_{yr=i} = \begin{cases} 1, & \dfrac{Gas\ Avoided_i}{Gas\ Consumption_{2030}} \geq Panel\ Upgrade\ Threshold \\ 0, & \dfrac{GasAvoided_i}{Gas\ Consumption_{2030}} < Panel\ Upgrade\ Threshold \end{cases}$$

$Where$:

$Aggregate\ Panel\ Costs_{yr=i}$ = Aggregate territory panel upgrade costs ($) in year, i.
$Upgrade\ Cost$ = Dollar cost ($) to update a panel in a single home.
$Stock\ of\ Added\ HVAC_i$ = Amount of the replaced HVAC systems in the unit basis [Cap-Tons] in year, i.
$Average\ HVAC\ Size$ = Size of a typical residential HVAC system [Cap-Ton/unit] .
$Panel\ Cost\ Decision_{yr=i}$ = Value either 0 or 1 indicating whether a panel upgrade is necessary in year, i.
$Gas\ Avoided_i$ = Replaced consumption (MM therms) due to fuel substitution of an existing home in the year, i.
$Gas\ Consumption_{2030}$ = Consumption (MM therms) of an existing home in the year 2030.
$Panel\ Upgrade\ Threshold$ = The percentage of removed natural gas due to fuel substitution that will trigger a panel upgrade in that year.

FSSAT allows for user input for the panel upgrade cost by utility territory and BCZ for homes. The tool calculates costs in real dollars for the year of installation based on a user’s chosen inflation rate.

The key inputs used to determine the annual cost are:

- **Panel upgrade threshold:** The percentage of reduced natural gas consumption due to fuel substitution that will trigger a panel upgrade in that year. The research team assumes any HVAC unit installed after the threshold will incur a panel upgrade cost.
- **Average HVAC size (tons):** Size of a residential HVAC system. The stock value of added HVAC systems is in the unit basis (Cap-Tons or capacity in tons). To determine the number of installed HVAC systems in a given a year, the tool divides the stock value by the inputted HVAC size.
- **Panel cost:** Total cost to upgrade the size of an electrical panel in the base year.

Emissions Reductions Cost

FSSAT calculates abatement cost on a per-metric-ton ($mtCO_2e$)[176] basis to compare fuel substitution to other AB 32 scoping plan measures. The calculation must include the total net cumulative investment cost over the defined period (2020–2030).

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[176] “Metric-ton” or mt is equal to 1,000 kilograms.

The annualized investment costs are determined using a capital recovery factor, shown in Equation 16, which is based on the real discount rate[177] and equipment useful life.

Equation 16: Capital Recovery Factor

$$CRF = \frac{d}{[1 - (1 + d)^{-EUL}]}$$

Where:
d is the real discount rate.
EUL represents the equipment useful life.

The annualized incremental equipment cost in each year is the annualized cost of the electric technology minus the annualized cost of the gas replacement technology, plus the annualized costs of ancillary equipment.

The net investment cost in each year is the annualized incremental equipment cost plus the net fuel costs. The net cumulative investment present cost, Equation 17, is the sum of the net investment cost in each year discounted at the real discount rate.

Equation 17: Total Net Cumulative Investment Cost

$$Total\ Net\ Cumulative\ Investment\ Cost = \sum_{i}^{year} \Big[\Big(Cumulative\ Technology\ Cost_{yr=i,electech=k} - Cumulative\ Baseline\ Technology\ Cost_{yr=i,gastech=j} + Ancilliary\ Costs\Big) * CRF + \Big(Added\ Electric\ Cost_{yr=i,electech=k} + Reduced\ Gas\ Cost_{yr=i,electech=k}\Big)\Big] / (1 + Real\ Rate){}^\wedge(year\ i - base\ year)$$

$Where:$

$Total\ Technology\ Cost_{yr=i,electech=}$ = Technology costs of electric technologies, k, in year, i.

$TotalaselineTechnologyCost_{yr=i,gastech=j}$ = Technology costs of gas technology replacement option, j, in year, i.

$Added\ Electric\ Cost_{yr=i,electech=}$ = Added annual electric cost by electric technology, k, in year, i.

$Reduced\ Gas\ Cost_{yr=i,electech=}$ = Added annual gas cost by electric technology, k, in year, i (note that this value is negative — the electric technology will avoid gas costs).

$Ancillary\ Cost$ = Cost of ancillary costs.

CRF = Capital recovery factor.

The substitute technologies R process includes inputs, outputs, and assumptions listed in Table 22.

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[177] Rate of return used to discount to the present value of future cash flows. The real discount rate removes the effects of inflation to reflect the real cost and is typically the nominal discount rate minus inflation rate.

Table 22: Substitute Technologies Inputs, Outputs, and Assumptions

Topic	Inputs	Outputs	Assumptions
Natural Gas Reduction and Electric Load Increase	• Modified AAEE technology-level natural gas forecast • Scenario inputs defined in scenario input workbook	• Revised natural gas forecast • Added electric consumption (including increased cooling)	• Electric energy consumed in fuel substitution is directly related to gas consumption. • Electric technology performance does not degrade over time. • Tool does not calculate end user choice algorithms between technologies or model any interactions of market dynamics for adoption. Adoption is user-defined algorithm per technology.
Stock Forecast	• Added electric consumption • Fuel substitution characterization	• Added stock	• Technology unit energy consumption at the utility, building, BCZ, and technology efficiency level is consistent across the forecast years.
Technology and Fuel Costs	• Added stock • Revised natural gas forecast • Electric load increase • Utility forecasted rates	• Added technology cost (split and total) • Fuel costs (split and net)	• Technology, installation, and overhead and profit costs are relatively consistent at the utility, building, BCZ, and technology efficiency levels.
Refrigerant and Natural Gas Leakage Emissions	• Refrigerant leakage input • Natural gas leakage input • Added stock • Revised natural gas forecast	• HFC emissions • Natural gas leakage emissions	• Refrigerant and natural gas leakage emissions are relatively consistent at the utility, building, BCZ, and technology efficiency levels. • Natural gas leakage emissions are directly related to overall natural gas consumption. • Added refrigerant emissions from HVAC heat pumps are assumed to be zero for all buildings with AC. All commercial buildings are assumed to have existing AC.

Topic	Inputs	Outputs	Assumptions
Increased Electricity Generation Emissions	• Revised natural gas forecast • Added electric consumption (including increased cooling) • Fuel substitution characterization	• Electricity generation emissions added	• The electric consumption is described by the natural gas consumption being replaced combined with the relevant efficiency factors of the electric technology. • Added AC load is considered only for the residential sector and only for the proportion of homes that did not previously have AC installed.
Ancillary Costs (Panel Costs)	• Panel costs input sheet • AAEE modified natural gas forecast • Added stock • Revised natural gas forecast	• Panel costs	• The total amount of installed HVAC systems after the natural gas removed threshold is met is equivalent to the number of required panel upgrades.
Emissions Reduction Cost	• Scenario Parameters • Total Emissions • Incremental technology and fuel costs	• Emissions Reduction Cost, $\$/mTCO_2e$	• Same assumptions present in all cost and emissions outputs

Source: Guidehouse

Write Scenario Definitions

This R process does not complete any new analysis. The process summarizes the user inputs defining the scenario as outputs. The resulting workbook is used for record-keeping only.

Scenario Definitions

The scenarios developed for this report are potential pathways for fuel substitution potential based on the goals established by AB 3232. The CEC published the "Building Decarbonization Assessment Project Scope" memorandum in November 2019[178] to ensure alignment of specifications across the various building decarbonization initiatives and analysis and seek stakeholder comments. The memorandum informs the chosen scenarios and savings analysis.

The FSSAT has flexibility to modify many inputs.[179] The R Input tab allows overrides for the inputs. Table 23 summarizes the range of inputs for the variables.

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[178] California Energy Commission. November 2019. Building Decarbonization Assessment Project Scope.

[179] The modeled scenarios for this report are applied across all technologies within the relevant categories. The tool has the capability to fine-tune targets by 2030.

Table 23: FSSAT Scenario Input Variables

Scenario Parameter	Definition	Variable Range
New construction	Percentage of eligible technologies that will be electric in the last year of the forecast period (2030).	0%–100%
Replace on burnout	Percentage of existing gas technologies that will burn out by the end of the forecast period (2030) and be replaced by an electric technology.	0%–100%
Early replacement	Percentage of existing gas technologies that will not burn out by the end of the forecast period (2030) and will be replaced by an electric technology.	0%–100%
Technology efficiency	A weighting that determines the distribution among potential electric replacement technologies according to the relative efficiencies.	Low efficiency weighted Evenly weighted High efficiency weighted
Cost threshold (% of maximum)	There is a range of technology costs by end use. This percentage defines the highest allowable technology cost by end use. When it is 100 percent, the highest-cost electric technology may be used as a substitute. When it is 65 percent, only technologies at or below the sixty-fifth percentile cost are eligible electric substitutes.	Minimum value: 0%–100% Maximum value: 0%–100% Maximum value > minimum value
Ancillary costs	Designation if ancillary (that is, panel) costs are included in total costs.	Not included Include panel
SB 1383 goals	On: SB 1383 HFC reduction goals are assumed to be achieved. Off: SB 1383 HFC reduction goals are assumed to not be achieved, and output emissions are defined by the user input HFC emissions scenario.	On Off
Industrial and agricultural	Percentage of eligible industrial and agricultural gas technologies replaced by electric technologies by the end of the forecast period (2030).	0%–100%

Source: Guidehouse

For the results presented in this report, the CEC specified three scenarios, each of which uses a specific setting for each input (defined in Table 24). The CEC designed these scenarios to help identify any gaps toward achieving decarbonization goals. The percentage values for the new construction, replace on burnout, and early replacement indicate the cumulative percentage of eligible equipment stock replaced by 2030.

Table 24: Scenario Definition

Scenario Parameter	Scenario 1: Minimize Cost to End Users	Scenario 2: Limited Cost Impacts to End Users	Scenario 3: Major Decarbonization Program
New construction	**Residential** - All end uses: 35% **Commercial** - All end uses: 0%	**Residential** - All end uses: 50% **Commercial** - All end uses: 50%	**Residential** - All end uses: 95% **Commercial** - All end uses: 50%
Replace on burnout	**Residential** - HVAC: 40% - WaterHeat: 40% - AppPlug: 30% **Commercial** - All end uses: 0%	**Residential** - HVAC: 50% - WaterHeat: 50% - AppPlug: 40% **Commercial** - All end uses: 0%	**Residential** - HVAC: 75% - WaterHeat: 75% - AppPlug: 60% **Commercial** - HVAC: 50% - WaterHeat: 50% - AppPlug: 40% - FoodServ: 40%
Early replacement	**Residential** - All end uses: 0% **Commercial** - All end uses: 0%	**Residential** - HVAC: 15% - WaterHeat: 15% - AppPlug: 10% **Commercial** - All end uses: 0%	**Residential** - HVAC: 20% - WaterHeat: 20% - AppPlug: 15% **Commercial** - HVAC: 15% - WaterHeat: 15% - AppPlug: 10% - FoodServ: 10%
Technology efficiency	Evenly weighted	Efficiency weighted	Efficiency weighted
Cost threshold (% of maximum)	Residential: 25% Commercial: 0%	Residential: 60% Commercial: 60%	Residential: 60% Commercial: 60%
Ancillary costs	Not included*	Not included*	Include panel
SB 1383 goals	On	On	On
Industrial and agricultural	No fuel substitution	No fuel substitution	50% of eligible technologies replaced

***In Scenarios 1 and 2, panel costs are not included. Each of these scenarios assumes that homes with the appropriate panel size are targeted in fuel substitution, and no upgrades are necessary.**

Source: Guidehouse

Scenario Tool Results

This section summarizes the results for the three scenarios described in the Scenario Definitions section; specifically, these results show the contribution of each scenario toward achieving emissions and energy savings goals. All detailed results are available in tabular format by scenario within the FSSAT output files. Each scenario has data at the sector, utility, and end-use levels. Some outputs are provided in a more granular manner, which may include technology level, building type, gas utility, electric utility, FCZ, and BCZ. The results posted in this report are based on the best available data and assumptions present in March 2020. Any updates are not reflected in this report.

The various legislative goals target the cumulative benefits of energy efficiency and other demand-side resources; they are not focused on just fuel substitution. This analysis produces the potential reduction in emissions and increase in energy savings resulting from fuel substitution to help relate the contributions of fuel substitution toward legislative goals. Two legislative strategies that may use these findings include:

- SB 350: Doubling energy efficiency savings by 2030, as of 2015 baseline.
- AB 3232: Reduce building stock emissions 40 percent below 1990 levels by 2030.

The rest of this section contains tables and graphs that summarize the results of the research team’s fuel substitution scenario analysis. This section presents results at the statewide level and shows some disaggregation by utility and sector.

The graphs and tables provide the emissions and energy data in incremental or cumulative terminology.

- **Incremental** energy or emissions are the annual consumption or savings values in the year of installation for that measure. Incremental values do not consider the savings that the measure will produce over the life of the equipment; rather, they consider only the savings incurred within that year.
- **Cumulative** energy or emissions are the total value from measures installed starting in 2020 and that are still active in the forecasted year. Generally, cumulative savings account for measures reaching the end of useful life. However, for the 2030 study period, no measures reach the end of life.

Figure 15 illustrates incremental and cumulative savings.

Figure 15: Illustrative Description for Incremental and Cumulative Values

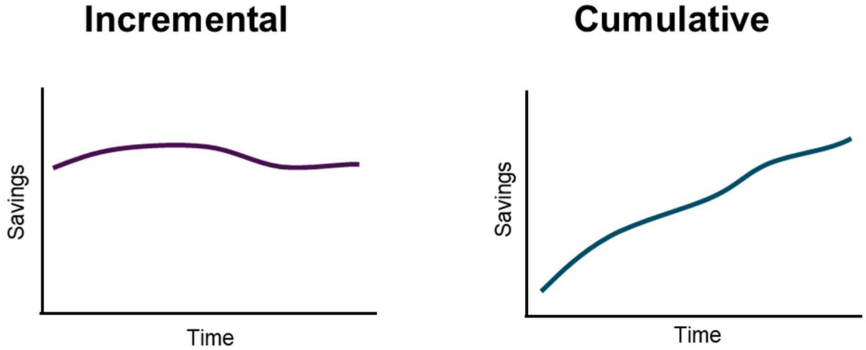
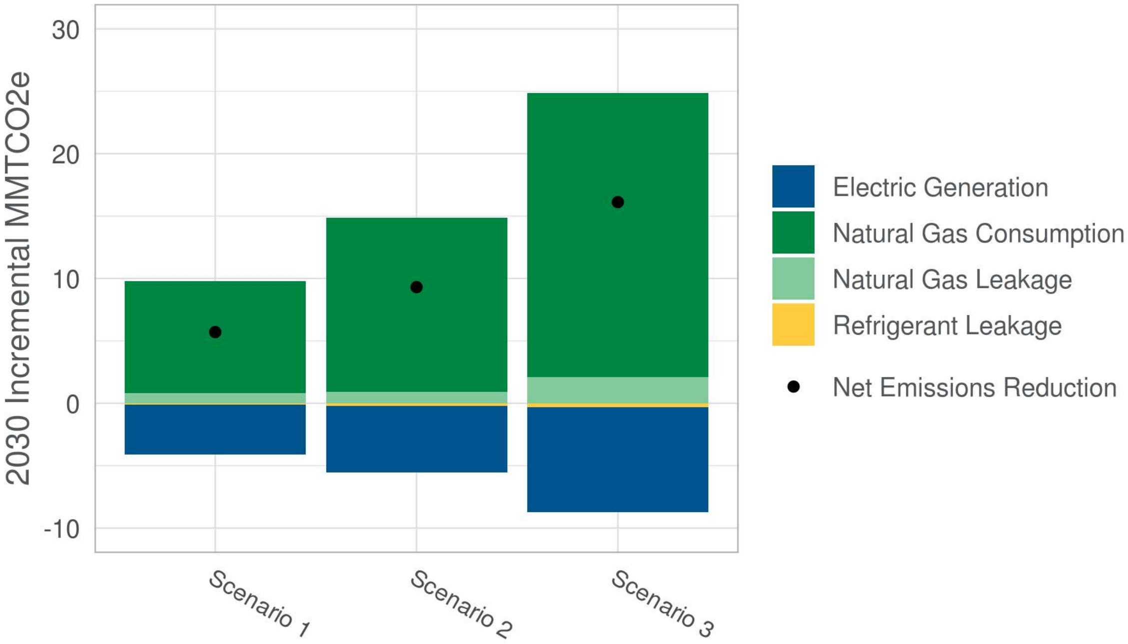


Illustration of the differences between reporting incremental versus cumulative savings. The incremental line defines the specific values claimed for the specific year. The cumulative line increases over time as the values from previous years are included in future years.
Source: Guidehouse

Figure 16 compares fuel substitution scenarios for the incremental emissions reduction by the source of the emissions in 2030.

Figure 16: Statewide Incremental 2030 Emissions Avoided by Source and Scenario

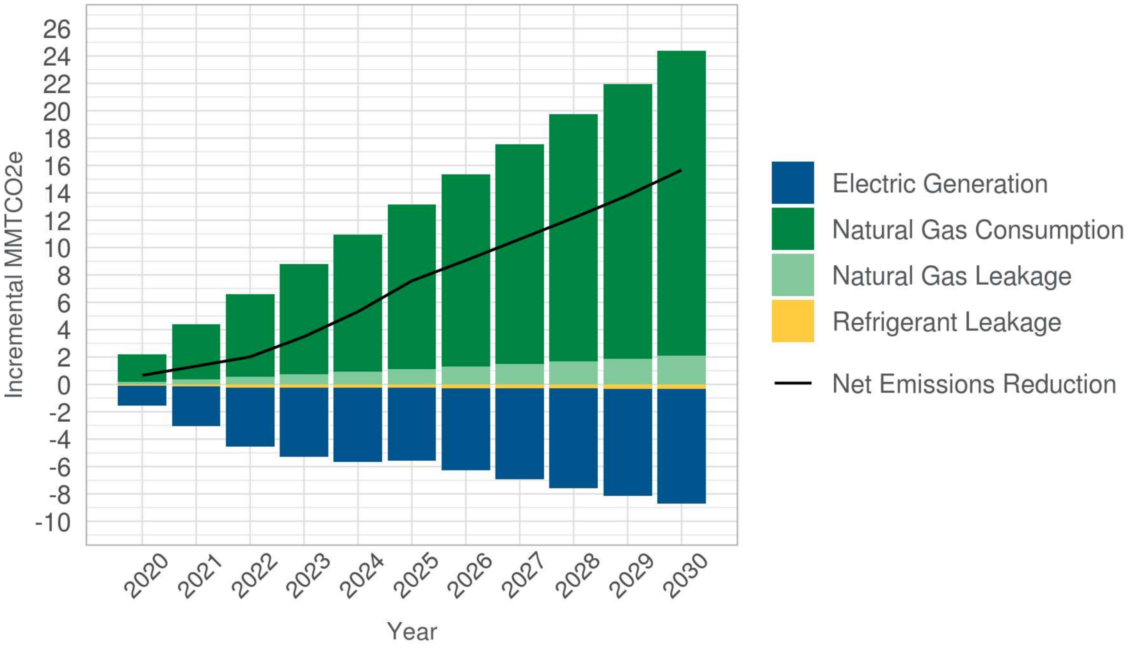


The stacked bar chart shows the emissions avoided or added by source, including emissions from electric generation, natural gas consumption, natural gas leakage, refrigerant leakage, and net emissions reduction, for the three scenarios in 2030. More aggressive fuel substitution schemes result in larger amounts of emissions reduced. Scenario 2 offers nearly double the net emissions savings relative to Scenario 1. Scenario 3 offers more than triple net emissions reductions compared to Scenario 1. While there are emissions increases due electric generation and refrigerant leakage, they are eclipsed by emissions reductions from reduced natural gas consumption.

Source: Guidehouse FSSAT output

Figure 17 provides Scenario 3 statewide incremental emissions avoided by source on an annual basis over the 2020–2030 period. The incremental emissions avoided forecast is shown here for Scenario 3 only because it is the most aggressive forecast. Other scenario outputs are available from the FSSAT.

Figure 17: Statewide Incremental Emissions Avoided by Source – Scenario 3

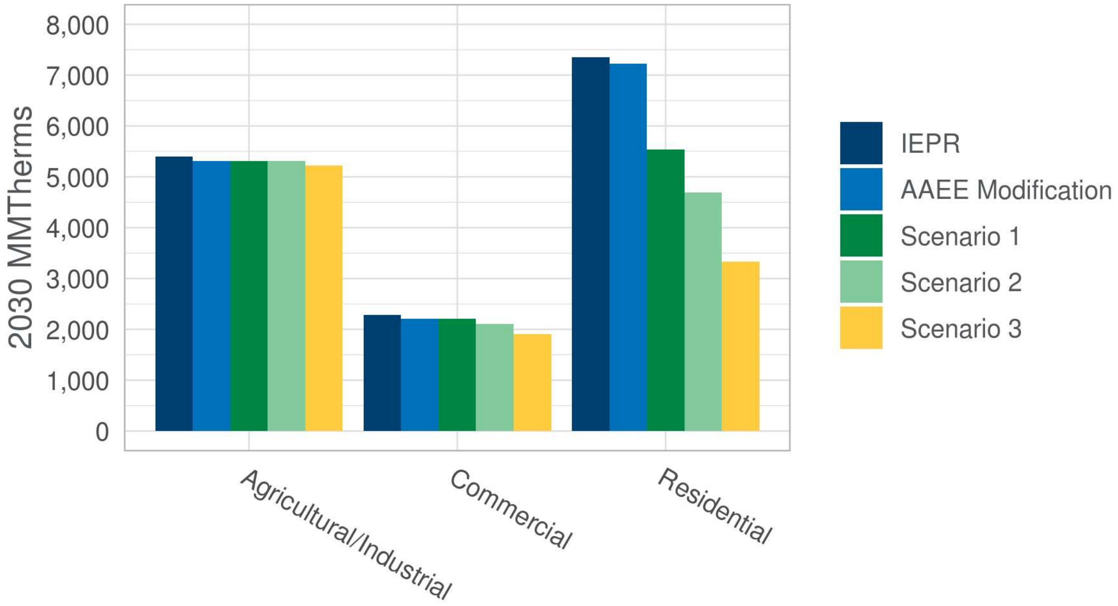


The stacked bar chart shows the emissions avoided in Scenario 3 for all years within the forecast period. Emissions avoided or added include those from electric generation, natural gas consumption, natural gas leakage, refrigerant leakage, and net emissions reduction. The figure shows a linear increase in emissions over the forecast period, which is driven largely by the adoption curves chosen in the FSSAT inputs. Electric emissions show nonlinear growth due an expected decrease in GHG intensity of electric generation in California over the forecast period.

Source: Guidehouse FSSAT output

Figure 18 provides the 2030 natural gas consumption by sector and scenario. This figure compares the scenarios to the baseline consumption forecast (IEPR) and the adjusted baseline forecast after including the AAEE impacts (AAEE modification).

Figure 18: Statewide 2030 Natural Gas Consumption by Sector

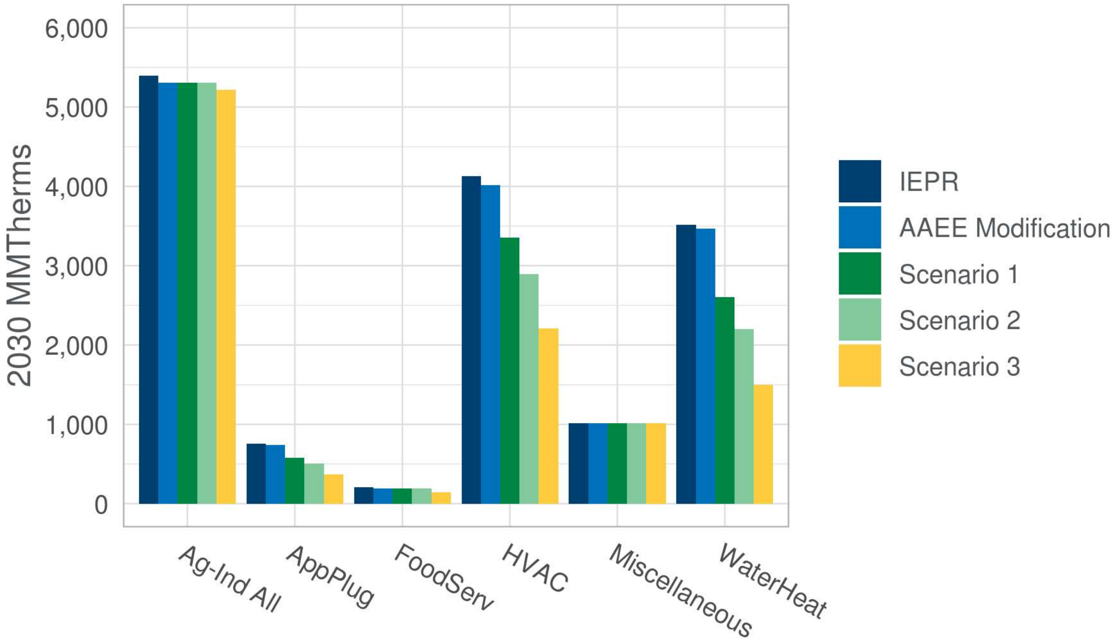


This side-by-side bar chart shows the natural gas consumption in 2030 by sector. The residential sector represents the largest decrease in forecasted natural gas consumption in 2030, with a reduction of more than 3,000 MMTherms in Scenario 3 compared to the IEPR. This result equals a 44 percent reduction for the residential sector and a 21 percent reduction of overall natural gas consumption statewide. While natural gas consumption is also reduced in the commercial, agricultural, and industrial sectors in the prescribed scenarios, the residential fuel substitution represents the majority of natural gas consumption reduction.

Source: Guidehouse FSSAT output

Figure 19 provides the 2030 natural gas consumption by end use and scenario. Like in Figure 18, this figure compares the scenarios to the baseline consumption forecast (IEPR) and adjusted baseline forecast after including the AAEE impacts (AAEE modification).

Figure 19: Statewide 2030 Natural Gas Consumption by End Use



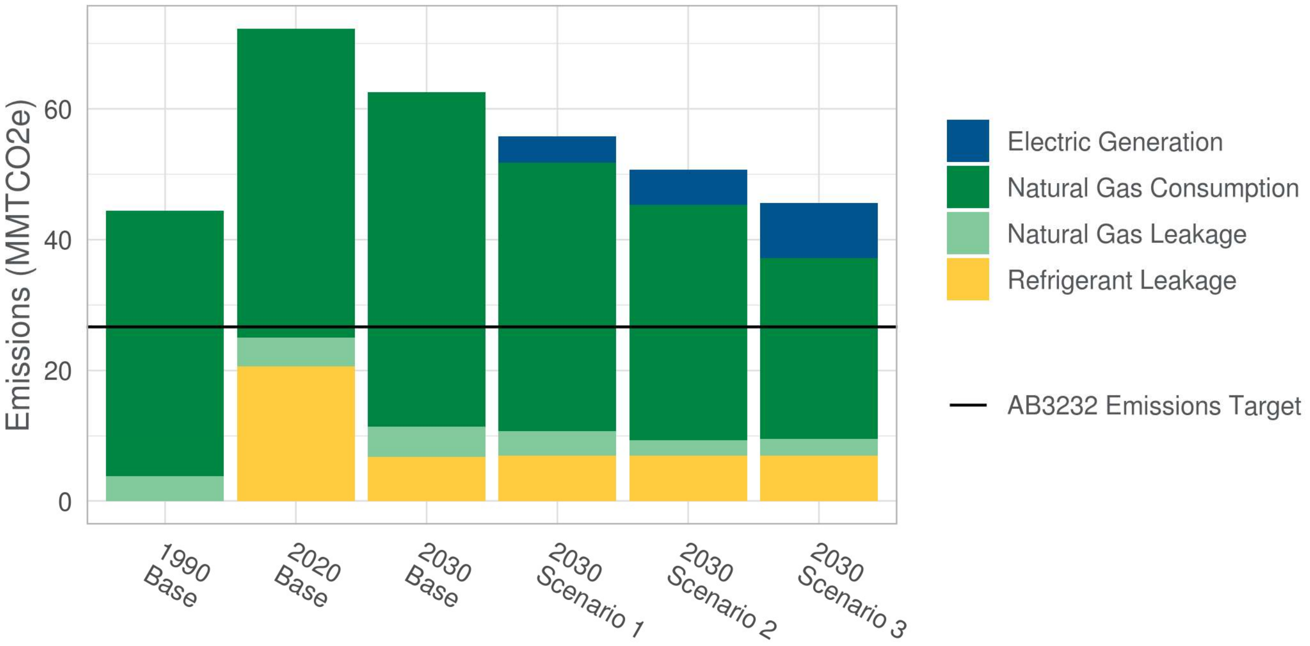
The side-by-side bar chart shows the natural gas consumption forecasted in 2030 at the end-use level. The HVAC and water heating end uses represent the largest decrease in forecasted natural gas consumption in 2030, representing 90 percent of natural gas reduction due to fuel substitution in Scenario 3.

Source: Guidehouse FSSAT output

Figure 20 shows the overall building emissions recorded in 1990 and forecasted in 2020 and 2030, according to the IEPR forecast and FSSAT scenario outputs. The data represented in Figure 20 are used to relate the FSSAT scenario results to AB 3232 goals. None of the scenarios as modeled appear to result in GHG emissions reductions to the 1990 levels. However, the research team notes the following caveats:

- HFC refrigerant leakage is the only quantified refrigerant GHG emissions impact in the baseline and forecast for this study. In 1990, chlorofluorocarbons (CFCs) were the dominant refrigerant in use, though they have been phased out by 2020. Figure 20 excluded emissions from CFCs. Thus, total refrigerant leakage emissions in 1990 appear miniscule (because they are driven by the very low use of HFCs at the time and exclude CFCs) compared to 2020 (where all refrigerants are converted from CFCs to HFCs). CEC staff directed the research team to account for total refrigerant leakage in this way.
- FSSAT users can generate additional scenarios that show savings beyond the three scenarios initially designed by the CEC.
- Alternate means of decarbonizing buildings beyond fuel substitution exist (for example, fixing/reducing natural gas leaks and additional energy efficiency).

Figure 20: Commercial and Residential Total Building Emissions for AB 3232 Goals



The stacked bar chart shows the overall emissions in 1990 (51.6 MMTCO$_2$e) for residential and commercial buildings and relates this amount to building emissions forecasted in 2020 and 2030. The figure shows that since 1990, California natural gas demand grew. The IEPR forecast predicts further growth in natural gas consumption through 2030, as shown in the 2020 base and 2030 base data.

Source: Guidehouse FSSAT output

Table 25 shows the progress toward AB 3232 goals based on building emissions in the commercial and residential sectors. In this table, positive percentages represent an increase in emissions and negative percentages represent a decrease in emissions compared to 1990. The residential and commercial emissions forecasted in 2020 and 2030 overall are expected to constitute a 63 percent and 41 percent increase in emissions compared to 1990. Much of this emissions increase is due to the way CEC staff directed the research team to account for total refrigerant leakage. Table 25 shows a subtotal row that removes consideration of total refrigerant leakage to illustrate the impact purely from an end-use energy perspective.

When considering refrigerants in the accounting framework as directed by CEC staff, all FSSAT scenarios do not result in an emissions decrease below 1990 values nor do they reach the emissions reduction goal set by AB 3232. When the impacts of total refrigerant leakage are removed and the focus is on energy use and natural gas leakage, Scenario 3 shows a net decrease in emissions.[180]

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[180] Including the impact of **added** refrigerant leakage due to electrification would have a minimal effect on the subtotal results from Table 25 because this incremental impact is so small compared the end-use energy emissions impacts (previously illustrated in Figure 16).

Table 25: Commercial and Residential Building Emissions Progress to AB 3232 Goals (% Change from 1990 Baseline)

Emissions Type	2020 IEPR	2030 IEPR	Scenario 1	Scenario 2	Scenario 3
Electric Generation	-	-	8.9%	12.0%	18.9%
Natural Gas Consumption	15%	24%	1.0%	-10.3%	-29%
Natural Gas Leakage	1%	2%	0.1%	-3.3%	-2.7%
Subtotal	*16%*	*26%*	*10.0%*	*-1.6%*	*-12.8%*
Refrigerant Leakage	46%	15%	15.5%	15.5%	15.5%
Total	**63%**	**41%**	**26%**	**14%**	**3%**
AB 3232 Goal	**-**	**-40%**	**-40%**	**-40%**	**-40%**

Note: Totals may not reflect the sum of their components due to rounding. Furthermore, the light gray columns are to indicate business as usual data points.

Source: Guidehouse FSSAT output

Table 26 provides the added electricity consumption by electric utility and by scenario in 2030 based on the FSSAT scenario outputs. The electric energy added included all electrified heating and load for cooling in homes without access to cooling before fuel substitution. Scenario 3 results in an estimated 52,015 GWh added.

Table 26: 2030 Electricity Consumption Added by Scenario (GWh)

Electric Utility	Scenario 1	Scenario 2	Scenario 3
LADWP	2,398	3,306	5,276
PG&E	8,875	12,202	19,492
SCE	8,307	11,376	18,080
SDG&E	1,187	2,604	4,116
SMUD	1,184	1,629	2,583
Other	1,138	1,564	2,468
Statewide	**23,789**	**32,681**	**52,015**

Source: Guidehouse FSSAT output

Table 27 provides the total net cumulative investment cost (in billions of dollars) to the consumer by scenario through 2030 at the sector level.

Table 27: Cumulative Cost for Panel Upgrades ($ Billions)

Sector	Scenario 1	Scenario 2	Scenario 3
Residential	$ -	$ -	$ 7.2

Source: Guidehouse FSSAT output

Table 28 provides the total net cumulative investment cost (in billions of dollars) to the consumer by scenario through 2030 at the sector level. The total net cumulative investment cost is the net cumulative cost for each year of installation, annualized at the real discount rate, and represented in 2020 dollars. Table 28 shows that fuel substitution is expected to cost $34.5 billion, $54.4 billion, and $97.9 billion in Scenarios 1, 2, and 3, respectively, over the forecast period. These costs included technology costs, installation costs, contractor overhead and profit, fuel costs, and electric panel upgrade costs. Where appropriate, these costs are incremental to the cost of the comparable baseline gas technology.

Table 28: Net Cumulative Investment Cost by Scenario ($ Billions*)

Sector	Scenario 1	Scenario 2	Scenario 3
Residential	$ 34.5	$ 51.9	$ 81.8
Commercial	$ -	$ 2.5	$ 5.8
Agricultural/Industrial	$ -	$ -	$ 10.4
Total	**$ 34.5**	**$ 54.4**	**$ 97.9**

***Costs in 2020 dollars**
Source: Guidehouse FSSAT output

Abatement Cost Curves

The FSSAT produces GHG abatement cost curves based on the identified method in the California ARB's AB 32 Scoping Plan (scoping plan).[181] The scoping plan includes the cost to implement policies or measures (marginal abatement costs) across all economic sectors. Social costs do not represent the cost of abatement or the cost of GHG emissions reductions; rather, social costs estimate the harm avoided by reducing GHG emissions.

FSSAT calculates abatement cost on a per-metric-ton ($mtCO_2e$) basis to compare fuel substitution technologies to each other. To be consistent with the scoping plan model framework calculation of costs per ton reduced,[182] the user will have the option to select whether to discount the emissions. If that option is set to no, the cumulative emissions will be the simple sum of the annual emissions up to each year. If the option to discount emissions is turned on, the cumulative emissions savings are discounted using the real discount rate.

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181 California Air Resources Board. November 2017. *California's 2017 Climate Change Scoping Plan*.

182 The PATHWAYS model is the scenario analysis for calculating the emissions reduction forecast of various GHG abatement measures reported in the AB 32 Scoping Plan: Energy and Environmental Economics, Inc., California PATHWAYS Model Framework and Methods, Model Version 2.4, January 2017.

Alignment of the Definition of Costs

For the marginal abatement costs, the scoping plan calculates the total cost required from 2020 to 2030 to achieve emissions reductions for each measure during that same period (including incremental capital costs and incremental fuel savings/expenditures). To calculate this, the team reviewed the scoping plan analysis, which uses the PATHWAYS model framework.[183] This cost is a cumulative value (cost per metric ton abatement) for each mitigation option over the years 2020–2030 and reported in 2020 dollars.

The PATHWAYS model annualizes the capital costs to a dollar/year basis using a capital recovery factor. This factor is based on a 10 percent real discount rate.[184] The total technology cost across the study period (2020–2030) as defined in Equation 9 is annualized in Equation 18 using the real discount rate and the life of the fuel substituted equipment.

Equation 18: Annualized Equipment Cost

$$Annualized\ Equipment\ Cost = Total\ Equipment\ Cost\ \times \frac{d}{[1-(1+d)^{-EUL}]}$$

$Where$:

d = the real discount rate

EUL = the effective useful life of a given technology

The second component of the annual cost is the net electricity and natural gas costs, which Equation 10 defined.

For each measure, the annual costs from 2020 to 2030 are calculated and then discounted to 2020 using the discount rate to levelized capital costs over the life of equipment. This discounted cost for each measure was divided by the associated cumulative emissions reductions from 2020 to 2030 to calculate a cost per ton for the measure for the period. Equation 19 provides the calculation of the discounted costs over the study period.

Equation 19: Net Present Value of the Annualized Costs

$$Net\ Present\ Value\ Cost = \sum_k^{ElecTech}\sum_i^{year} NPV\Big[Annualized\ Equipment\ Cost_{yr=i,electech=k} + \big(Added\ Electric\ Cost_{yr=i,electech=k} + Reduced\ Gas\ Cost_{yr=i,electech=k}\big) + Ancillary\ Cost_i\Big], d, EUL)$$

$Where$:
$Annualized\ Equipment\ Cost$ = As explained on Equation 18
$Added\ Electric\ Cost$ = Additional annual cost of electricity consumed
$Reduced\ Gas\ Cost$ = Reduced annual cost of gas consumption saved
$Ancillary\ Cost$ = Additional capital cost in ancillary equipment for electric demand
NPV = Net present value calculation
d = the real discount rate
EUL = the effective useful life of a given technology

FSSAT uses the same analysis equations and applies them to fuel substitution costs. FSSAT allows users to adjust the discount rate. (CARB's default is 10 percent.) In addition, the FSSAT

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[183] Energy and Environmental Economics, Inc. January 2017. *California PATHWAYS Model Framework and Methods, Model Version 2.4.*

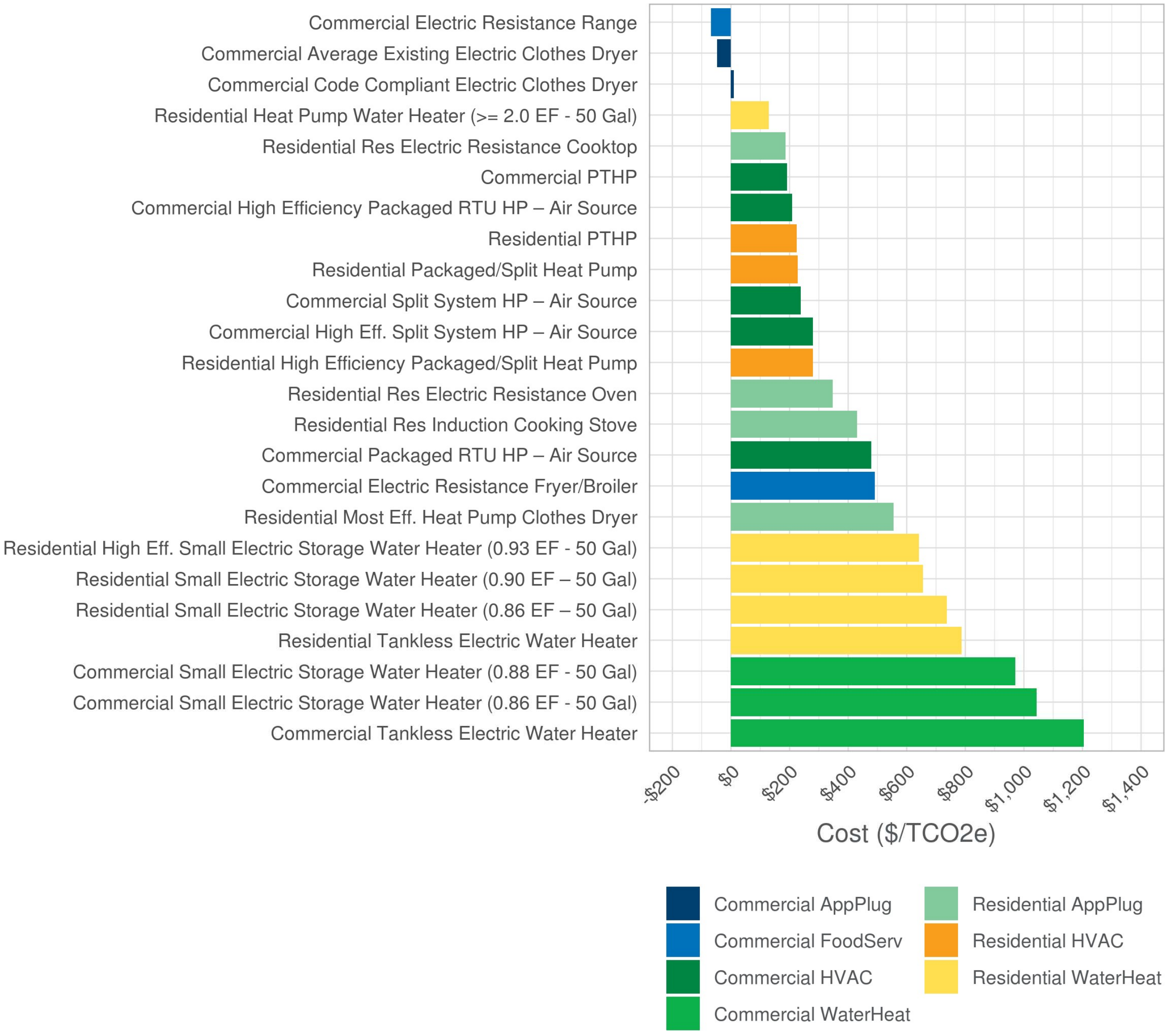
[184] P. 28 of the PATHWAYS model framework details this value.

allows the user the option to discount emissions over the forecast period. In the default scenario outputs and abatement curves included in this report, emissions are not discounted.

Abatement Curves Results and Analysis

Figure 21 displays the FSSAT-characterized electric technologies ranked based on the cost per mTCO$_2$e avoided per technology in Scenario 3. The avoided carbon emissions represented in this figure are not discounted over the forecast period. This figure represents the scale and order of the vertical axis in the marginal abatement cost curves developed in this study and can be used as a reference to map technology blocks to the detailed technology name given in Figure 21**Error! Reference source not found.**.

Figure 21: Electric Technology Cost per mTCO$_2$e Avoided – Scenario 3



The figure Error! Reference source not found.**shows the technology cost per mTCO$_2$e avoided ranked from lowest to highest cost. Commercial electric resistance ranges and commercial average existing electric clothes dryers have the two lowest cost per ton avoided and are negative values. Negative cost per ton avoided values indicate technologies for which the**

electric replacement is less expensive over the lifetime than the comparable gas equipment. The technologies with highest cost per ton avoided are all commercial electric resistance water heaters.
Source: Guidehouse FSSAT output

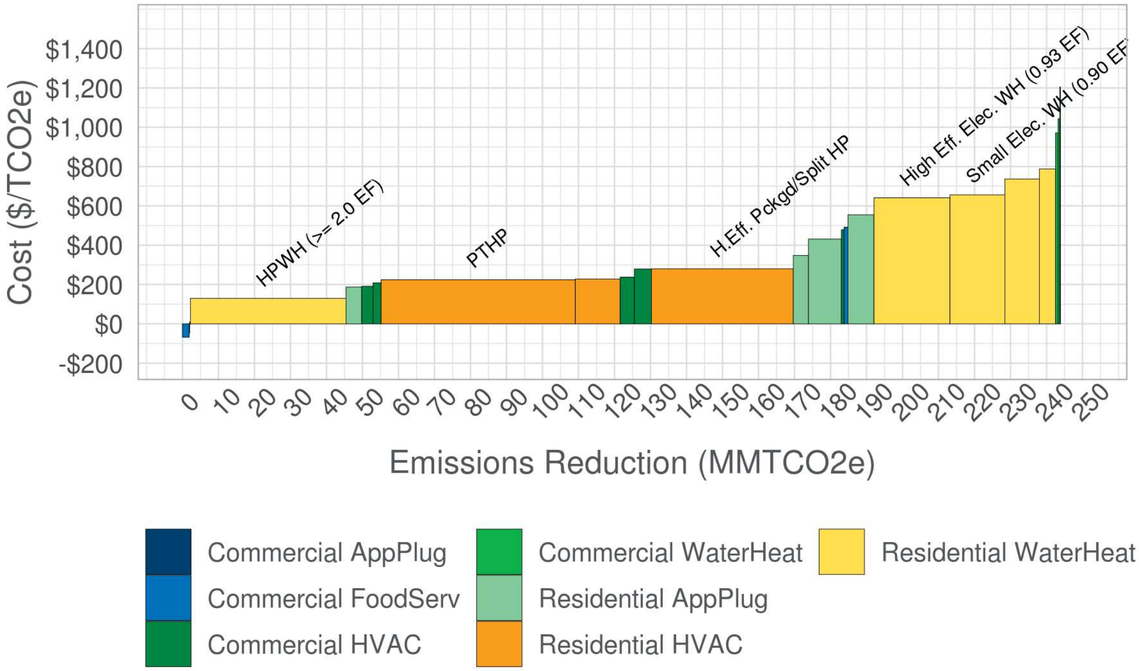
Figure 22 provides cumulative emissions avoided at the technology level over the forecast period through the end of life of the technology (2020–2045). The carbon emissions avoided represented in this figure are not discounted over the forecast period. This figure represents the scale of the horizontal axis in the marginal abatement cost curve in Figure 23 for the same scenario and period.

Figure 22: 2020–2045 Cumulative Emissions Avoided by Technology – Scenario 3

The figure shows the cumulative emissions avoided by technology from 2020 to 2045 in Scenario 3. Residential packaged terminal heat pumps and residential heat pump water heaters represent the two technologies with highest emissions avoided. Residential heat pumps are the third highest technology.
Source: Guidehouse FSSAT output

Figure 23 displays the emissions rank order shown in Figure 22 compared against the cost per emissions rank order in Figure 21 and **Error! Reference source not found.**the 2020–2045 cumulative marginal abatement cost curve for Scenario 3. Carbon emissions avoided represented in this figure are not discounted over the forecast period.

Figure 23: 2020-2045 Cumulative Marginal Abatement Curve by Technology – Scenario 3



The figure shows the 2020–2045 cumulative marginal abatement cost curve by technology for Scenario 3. The highest impact technologies, those with high emissions reduced and low cost per ton reduced, are residential heat pump water heaters (HPWH [>= 2.0 EF]), residential packaged/split heat pumps (Pckgd/Split HP), residential packaged terminal heat pumps (PTHP), residential high-efficiency packaged/split heat pumps (H.Eff.Pckgd/Split HP), and residential high-efficiency electric water heaters (High Eff. Elec. WH [0.93 EF]).
Source: Guidehouse FSSAT output

Agricultural and industrial emissions and cost per emissions are calculated at the end-use level rather than the technology level; they are reported separately in Table 29.

Table 29: 2020-2045 Agricultural/Industrial Cumulative Emissions Avoided and Cost

Sector	End Use	Avoided Emissions (mTCO$_2$e)	Cost per Ton ($/mTCO$_2$e)
Agricultural	HVAC	22,478	$233.23
Agricultural	Water Heat	79,099	$357.93
Industrial	Process Heat	2,590,279	-$59.34

Source: Guidehouse FSSAT output

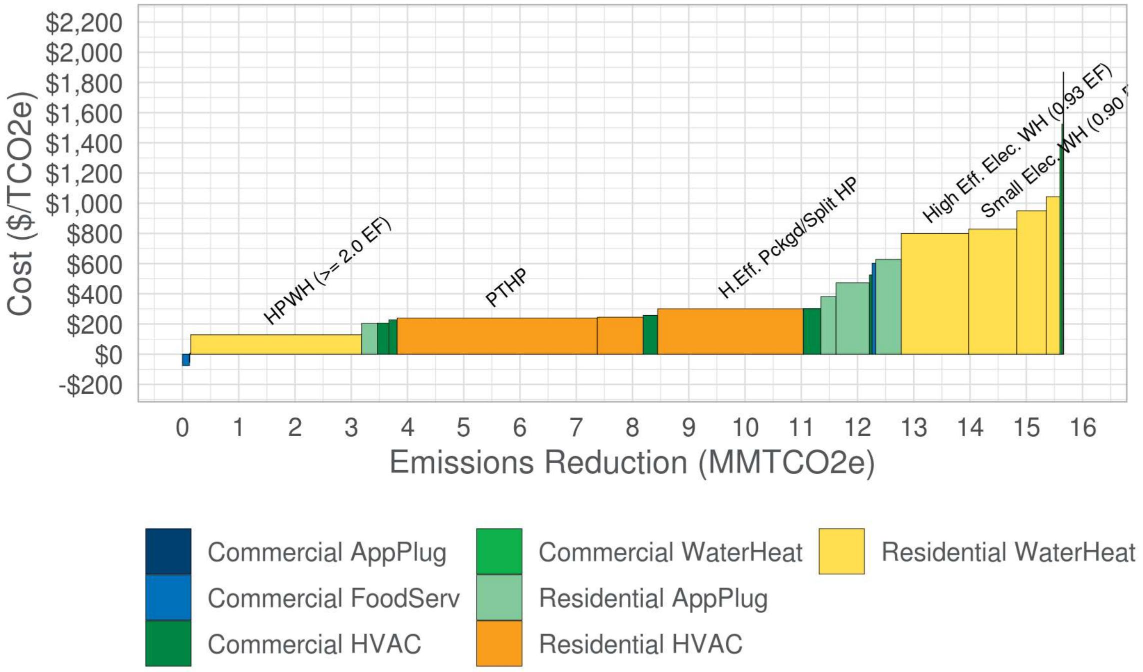
Figure 24 provides incremental aggregate emissions avoided at the technology level in 2030 for the residential and commercial sectors. Carbon emissions avoided represented in this figure are not discounted over the forecast period. This figure represents the scale of the horizontal axis in the marginal abatement cost curve for the same scenario and period (Figure 25).

Figure 24: 2030 Incremental Emissions Avoided by Technology – Scenario 3

This figure shows the incremental emissions avoided by technology in 2030 for Scenario 3. Residential packaged terminal heat pumps and residential heat pump water heaters represent the two technologies with highest emissions avoided. Commercial electric clothes dryers (average existing and code) and commercial tankless electric water heaters represent the three technologies with the least avoided emissions.
Source: Guidehouse FSSAT output

Figure 25 displays the emissions rank order in Figure 24 compared against the cost per emissions rank order in Figure 21 in the incremental aggregate marginal abatement cost curve in 2030 for Scenario 3. Carbon emissions avoided represented in this figure are not discounted over the forecast period.

Figure 25: 2030 Incremental Marginal Abatement Curve by Technology – Scenario 3



This figure shows the 2030 incremental marginal abatement cost curve by technology for Scenario 3. The highest-impact technologies, those with high emissions reduced and low cost per ton reduced, are residential heat pump water heaters (HPWH [>= 2.0 EF]), residential packaged/split heat pumps (Pckgd/Split HP), residential packaged terminal heat pumps (PTHP), residential high-efficiency packaged/split heat pumps (H.Eff.Pckgd/Split HP), and residential high-efficiency electric water heaters (High Eff. Elec. WH [0.93 EF]).
Source: Guidehouse FSSAT output

Agricultural and industrial emissions and cost per emissions are calculated at the end-use level rather than the technology level; they are reported separately in Table 30.

Table 30: 2030 Agricultural/Industrial Cumulative Emissions Avoided and Cost

Sector	End Use	Avoided Emissions ($mTCO_2e$)	Cost per Ton ($\$/mTCO_2e$)
Agricultural	HVAC	3,602	$199.45
Agricultural	Water Heat	16,148	$329.69
Industrial	Process Heat	493,449	-$50.49

Source: Guidehouse FSSAT output

Hourly Demand and Emissions

The FSSAT hourly analysis calculates the hourly load impacts of each fuel substitution scenario. While the FSSAT outputs are generally at the annual level for consumption and GHG emissions, annual values are insufficient to accurately predict the GHG impacts of additional electric load due to fuel substitution. Because of the high penetration and intermittency of renewables in California, the emissions factor associated with marginal electric load can vary substantially at the hourly level. The hourly calculation in the FSSAT applies the annual additional electric load FSSAT output to normalized load shapes at the utility and end-use levels. The resulting hourly load impacts are converted to hourly emissions impacts using hourly emissions factors developed by CEC staff.

At higher penetrations of renewable generation as expected in future years, it is more accurate to apply hourly electric generation emissions factors to determine GHG emissions effects. Hourly demand data also help analyze potential grid constraint concerns as systemwide peak demand may shift to different periods. For example, large increases in electric heating may produce a significant winter peak that rivals the traditional summer peak. Furthermore, the winter mornings will not have any solar PV contribution, potentially exacerbating the winter peak. The nature and magnitude of this potential winter peak can be better analyzed using hourly data from FSSAT.

The FSSAT uses the hourly calculation R process, detailed in Appendix H, to determine the hourly electric load impacts of the added electricity due to fuel substitution. Representative load shapes for all technologies are available, including space-heating heat pumps. Appendix G describes the development of space-heating and space-cooling heat pump load shapes. The hourly emissions factors provided by the CEC represent the emissions factor for marginal electric generation due to fuel substitution and does not represent the electric generation mix as a whole. As such, when these hourly values are aggregated to an annual value, they are not directly comparable to the annual emissions factors of the full California electric generation mix.

Hourly Analysis Results

Table 31 shows the annualized emissions factors calculated from the hourly GHG analysis. These values are the quotient of the annual aggregate GHG emissions calculated from the sum of the hourly GHG emissions and the annual additional electric load from fuel substitution. Table 31 shows that fuel substitution in the FSSAT scenario outputs become progressively less emissions-intensive from Scenario 1 to Scenario 2 to Scenario 3. This finding would indicate that the additional load from fuel substitution in these scenarios is coincident with generation with lower emissions intensity, on average.

Table 31: Annualized Emissions Factors Based on Hourly GHG Analysis Results, mTCO$_2$e per MWh

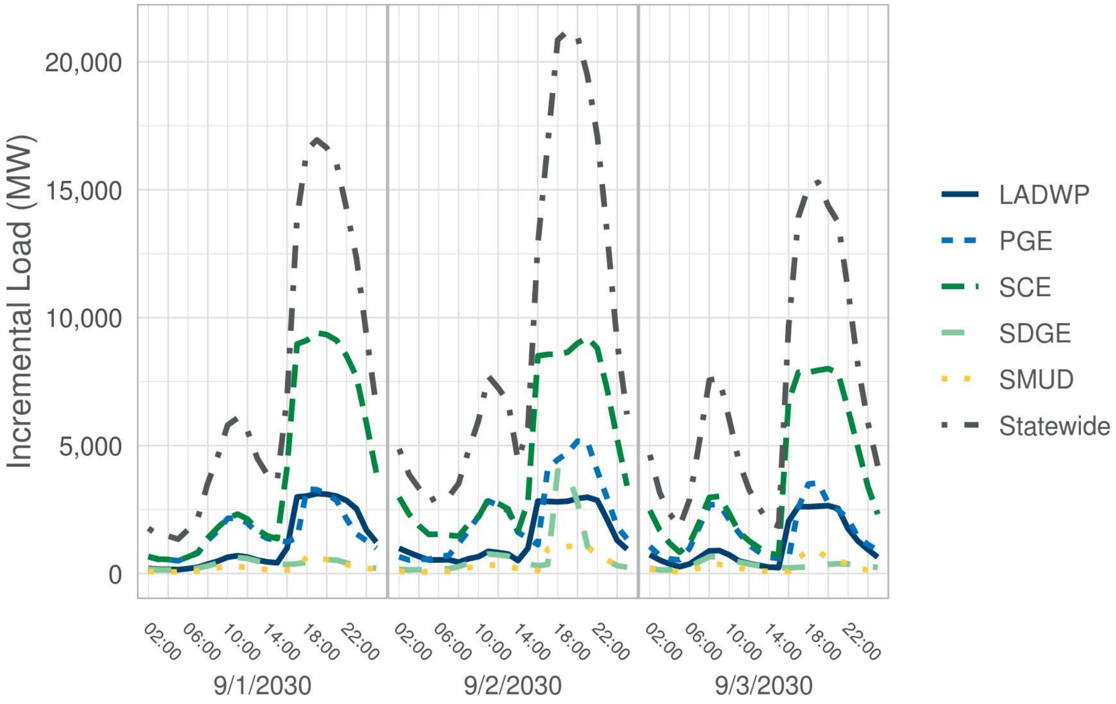
Year	Scenario 1	Scenario 2	Scenario 3
2020	0.334	0.334	0.335
2021	0.334	0.334	0.334
2022	0.333	0.333	0.333
2023	0.296	0.294	0.293
2024	0.261	0.255	0.254
2025	0.222	0.213	0.211
2026	0.216	0.206	0.204

Year	Scenario 1	Scenario 2	Scenario 3
2027	0.210	0.200	0.197
2028	0.205	0.195	0.192
2029	0.200	0.189	0.187
2030	0.195	0.184	0.181

Sources: Guidehouse FSSAT output based on hourly inputs provided by the CEC

Figure 26 shows the hourly load for the summer peak day for electric load added due to fuel substitution and the two surrounding days. Both the statewide and constituent utility hourly load impacts are provided in this figure. Statewide, the FSSAT calculates that Scenario 3 will require an additional 19,367 MW of capacity.

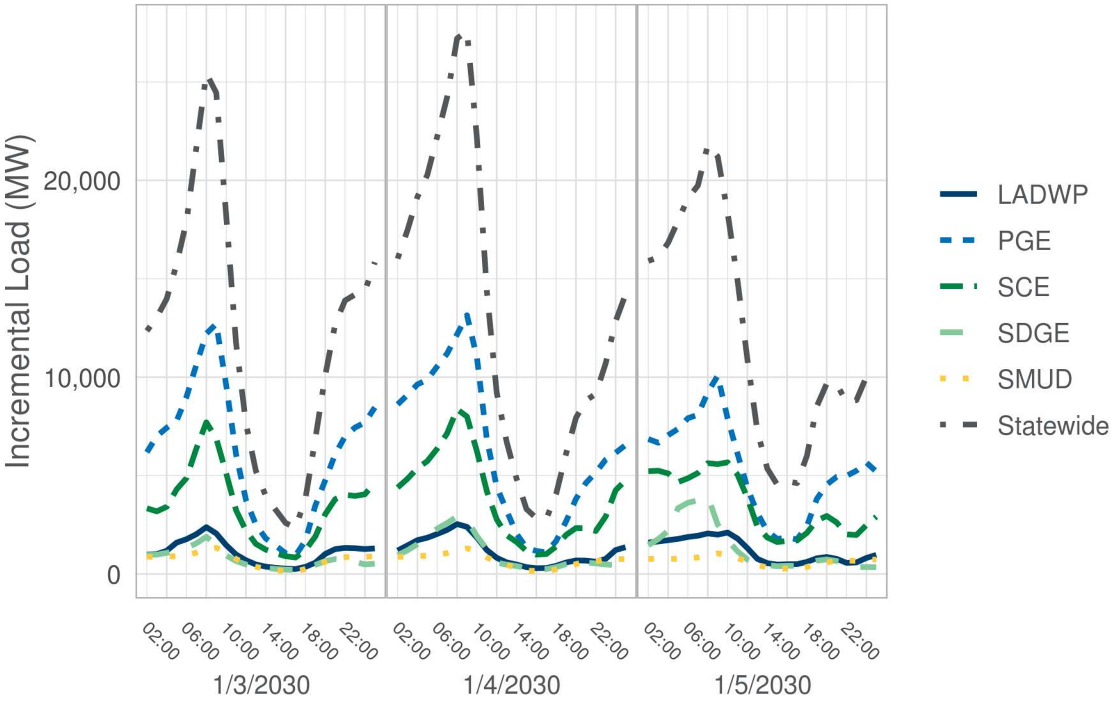
Figure 26: 2030 Hourly Added Electric Load on Summer Peak Day – Scenario 3



This line chart shows the hourly load for the summer peak day for electric load added due to fuel substitution and the two surrounding days.
Source: Guidehouse FSSAT output

Figure 27 shows the hourly load for the winter peak day for electric load added due to fuel substitution and the two surrounding days. Both the statewide and constituent utility hourly load impacts are provided in this figure. Statewide, the FSSAT calculates that Scenario 3 will require an additional 24,520 MW of capacity.

Figure 27: 2030 Hourly Added Electric Load on Winter Peak Day – Scenario 3



This line chart shows the hourly load for the winter peak day for electric load added due to fuel substitution and the two surrounding days.
Source: Guidehouse FSSAT output

Future Research

The CEC tasked the research team with prioritizing tool infrastructure and functionality development. The collection and vetting of input data were a secondary priority and depended on available secondary research. As such, the research team built assumptions into the current tool in the absence of data. The drive toward building decarbonization and fuel substitution is a nascent strategy for reducing GHG emissions. As the electricity grid decarbonizes, the overall effectiveness for abating GHG emissions at a cost-effective dollar per metric ton improves. Given this result, the following specific assumptions merit further research as the market develops.

- The propensity and rate of electrification adoption by sector and building segment are unknown. The FSSAT uses simplified assumptions. Research should be conducted at the technology level and in technology bundles. Once a customer adopts, for example, an electric water heater, the likelihood of adopting additional electric technologies will change.
- Electric technology characterization metrics should be based on technology field performance. Electric technology consumption is calculated assuming the technology achieves the associated rated performance over the lifetime of the technology. Future research may vet this assumption with field data and a better understanding of heat pump technology.

- Hourly GHG emissions factors for electric generation are based on one year and extrapolated to other years in the forecast period. In future research, interpolation and extrapolation could be minimized by developing hourly emissions factors for each forecast year.
- No data exist on the adoption rate of fuel substitution. The FSSAT does not include these consumer decision and behavior parameters. The tool designed for this study is meant to forecast policy objective scenarios. These scenario efforts are important because they help articulate a vision of the mid- and high-level parameter outcomes and metrics that correspond to policy goals. Forecasts that employ bottom-up consumer decision theories are necessary to make precise forecasts that rely on changes in customer behavior. Near-term changes in behavior may be sufficiently captured by slight changes to high-level calibrated parameters because drastic changes are unlikely. For longer-term forecasts where widespread changes could be expected, better decision models and regularly tracked metrics are needed.

APPENDIX A:
Utility and Customer Fuel Substitution Costs

Utility Costs

Fuel substitution will result in an increase in electricity loads on the electric grid. California utilities will have to upgrade equipment to adequately handle this increased load. The following tables outline utility costs on a unit basis for a variety of electrical upgrades. Pacific Gas and Electric (PG&E) costs are provided because it is the largest utility provider in California and the only utility with public cost data on a per-unit basis.

Table A-1: Utility Costs per Unit:
Category 1 – 12/16 kV 480 V Transformer, Includes 100' Sec. Cable Length

Item #	Equipment	Unit Cost
1	150kva & Sec. Cable (120/208V)	$39,000
2	300kva & Sec. Cable (120/208V)	$47,000
3	500kva & Sec. Cable - 500kvz is not current standard size for PG&E	N/A
4	750kva & Sec. Cable (480/277V)	$58,000
5	1000kva & Sec. Cable (480/277V)	$72,000
6	1500kva & Sec. Cable (480/277V)	$98,000
7	2500kva & Sec. Cable - Not generally used for distribution interconnections	N/A

Source: Pacific Gas and Electric Company's Unit Cost Guide, updated: April 1, 2019

Table A-2: Utility Costs per Unit:
Category 2 – Overhead to Underground (UG) — Set Pole and Make Up Cable

Item #	Equipment	Unit Cost
1	Primary UG Service up to 200ft cable	$45,000
2	Pri 350 Cable - PG&E does not separate costs for different cable size	N/A
3	Pri 1000 Cable - PG&E does not separate costs for different cable size	N/A

Source: Pacific Gas and Electric Company's Unit Cost Guide, updated: April 1, 2019

Table A-3: Utility Costs per Unit: Category 3 – Overhead (OH) Service

Item #	Equipment	Unit Cost
1	Primary Service-OH include 1 span ovh line	$20,000
2	New Conductor extension from POI to PCC	$120/ft

Source: Pacific Gas and Electric Company's Unit Cost Guide, updated: April 1, 2019

Table A-4: Utility Costs per Basis: Category 4 – Underground to Underground — Cable With Terminators

Item #	Equipment	Unit Cost
1	Pri Low Ampacity Cable - PG&E does not separate costs for different cable size	N/A
2	Pri High Ampacity Cable - PG&E does not separate costs for different cable size	N/A
3	UG Reconductor - repull or customer installed conduits	$130/ft
4	New UG Line(SF) - Trench and install	$495/ft
5	Padmounted Visible SW at PCC	$45,500
6	New Feeder and Conduit - Addressed Under Prior Category	N/A
7	New 1000 KCIML AL Cable and Connections (ft) Addressed Under Prior Category	N/A
8	New 2/0 AL cable and connections - Addressed Under Prior Category	N/A

Source: Pacific Gas and Electric Company's Unit Cost Guide, updated: April 1, 2019

Table A-5: Utility Costs per Unit: Category 5 – Metering

Item #	Equipment	Unit Cost
1	Secondary Service Meeting	$5,000
2	Primary Service Meeting	$15,000
3	33kV Pole Top - Not generally used for PG&E	N/A

Source: Pacific Gas and Electric Company's Unit Cost Guide, updated: April 1, 2019

Table A-6: Utility Costs per Unit: Category 6 – Telemetry

Item #	Equipment	Unit Cost
1	Overhead SCADA Recloser	$80,000
2	Underground SCADA Switch	$130,000
4	Dedicated Remote Terminal Unit	$120,000
5	Bi-directional watt transducer - Not generally used at PG&E	N/A
6	Data Point addition and existing HMI - Not generally used at PG&E	N/A
7	Overhead Remote Control Switch - Not generally used at PG&E	N/A

Source: Pacific Gas and Electric Company's Unit Cost Guide, updated: April 1, 2019

Table A-7: Utility Costs per Unit: Category 7 – System Equipment

Item #	Equipment	Unit Cost
1	New overhead Air Switch	$30,000
2	New Capacitor OH	$33,000
3	PME 5 Padmount Switch	$57,000
4	New Capacitor Pad mounted	$47,000
5	New Regulator - Close Delta	$150,000
6	33kV Regulator 3-690/722 - Not generally used at PG&E	N/A
7	New Voltage Regulator 600A Padmount with two switches - Not generally used at SCE	N/A
8	Grounding/Stabilizing Transformer - Pole Mounted	$20,000
9	Grounding/Stabilizing Transformer – Pad Mounted	$52,000
10	Conductor (Per feet) - Overhead - Urban	$220/ft
11	Reconductor (Per feet) - Overhead - Rural	$130/ft
12	Reconductor (Per feet) - UG	$260/ft
13	New Steel Pole (not priced separately, would be part of facility supporting need for pole)	N/A
14	New Wooden Pole (not priced separately, would be part of facility supporting need for pole)	N/A
15	Overhead Fuses	$10,000
16	Fuse Cabinet UG 3 phase - Not generally use at PG&E	N/A
17	Relocate Capacitor Bank	$18,000
18	Regulator Control settings modifications	$2,500
19	Relocate Regulator	$50,000
20	Add a third Regulator to close the Delta	$55,000
21	New Regulator - Closed Delta	$150,000
22	Reclose blocking	$145,000
23	Hardwire Tripping from Transformer Hi-side	$60,000
24	Substation LTC Control change out	$60,000
25	New IPAC relay cabinet for bi-direction power flow	$125,000
26	Direct Transfer Trip	$600,000
27	New Substation Circuit Breaker - Not generally used for distribution interconnections	N/A
28	New 28MVA 69/12kV Transformer - Not generally used for distribution interconnections	N/A
29	New 28MVA 138/12kV Transformer - Not generally used for distribution interconnections	N/A

Source: Pacific Gas and Electric Company's Unit Cost Guide, updated: April 1, 2019

The National Renewable Energy Laboratory (NREL) studied the cost of distributed system upgrades and provided a focus on feeder modeling. Feeder costs pose a cost barrier in terms of electrical upgrades. Two case studies (Feeder A and Feeder B) in the study were in California; Table A-8 shows a breakdown of costs.

Table A-8: Summary of Upgrade Costs on the Two Feeder Case Studies

Upgrade Selected	Unit Cost (Low, Mid, High)	Units Required	Total Cost (Low, Mid, High)	Relevant Spatial DPV Deployment Scenarios
Advanced inverter functionality: set all inverter absorbing PF of 0.95 or using volt/VAR control	$0 for all for the baseline case, $143 for all for the high-inverter cost case	Depends on penetration level		All scenarios
New line voltage regulator (Feeder A)*	$150,000, $166,000, $183,000	1	$150,000, $166,000, $183,000	All scenarios
New LTC at the substation transformer (Feeder A)	$310,000, $310,000, $310,000	1	$310,000, $310,000, $310,000	All scenarios
New 3-phase, 300 kVar capacitor (Feeder B)	$6,000, $8,290, $10,700	1	$6,000, $8,290, $10,700	Close to the substation only
Reduce LTC set point (Feeder B)	$500, $8,000, $26,000	1	$500, $8,000, $26,000	Close to the substation only
New 3-phase, 50 kVA transformer (OH)** (Feeder B)	$10,400, $10,400, $10,400	1	$10,400, $10,400, $10,400	Close to the substation only
New 3-phase, 100 kVA transformer (OH)** (Feeder B)	$15,600, $32,500, $49,300	9	$140,000, $292,000, $444,000	Close to the substation only

***These upgrades were undertaken simultaneously.**

****OH = overhead**

Source: National Renewable Energy Laboratory, *The Cost of Distribution System Upgrades to Accommodate Increasing Penetrations of Distributed Photovoltaic Systems on Real Feeders in the United States*, 2018

Customer Costs

TRC Companies, Inc. conducted a variety of reach code studies in California to appraise the costs associated with various equipment installations. The baseline scenario represents the existing or standard equipment status as outlined in the 2019 Title 24 measure requirements. The proposed scenario represents the electrification upgrade beyond Title 24 requirements.

Table A-9: Residential New Construction Heat Pump Water Heater, Single-Family Costs

Cost Type	Baseline	Proposed
First Cost	$2,494	$3,158
Water Heater	*$789*	*$1,713*
Installation	*$1,017*	*$945*
Flue	*$313*	*$0*
Electrical	*$375*	*$500*
Replacement	$1,806	$2,658
Maintenance (per year)	$59	$0
EUL (years)	20	15

Source: City of Carlsbad Energy Conservation Ordinance Cost Effectiveness Analysis, TRC Companies, Inc., Feb. 2019

Table A-10: Residential New Construction Heat Pump Water Heater, Multifamily Costs

Cost Type	Baseline	Proposed
First Cost	$19,951	$25,264
Water Heater	*$6,312*	*$13,704*
Installation	*$8,136*	*$7,560*
Flue	*$2,504*	*$0*
Electrical	*$3,000*	*$4,000*
Replacement	$14,451	$21,264
Maintenance (per year)	$474	$0
EUL (years)	20	15

Source: City of Carlsbad Energy Conservation Ordinance Cost Effectiveness Analysis, TRC Companies, Inc., Feb. 2019

Table A-11: Commercial New Construction Electric-Resistance Water Heating Prototype Costs

Cost Type	Baseline	Proposed
First Cost	$1,794	$1,100
Water Heater	*$600*	*$600*
Natural Gas Piping	*$550*	*$0*
Installation	-	-
Flue	*$313*	*$0*
Electrical	*$331*	*$500*
Replacement	$600	$600
EUL (years)	15	15

Source: City of Carlsbad Energy Conservation Ordinance Cost Effectiveness Analysis, TRC Companies, Inc., Feb. 2019

Table A-12: Commercial New Construction Heat Pump Water Heater Prototype Costs

Cost Type	Baseline	Proposed
First Cost	$1,919	$2,658
Water Heater	*$941*	*$1,713*
Natural Gas Piping	-	-
Installation	*$666*	*$945*
Flue	*$313*	*$0*
Electrical		
Replacement	$1,606	$2,658
EUL (years)	15	15

Source: City of Carlsbad Energy Conservation Ordinance Cost Effectiveness Analysis, TRC Companies, Inc., Feb. 2019

Table A-13: Residential New Construction and Alterations Electric Panel Costs, Heat Pump Water Heater Outlet, Single-Family – 2,100 ft^2

First Measure Cost	Baseline	Proposed
Electrical Panel*	$2,480	$2,480
Incremental Cost	**$0**	

***200 A panel was determined to be enough for an all-electric single-family building and matches common baseline of 200 A for new construction and alterations. Multifamily baseline is 125 A and proposed is 150 A.**
Source: City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT, TRC Companies, Inc., Sept. 2018

Table A-14: Residential New Construction and Alterations Electric Panel Costs, Heat Pump Water Heater Outlet, Multifamily

First Measure Cost	Baseline	Proposed
Electrical Panel*	$12,603	$16,859
Incremental Cost	**$4,256**	

***200 A panel was determined enough for an all-electric single-family building and matches common baseline of 200 A for new construction and alterations. Multifamily baseline is 125 A and proposed is 150 A.**
Source: City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT, TRC Companies, Inc., Sept. 2018

Table A-15: Commercial New Construction Heat Pump Space Heating Costs, Small Office

Cost Type	Baseline	Proposed
First Cost	$5,126	$4,650
Replacement	$-	$-
Maintenance	$-	$-
EUL (years)	20	16
Total Cost (NPV)	**$5,126**	**$4,650**
Incremental Cost	**-$476**	

Source: City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT, TRC Companies, Inc., Sept. 2018

Table A-16: Residential New Construction Heat Pump Water Heater Costs, Single-Family – 2,100 ft^2

Cost Type	Baseline	Proposed
First Cost	$2,449	$2,758
Water Heater	*$789*	*$1,313*
Installation	*$1,017*	*$945*
Flue	*$313*	*$0*
*Electrical**	*$331*	*$500*
Replacement	$1,372	$2,380
Maintenance	$1,502	$-
EUL (years)	20	15
Total Cost (NPV)	**$5,324**	**$5,137**
Incremental Cost	**-$186**	

*** Note heat pump water heater receptacle, or outlet, is included under "Electrical."**
Source: City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT, TRC Companies, Inc., Sept. 2018

Table A-17: Residential New Construction Heat Pump Water Heater Costs, Multifamily

Cost Type	Baseline	Proposed
First Cost	$18,714	$20,730
Water Heater	*$6,315*	*$10,504*
Installation	*$8,136*	*$7,560*
Flue	*$2,500*	*$0*
*Electrical**	*$1,763*	*$2,666*
Replacement	$10,978	$19,037
Maintenance	$12,017	$-
EUL (years)	20	15
Total Cost (NPV)	**$41,709**	**$39,766**
Incremental Cost	**-$1,943**	

*** Note heat pump water heater receptacle, or outlet, is included under "Electrical."**
Source: City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT, TRC Companies, Inc., Sept. 2018

Table A-18: Residential New Construction Heat Pump Clothes Dryer Costs, Single-Family – 2,100 ft^2

Cost Type	Baseline	Proposed
First Cost	$1,334	$1,807
Dryer	*$956*	*$1,245*
Electrical	*$378*	*$1,245*
Replacement	$1,094	$1,425
Maintenance	$-	$-
EUL (years)	13	13
Total Cost (NPV)	**$2,428**	**$3,232**
Incremental Cost	**$804**	

Source: City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT, TRC Companies, Inc., Sept. 2018

Table A-19: Residential New Construction Heat Pump Clothes Dryer Costs, Multifamily

Cost Type	Baseline	Proposed
First Cost	$9,664603	$12,958
Dryer	*$7,646*	*$9,961*
Electrical	*$2,108*	*$2,997*
Replacement	$8,752	$11,402
Maintenance	$-	$-
EUL (years)	13	13
Total Cost (NPV)	**$18,416**	**$24,361**
Incremental Cost	**$5,945**	

Source: City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT, TRC Companies, Inc., Sept. 2018

Table A-20: Residential New Construction Heat Pump Space-Heater Costs, Single-Family – 2,100 ft^2

Cost Type	Baseline	Proposed
First Cost	$2,369	$2,102
Package Unit/Heat Pump	*$2,019*	*$2,102*
Installation (Pad/Fuel)	*$350*	*$0*
Replacement	$1,543	$2,215
Maintenance	$0	$0
EUL (years)	20	15
Total Cost (NPV)	**$3,903**	**$4,317**
Incremental Cost	**$414**	

Source: City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT, TRC Companies, Inc., Sept. 2018

Table A-21: Residential New Construction Heat Pump Space-Heater Costs, Multifamily

Cost Type	**Baseline**	**Proposed**
First Cost	$18,954	$16,816
Package Unit/Heat Pump	*$16,154*	*$16,816*
Installation (Pad/Fuel)	*$2,800*	*$0*
Replacement	$12,272	$17,722
Maintenance	$0	$0
EUL (years)	20	15
Total Cost (NPV)	**$31,226**	**$34,538**
Incremental Cost	**$3,312**	

Source: City of Palo Alto 2019 Title 24 Energy Reach Code Cost Effectiveness Analysis DRAFT, TRC Companies, Inc., Sept. 2018

Life-Cycle Customer Costs

The Rocky Mountain Institute[185] performed a detailed assessment of electrification upgrades in the residential sector, with case studies completed in multiple locations. In the Oakland scenario in Figure A-1, natural gas furnace replaced with existing air conditioning is cheaper on the 15-year net-present cost (first and operating costs) scale for retrofits compared to standard and flexible heat pumps. New construction does not present the same cost barriers because heat pump installations are cheaper than natural gas with air conditioning on the same 15-year net present cost scale in both scenarios.

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[185] Rocky Mountain Institute. 2018. *The Economics of Electrifying Buildings*.

Figure A-1: Heat Pump vs. Natural Gas Furnace Lifetime Net-Present Cost Comparison (Oakland, California)

Bar chart comparing electric and natural gas technologies over the lifetime for retrofit and new construction homes in Oakland, California. Natural gas has higher net operating costs in most scenarios — retrofit type and time-of-use rates.

Source: Rocky Mountain Institute, *The Economics of Electrifying Buildings*, Figure 14, 2018.

APPENDIX B: Electrification Incentive Pathways

California provides unique incentive opportunities for new home construction in response to homes destroyed by wildfires. **Error! Reference source not found.** provides an overview of the home energy upgrades that new home construction could claim and the incentives by upgrade. New homes can claim multiple upgrades. The Simple Menu-based Path (in orange) lists the requirements necessary to fulfill this upgrade — for example, new homes must include a smart thermostat. The Flexible Performance Path (in orange) provides flexibility in the requirements, allowing upgrade variability — for example, 20 percent above Title 24 energy code for all-electric end uses.

Table B-22: California Advanced Home Incentives for Electrification

Type of Home	Single Family	Multifamily
Advanced Energy Home (mixed fuel)	$7,500	$3,750
All-Electric Home	$12,500	$6,250
Solar and Battery Option	$5,000	$5,000

Source: Incentive Pathways, California Advanced Homes

APPENDIX C:
Industrial and Agricultural Technologies

Fuel Substitution Opportunities by Segment

Electroheating solutions provide additional benefits by reducing final energy demand by a factor of 1.5 to 8 compared to conventional fossil fuel heating. Reductions can reach a factor of 2-3, especially when considering the reduced oxidation losses in electrical furnaces. Other benefits include improved economic productivity, product quality, and worker conditions. These benefits result from the contained electric heating conditions, which provide less variability in the heating process from increased heating control and overall safer conditions relative to those produced under fossil fuel conditions.[186] Table C-1 and Table C-2 provide feasibility and opportunities for electrifying end uses by segment. The matrix presented in Table C-1 evaluates boiler systems, combined heat and power (CHP), process heat, and facility heating, ventilation, and air conditioning (HVAC) for a variety of building types and designates the possible alternatives and the associated potential. This matrix provides higher granularity in terms of industrial process evaluation and solution specificity compared to Table C-2.

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[186] U.S. Department of Energy. 2016. *Quadrennial Technology Review 2015 – Chapter 6: Innovating Clean Energy Technologies in Advanced Manufacturing – Process Heating.*

Table C-1: Application Matrix of Eight Electroheating Technologies in 24 Industrial Sectors

Industry Sector	**Infrared Heating**	**Resistance Heating**	**Ultraviolet Curing**	**Microwave Heating**	**Radio Frequency Heating**	**Induction Heating/ Hardening**	**Induction Melting**	**Electric Arc Furnace**
Food products				X	X			
Beverages								
Tobacco					X			
Textiles	X	X	X	X	X	X		
Wearing apparel	X			X	X			
Leather products	X			X	X			
Wood products	X		X	X	X			
Paper & paper products	X		X	X	X			
Printing				X	X			
Coke & refined petroleum				X	X			
Chemicals	X		X	X	X			
Pharmaceuticals			X	X	X			
Rubber & plastics	X	X	X	X	X	X		
Nonmetallic minerals	X	X	X	X	X	X		
Basic metals	X			X	X		X	X
Fabricated metal products	X	X	X	X	X	X		
Computers & electronics	X	X		X	X	X		
Electrical equipment	X	X	X	X	X	X		
Machinery & equipment	X	X	X	X	X	X	X	
Motor vehicles	X	X	X	X	X	X		
Other transport equipment	X	X	X	X	X	X		
Furniture	X		X	X	X			
Other manufacturing	X	X		X	X	X		
Repair and installation	X	X	X			X		

Source: Navigant Consulting, Inc. (Ecofys), *Opportunities for electrification of industry in the European Union*, 2018

Table C-2: Industrial Sector Breakdown of Onsite Fuel Consumption, Representative Process Temperatures, and General Outlook for Electrification

Industrial Sector	Boiler System Percentage Onsite Fuel Consumption	CHP Percentage Onsite Fuel Consumption	Process Heating Percentage Onsite Fuel Consumption	Facility HVAC Percentage Onsite Fuel Consumption	High-temperature process steps	Temp L/M/H	Approximated Potential for Electrification	Disposition for electrification
Primary metals excluding steel	3.9%	7.4%	74.8%	5.8%	Primary Al Furnace 2200F (1200C); Copper furnace 1200C; Zinc Furnace (1260C)	HIGH	HIGH	Induction melting candidate
Fabricated metal products	7.2%	6.6%	61.2%	19.7%	Al sheet, foil furnace melting 1250F (680C); preheating 1000F (540C); annealing 800F (430C)	HIGH	HIGH	Induction heating/melting candidate, but low overall energy consumption
Machinery	4.2%	4.2%	38.9%	45.8%	Farm and construction equipment Heat treatment 1350F (732C)	HIGH	HIGH	Induction heating candidate, but low overall energy consumption
Iron and steel mills	0.0%	0.0%	87.0%	4.1%	Blast furnace 2600F(1430C) Basic oxygen furnace 2800F (1540C)	HIGH	HIGH	Electric arc furnace; electrowinning
Wood Products	4.8%	14.3%	50.0%	9.5%	Fiberboard Stabilization/Drying 350F (180C)	MED	HIGH	Good candidate for electrification, but low overall energy consumption
Transportation equipment	13.6%	12.1%	32.6%	31.1%	Motor vehicle car body Drier 300F (150C); Vehicle parts furnace 2900F (1600C)	MED/ HIGH	HIGH	Driers ok for electrification, but furnace challenging; but low overall energy consumption

Industrial Sector	**Boiler System Percentage Onsite Fuel Consumption**	**CHP Percentage Onsite Fuel Consumption**	**Process Heating Percentage Onsite Fuel Consumption**	**Facility HVAC Percentage Onsite Fuel Consumption**	**High-temperature process steps**	**Temp L/M/H**	**Approximated Potential for Electrification**	**Disposition for electrification**
Plastics and rubber products	19.4%	24.3%	33.0%	20.4%	Polystyrene Heater 500F (260C); Synthetic Rubber dryer 180F (82C)	LOW/ MED	HIGH	Good candidate for electrification, but low overall energy consumption
Food and beverages	25.0%	4.0%	24.9%	4.2%	250-350°F boiler (121-149°C); 450°F (232°C) baking oven; 930°F charcoal regen. (cane sugar) (499°C); 600°F lime kiln (beet sugar)(316°C)	MED/ HIGH	MED	Good candidate except high degree of CHP systems
Chemical manufacturing	16.8%	43.0%	32.0%	1.3%	H2, Ammonia - 1550°F furnace (840°C), Ammonia 600°F boiler (315°C); Pharma. 250°F (121°C) boiler, drying; Ethanol cooker/dryer 212°F (100°C) Boiler 250°F (121°C)	HIGH	MED	See text for basic chemicals For example, ammonia, chlorine; and for petro chemicals; high degree of CHP systems
Paper Mills	10.0%	63.3%	21.2%	2.2%	Pulp/Paperboard mill lime kiln 1200F (650C)	HIGH	LOW	High degree of integrated process design (high CHP)
Non-metallic mineral proc	0.6%	1.4%	90.1%	3.2%	Flat glass (2900°F, 1593°C furnace, 1600°F (870°C) final heat treatment; Cement 2700°F (1482°C) dry kiln; Brick 2100°F (1149°C) kiln	HIGH	LOW	Very high temperatures make this challenging but technically possible
Petroleum and coal products manufacturing	11.4%	22.0%	57.9%	0.4%	For example, Catalytic cracking 900°F (482°C), Catalyst reforming 1000°F(538°C), Boiler 422°F (217°C)	HIGH	LOW	Hard b/c high degree of process design and own-use fuel consumption

Source: Berkeley Lab, Electrification of Buildings and Industry in the United States, March 2018

Table C-3 provides a more straightforward breakdown of relevant fuel substitution pursuits by building type, as identified by the National Renewable Energy Laboratory (NREL). While less granular, it provides broader solutions.

Table C-3: Subsectors and End Uses Relevant to Electrification

Industrial Subsector	**End Use**	**Representative Electrotechnology**
All manufacturing industries and agriculture	Building HVAC	Industrial heat pump
All manufacturing industries and agriculture	Machine drive	Electric machine drive
Food, chemicals, transportation equipment, plastics, and other manufacturing	Process heat	Electric boiler
Food	Process heat	Industrial heat pump
Chemicals	Process heat	Resistance heating
Chemicals	Process heat	Industrial heat pump
Glass and glass products	Process heat	Direct resistance melting (electric glass melt furnace)
Primary metals	Process heat	Induction furnace
Transportation equipment	Process heat	Induction furnace
Plastic and rubber products	Process heat	Resistance heating
Plastic and rubber products	Process heat	Infrared processing
Other manufacturing	Process heat	Resistance heating
Other wood products and printing and related support	Process heat: curing	Ultraviolet curing

Source: National Renewable Energy Laboratory, Electrification Futures Study, 2017

Select Fuel Substitution Technologies

In Navigant (now Guidehouse)'s *Energy Technologies for the Food Processing Industry* study (released January 2018), the research team identified specific opportunities that can provide greenhouse gas (GHG) reduction benefits, including fuel substitution technologies. These technologies are transferable to other industrial and agricultural segments, as applicable. These technologies may be a cost-effective and appropriate solution in the future. The study chose to characterize the following fuel substitution technologies because enough information was available:

- Mechanical dewatering
- Heat pump drying
- Large-scale industrial heat pump
- Ohmic heating – the process of heating food by passing electric current
- Induction heating

Mechanical Dewatering

Mechanical dewatering, using mechanical movement to pre-dry or dry product, can reduce the moisture loading on the dryer and save significant amounts of energy. As a rule of thumb, for each 1 percent reduction in product moisture, the dryer energy input can be reduced by up to 4 percent. Mechanical dewatering methods include filtration, using centrifugal force, gravity, mechanical compression, and high-velocity air.

Table C-4: Mechanical Dewatering Cost and Reduction Potential

Metric	Units	Result
Estimated annual energy savings	(% of Site)	1.25% of total therms, with a 0.31% increase in kWh
Estimated measure life	(Years)	15
Cost to implement	($/kWh)	There is insufficient information to properly quantify the cost of this measure.
GHG reduction per site	(Metric Tonnes of CO_2)	124.6–205.7
Estimated percentage of GHG emissions reductions	(%)	0.58%–1.07%
Total Measure Potential	**(Metric Tonnes of CO_2)**	**12,929**

Source: Guidehouse

Table C-5: Mechanical Dewatering Barriers and Recommended Strategies for Implementation

Barriers to Implementation	Recommended Strategies for Implementation
• Lack of process-specific knowledge • High initial cost • Product quality concerns • Potential to affect primary process equipment and require long periods of shut down • Lack of awareness of measure	• Favorable incentives to cover initial cost • Process-specific examples to highlight benefits • Provide process-specific solution

Source: Guidehouse

Heat Pump Drying

Dry heated air is passed continuously over the product; as it picks up moisture, it condenses on the heat pump, giving up the latent heat of vaporization, which is taken up by the refrigerant in the evaporator. This heat is used to reheat the cool dry air passing over the hot condenser of the heat pump.

Table C-6: Heat Pump Drying Cost and Reduction Potential

Metric	Units	Result
Estimated annual energy savings	(% of Site)	5% of total therms, with a 0.83% increase in kWh
Estimated measure life	(Years)	15
Cost to implement	($/kWh)	There is insufficient information to properly quantify the cost of this measure, likely due to the process-specific nature.
GHG reduction per site	(Metric Tonnes of CO_2)	504.0-885.4
Estimated percentage of GHG emissions reductions	(%)	2.51%-4.33%
Total Measure Potential	**(Metric Tonnes of CO_2)**	**53,098**

Source: Guidehouse

Table C-7: Heat Pump Drying Barriers and Recommended Strategies for Implementation

Barriers to Implementation	Recommended Strategies for Implementation
• Reduced load on the boiler but may require maintenance	• Process-specific replacement options • Gas-only incentives to cover initial costs • Process-specific case studies to highlight benefits

Source: Guidehouse

Large-Scale Industrial Heat Pump

A large-scale industrial heat pump is a specialized heat recovery system meant to recover heat from major processes or from ambient air and through the refrigeration cycle to create high-temperature useful heat at high efficiency levels. This system can generate heat four or five times more efficiently than a standard electric boiler.

Table C-8: Large-Scale Industrial Heat Pump Cost and Reduction Potential

Metric	Units	Result
Estimated annual energy savings	(% of Site)	10% of total therms, with a 1.67% increase in kWh
Estimated measure life	(Years)	15
Cost to implement	($/kWh)	There is insufficient information to properly quantify the cost of this measure, likely due to the process-specific nature.
GHG reduction per site	(Metric Tonnes of CO_2)	5.7-1,770.7

Metric	Units	Result
Estimated percentage of GHG emissions reductions	(%)	1.62% - 8.66%
Total Measure Potential	**(Metric Tonnes of CO_2)**	**122,912**

Source: Guidehouse

Table C-9: Large-Scale Industrial Heat Pump Barriers and Recommended Strategies for Implementation

Barriers to Implementation	Recommended Strategies for Implementation
• High initial cost • Detailed understanding of process required to identify opportunities • Lack of visibility of waste heat streams • Uncertainty of savings	• Provide training/experts to understand site-specific opportunities • Provide a highly custom calculation tool • Provide incentives to cover initial cost

Source: Guidehouse

Ohmic Heating

Ohmic heating is an emerging technology and thermal processing method in which an alternating electrical current is passed through products to generate heat internally. Research indicates that ohmic heating is said to produce a uniform, inside-out heating pattern that heats products more evenly than conventional outside-in heating methods.

Table C-10: Ohmic Heating Cost and Reduction Potential

Metric	Units	Result
Estimated annual energy savings	(% of Site)	Not available, dependent on specific application
Estimated measure life	(Years)	15
Cost to implement	($/kWh)	There is insufficient information to properly quantify the cost of this measure. However, the cost to implement ohmic heating is typically less than conventional technologies.
GHG reduction per site	(Metric Tonnes of CO_2)	Not available
Estimated percentage of GHG emissions reductions	(%)	Not available
Total Measure Potential	**(Metric Tonnes of CO_2)**	**Insufficient information to calculate**

Source: Guidehouse

Table C-11: Ohmic Heating Barriers and Recommended Strategies for Implementation

Barriers to Implementation	Recommended Strategies for Implementation
• Lack of in-use data/best practices for industrial application • Potential difficulty in monitoring and control of unit • Complex coupling between temperature and electrical filed distribution	• Pilot units in field to develop data, best practices, and confidence in technology • Develop predictive, determinable, and reliable models of ohmic heating patterns • Develop a reliable feedback control system to adjust the supply power according to the conductivity change in the process stream

Source: Guidehouse

Induction Heating of Liquids

Induction heaters are an established technology that work by dissipating the energy generated when the secondary winding of a transformer is short-circuited, which instantly imparts heat to liquid circulating in a coil around the transformer core.

Table C-12: Induction Heating of Liquids Cost and Reduction Potential

Metric	Units	Result
Estimated annual energy savings	(% of Site)	80%–90% more efficient than a conventional gas fired heater and 15%–20% more efficient than an electric coil heater.
Estimated measure life	(Years)	20
Cost to implement	(\$/kWh)	There is insufficient information to properly quantify the cost of this measure.
GHG reduction per site	(Metric Tonnes of CO_2)	Not available
Estimated percentage of GHG emissions reductions	(%)	Not available
Total Measure Potential	**(Metric Tonnes of CO_2)**	**Insufficient information to calculate**

Source: Guidehouse

Table C-13: Induction Heating of Liquids Barriers and Recommended Strategies for Implementation

Barriers to Implementation	Recommended Strategies for Implementation
• High capital cost • Applicable only to heating relatively simple shapes • Relatively complex peripheral equipment requirements required for operation (impedance matching network, water cooling systems, control electronics)	• Pilot units in field to develop data, best practices, and confidence in technology • Provide rebate program to overcome initial high capital cost of nascent technology

Source: Guidehouse

Gas Boiler vs. Electric Boilers

Many industrial processes are dominated by high-temperature procedures and typically use gas boilers to provide the necessary energy to meet operational needs. In some instances, an electric boiler could meet gas boiler capacity and temperature requirements. Replacing a gas boiler with an electric boiler would require higher operating costs and larger equipment to meet the process requirements. The barriers for electric boilers to meet these requirements are mostly based on energy costs. Table C-14 lists an example of the costs.

Table C-14: Relative Comparison of Electric vs. Gas Boiler

Component	Gas	Electric
Capacity requirements	50 therms	50 therms x 29.3 kWh/therm = 1,465 kWh
Boiler efficiency	80%	99%
Energy cost	$1/therm	$0.20/kWh
Monthly energy cost	$50	$193

Source: Guidehouse analysis; for energy costs: PG&E Electric Schedule A-15 and PG&E Gas Schedule G-NR2

Customers would pay an increase of around four times as much per month if they switched from a gas boiler to an electric boiler. Although an electric boiler is more efficient, the cost of gas per unit of energy is less than that of electricity. This cost may change. Electric boilers and gas boilers are priced similarly; however, electric boilers have lower installation costs for new properties because the cost of providing electric service to an electric boiler is less than installing gas service. Electric boilers are quieter to run and require less maintenance because of an absence of mechanical parts. The decision to pursue electric boilers will depend largely on the cost of electricity from renewable sources and the potential to leverage oversupply conditions and thermal storage opportunities.

Steam Turbine Drive vs. Electric Motor Drive

Machine drives are typically used for direct or indirect product movement, the requirements for which vary widely across the industry. As such, the choice of motor is closely tied to the desired application. Steam-turbine motors are driven primarily by steam generated with carbon fuel combustion, while electric motors are driven by electricity generated from the grid or local generation. Steam-driven turbines, typically pumps, are used for specific applications such as pumping material of varying viscosity. In most cases, the applications limit the replacement of these steam-driven turbines with electric motors, so Guidehouse decided to not pursue this measure.

Table C-15: Steam Turbine vs. Electric Motor

Component	Steam Turbine	Electric Motor
Power output	• Typically capable of higher-output power than an electric motor.	• Typically capable of lower-output power than a steam turbine drive.
Variable speed capability	• Capable of variable speed but typically with a lower range of variability than electric variable-frequency drives and at high cost to efficiency.	• Capable of robust and responsive variability in speed using a variable-frequency drive with some sacrifices in torque with changing speed.
Initial capital cost	• Comparatively high capital cost reliant on source of steam.	• Comparatively low capital cost.
Operating cost	• Continued operating costs via fuel procurement for heat production.	• Continued operating cost via electricity costs.

Source: Guidehouse

Solar Air Heating

Convection via heated air has long been used in industry drying processes. Air is heated for this process using primarily carbon fuels. Solar air heating uses heat from the sun rather than carbon fuels to heat air that then is used to dry foods via convection. This technology is used primarily for food product preservation.[187,188]

Table C-16: Solar Air Heating vs. Gas Heating

Component	Conventional Technology	Solar Air Heating
Product Quality	• Drying is even and continuous	• Drying is even but only capable during sunlight hours (discontinuous)
Initial Capital Cost	• High initial cost of equipment	• High initial cost of equipment

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[187] Eswara, Amruta R., and M. Ramakrishnarao. "Solar Energy in Food Processing — A Critical Appraisal." *Journal of Food Science and Technology*, vol. 50, no. 2, June 2012, pp. 209–227., doi:10.1007/s13197-012-0739-3.

[188] Aravindh, M. A., and A. Sreekumar. "Solar Drying — A Sustainable Way of Food Processing." *Sustainability Through Green Energy Green Energy and Technology,* 2015, pp. 27–46., doi:10.1007/978-81-322-2337-5_2.

Component	Conventional Technology	Solar Air Heating
Operating Cost	• Continued operating costs via fuel procurement for heat production	• No operating cost for heat production
Other		• Higher drying temperatures lead to more complete drying and therefore longer shelf life • Can be easily adopted into carbon fuel systems.

Source: Guidehouse

UV Pasteurization

Sterilization requirements in the food processing industry are typically rigorous internationally. These requirements have historically been achieved using thermal heating of food using carbon fuels. Sterilization/pasteurization using UV light[189] provides an opportunity in industrial processing to reduce the use of carbon fuels, improve the quality of processed goods, and increase the magnitude of sterilization in a given process.

UV pasteurization is most applicable to the dairy, juice, and beverage industries but also has potential application for controlling contamination in meats and egg shells. Many applications are still being tested and validated industrywide, but the low capital and operating cost of the technology, as well as superior resulting food product, make it an attractive emerging technology in the industry. Table C-17 tabulates further comparison between the conventional technology and UV pasteurization.[190]

Table C-17: UV Pasteurization vs. Conventional Technology

Component	Conventional Technology	UV Pasteurization
Product quality	• Some degradation of products	• Minimal collateral effect on products
Initial capital cost	• High initial cost of equipment	• Medium initial capital cost
Operating cost	• Continued operating costs via fuel procurement for heat production	• Lower electricity cost with high energy efficiency

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[189] UV disinfection is a common technology used in advanced recycled water treatment plants in California.

[190] Choudhary, Ruplal, and Srinivasarao Bandla. "Ultraviolet Pasteurization for Food Industry." *International Journal of Food Science and Nutrition Engineering*, vol. 2, no. 1, Jan. 2012, pp. 12–15., doi:10.5923/j.food.20120201.03.

Component	Conventional Technology	UV Pasteurization
Other	• Robust operating ability	• Short processing time • Reliability for different food products to be established • Certain products and process may not be applicable to UV such as pasteurizing cans or canned food

Source: Neetoo, Hudaa, and Haiqiang Chen. "Alternative Food Processing Technologies." *Food Processing*, Nov. 2014, pp. 137–169., doi:10.1002/9781118846315.ch7.

Ozone Cleaning

Ozone cleaning is another sterilization technique that could be used to replace traditional thermal sterilization in food processing. The technology uses UV radiation and corona discharge methods to generate ozone, which is subsequently used as a strong oxidant and potent disinfecting agent.

Ozone cleaning has been used in bottled water processing and has potential application in food surface hygiene and fruit, vegetable, meat, and seafood processing. Table C-18 tabulates further comparison between the conventional technology and ozone cleaning.[191]

Table C-18: Ozone Cleaning vs. Conventional Technology

Component	Conventional Technology	Ozone Cleaning
Food Product Quality	• Some degradation of products	• Reduced weight loss and spoilage of plant products
Initial Capital Cost	• High initial cost of equipment	• High initial capital cost
Operating Cost	• Continued operating costs via fuel procurement for heat production	• Lower electricity cost with high energy efficiency • Continued cost to produce and store ozone (relatively high due to toxicity)
Other	• Robust operating ability	• Short contact time • No hazardous residues in treatment medium • Reliability for different food products to be established

Source: Guidehouse

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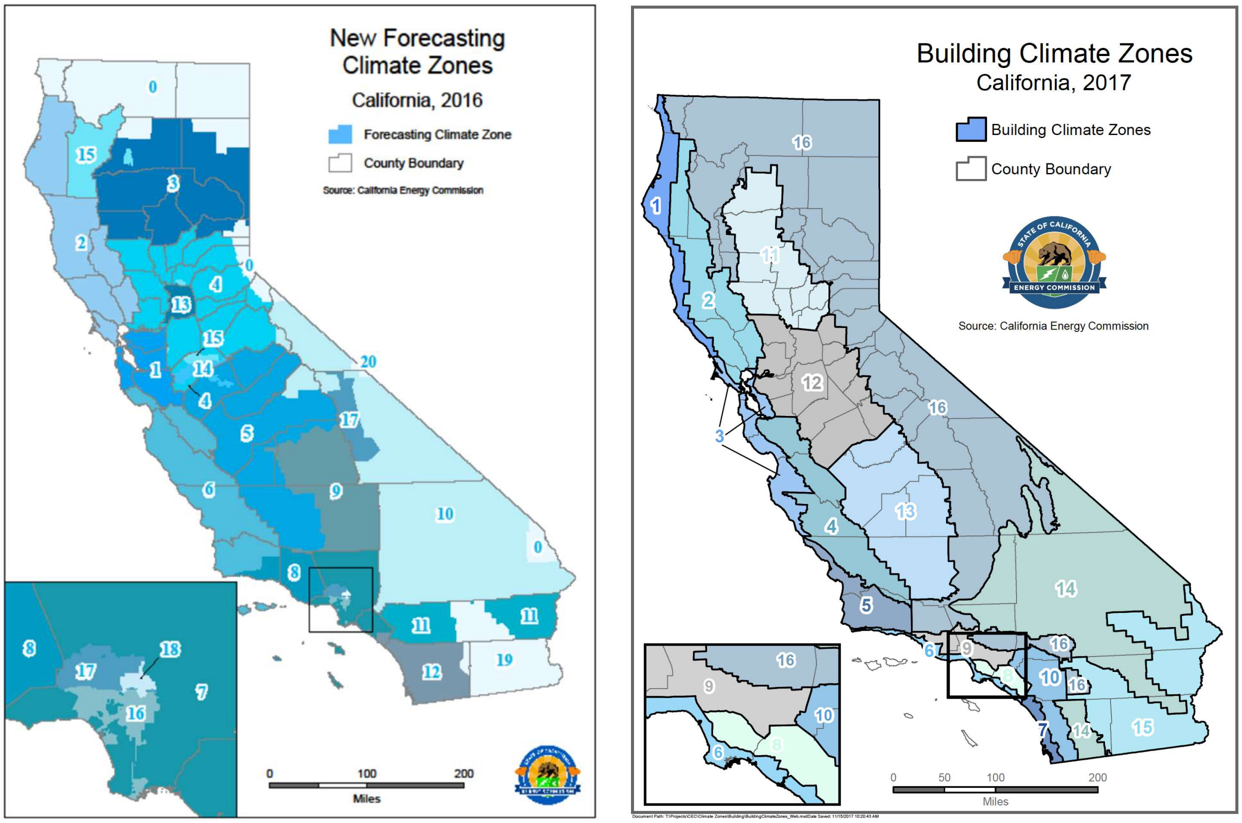
[191] Guzel-Seydim, Zeynep B. January 14, 2004. "Use of Ozone in the Food Industry." *LWT - Food Science and Technology*, Academic Press.

APPENDIX D:
Building Climate Zone to Forecasting Climate Zone

To support statewide locational planning, the team provided the CEC with factors to break down IOU service territory consumption into the CEC's forecasting climate zones (FCZs).[192] The CEC's FCZs are used in the *IEPR* and differ from the building climate zones (BCZs) used in the Database for Energy-Efficient Resources and Title 24 analysis. Both sets of zones are illustrated in Figure D-1, and an overlap map is illustrated in Figure D-2. As shown in Figure D-2, no direct relationship exists between the two systems — each FCZ consists of multiple BCZs and vice versa.

Figure D-1: California Forecasting and Building Climate Zones



This figure shows the FCZ map on the left and BCZ map on the right. There is some overlap of the building and forecast climate zones. The T&D planning is grouped into FCZs, whereas climate impacts on building energy consumption define the geography for the BCZs.
Source: CEC. [Building Climate Zones](#).

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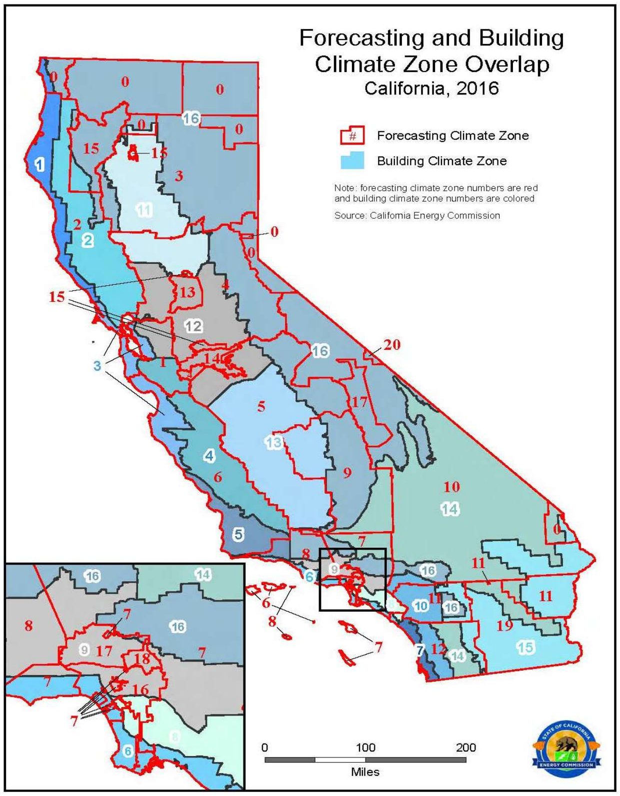
[192] The research team recognizes locational planning often entails more detailed granularity than climate zones. Climate zones are the most detailed level of granularity the Potential and Goals study produces due to its scope.

Figure D-2: California Forecasting and Building Climate Zone Overlap



This figure shows the overlap between the FCZs and BCZs.
Source: CEC. Energy Code Data: Maps

The Potential and Goals model operates using BCZs. The research team conducted analysis to estimate savings at the BCZ level and then translated the findings from BCZs to FCZs before delivering the data.

Outputs varying by BCZ are a function of key input data, building stock and unit energy savings. BCZ variation in building stock comes from the CEC's Demand Analysis Office (further discussed in Section 3.1.2 of the 2019 Potential and Goals Study report[193]). Because savings data are sourced from Database for Energy-Efficient Resources and IOU workpapers, they vary by BCZ (aligning like climate conditions geographically), not by FCZ. Furthermore, not all unit energy savings values vary by BCZ, as Table D-1 shows.

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[193] Navigant Consulting, Inc. July 2019. *2019 Energy Efficiency Potential and Goals Study*, California Public Utilities Commission.

Table D-1: Climate Zone Variation for Unit Energy Savings

Sector	End Use	Unit Energy Savings Varies by BCZ
Commercial	Appliances/Plug Loads	Only for freezer and pool cover
Commercial	Building Envelope	Yes
Commercial	Com. Refrigeration	Yes
Commercial	Data Center	No
Commercial	Food Service	No
Commercial	HVAC	Yes
Commercial	Lighting	No
Commercial	Water Heating	Yes
Commercial	Whole Building	Only for code and zero net energy measures
Residential	Appliances/Plug Loads	Only for refrigerators/freezers and pool pumps
Residential	Building Envelope	Yes
Residential	HVAC	Yes
Residential	Lighting	No
Residential	Water Heating	Yes[194]
Residential	Whole Building	Only for code and zero net energy measures
Agriculture	All	No
Industrial	All	No

Source: Guidehouse

To generate disaggregation percentages by FCZ, the research team followed a two-step process. First, the 2019 Potential and Goals team modified the model to run at the BCZ level. As published, the 2019 Potential and Goals model contains IOU-wide average savings values for all weather-sensitive measures. The analysis team calculated the average savings values by weighting unit energy savings by the building stock in each BCZ. As a result, the IOU-wide average tends to represent the largest BCZs by population. For the AAEE analysis, the research team reimported measure input data at the BCZ level (before the weighted averaging exercise) to run the model at the BCZ level instead of the aggregate IOU level.

The research team ran the model for weather-sensitive end uses (listed above in Table D-1) for AAEE Scenario 3 to produce results that show the percentage distribution of savings for each sector and end-use combination across the BCZs within an IOU territory. Savings disaggregation factors for nonweather-sensitive measures match the BCZ building stock distributions.

The second step was to translate these disaggregation factors from BCZ to FCZ. To do this, the research team mapped IOU customer energy use data at the sector and ZIP code level.

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[194] With the exception of drain water heat recovery and water heating controls, all water heating measures are weather sensitive.

Each ZIP code and the corresponding consumption from the IOUs[195] were mapped to the appropriate BCZs and FCZs based on CEC energy maps[196] and data obtained from the CEC.[197] Each ZIP code corresponds only to a maximum of one BCZ and one FCZ. Some ZIP codes in the IOU datasets did not map to any BCZs or FCZs based on the CEC data. The analysis team proportionally redistributed consumption from these ZIP codes to the other zones within the IOU. From this combined dataset (IOU, sector, ZIP code, BCZ, FCZ, consumption), the team developed tables representing the proportion of consumption from a BCZ that falls within each FCZ.

Table D-2 through Table D-17 show these percentages for residential and commercial and electric and gas. The tables that show FCZ by IOU territory only are normalized such that the translation percentages within each BCZ and IOU sum up to 100 percent. While drafting these tables, the research team noticed that data for commercial gas within BCZs 14 to 16 were vastly different from what was observed in the residential sector for the same BCZs. Digging into the data, the team observed that many of the ZIP codes in the IOU datasets mapping to these BCZs were missing data. These missing data were likely due to data reporting policies set by the CPUC.[198] As a result, the research team assumed commercial gas disaggregation factors are the same as residential for BCZs 14 to 16.

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[195] Quarterly Customer Data Reports available on IOU websites. The research team analyzed values for 2017.

[196] Source: CEC's California energy maps

[197] Chris Kavelec. September 5, 2019. Personal communication.

[198] "Customer Confidentiality: The IOUs are authorized to provide aggregated usage data to the extent customer confidentiality is not compromised. The "15/15 Rule" was adopted by the CPUC in the Direct Access Proceeding (CPUC Decision 97-10-031) to protect customer confidentiality. The 15/15 Rule requires that any aggregated information provided by the IOUs without customer written authorization must be made up of at least 15 customers and a single customer's load must be less than 15 percent of an aggregated category. If the number of customers in any one group falls below 15, or if a single customer's load accounts for more than 15 percent of the total group data, data must be further aggregated before the information is released. If the 15/15 Rule is triggered for a second time after the data has been screened once already using the 15/15 Rule, the Rule further requires that the customer be dropped from the aggregated data. The 15/15 Rule ensures that the identities of larger customers are protected from disclosure." California Public Utilities Commission, October 1997, CPUC Decision 97-10-031.

Table D-2: Translating Building Climate Zone to Forecast Climate Zone: Residential, Electric

FCZ	**BCZ 1**	**BCZ 2**	**BCZ 3**	**BCZ 4**	**BCZ 5**	**BCZ 6**	**BCZ 7**	**BCZ 8**	**BCZ 9**	**BCZ 10**	**BCZ 11**	**BCZ 12**	**BCZ 13**	**BCZ 14**	**BCZ 15**	**BCZ 16**
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	0.0%	0.0%	79.8%	88.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	36.4%	0.0%	0.0%	0.0%	0.0%
2	100.0%	100.0%	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.7%	0.0%	0.0%	0.0%	0.0%	0.7%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	38.9%	0.0%	0.0%	0.0%	0.0%	15.1%
4	0.0%	0.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	57.4%	54.9%	0.0%	0.0%	0.0%	15.9%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.8%	80.2%	0.0%	0.0%	4.8%
6	0.0%	0.0%	15.6%	11.4%	92.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7	0.0%	0.0%	0.0%	0.0%	0.0%	66.9%	0.0%	96.2%	84.5%	0.0%	0.0%	0.0%	0.0%	39.4%	0.0%	6.7%
8	0.0%	0.0%	0.0%	0.0%	7.6%	21.8%	0.0%	0.0%	15.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
9	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	19.8%	8.8%	0.0%	17.0%
10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	34.4%	0.0%	0.0%	0.0%	50.3%	0.6%	38.2%
11	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	40.8%	0.0%	0.0%	0.0%	0.0%	98.2%	1.7%
12	0.0%	0.0%	0.0%	0.0%	0.0%	11.3%	100.0%	3.8%	0.0%	24.9%	0.0%	0.0%	0.0%	1.5%	1.2%	0.0%
13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
14	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
17	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Source: Guidehouse analysis

Table D-3: Translating Building Climate Zone to Forecast Climate Zone: Residential, Electric – PG&E Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
1	0%	0%	80%	89%	0%	0%	0%	0%	0%	0%	0%	36%	0%	0%	0%	0%
2	100%	100%	3%	0%	0%	0%	0%	0%	0%	0%	4%	0%	0%	0%	0%	2%
3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	39%	0%	0%	0%	0%	41%
4	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	57%	55%	0%	0%	0%	43%
5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	9%	100%	0%	0%	13%
6	0%	0%	16%	11%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**0%**	**0%**	**0%**	**0%**	**0%**	**100%**	**100%**	**100%**	**0%**	**0%**	**100%**

Source: Guidehouse analysis

Table D-4: Translating Building Climate Zone to Forecast Climate Zone: Residential, Electric – SCE Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
7	0%	0%	0%	0%	0%	75%	0%	100%	84%	0%	0%	0%	0%	40%	0%	11%
8	0%	0%	0%	0%	100%	25%	0%	0%	16%	0%	0%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	9%	0%	27%
10	0%	0%	0%	0%	0%	0%	0%	0%	0%	46%	0%	0%	0%	51%	1%	60%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	54%	0%	0%	0%	0%	99%	3%
Total	**0%**	**0%**	**0%**	**0%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**0%**	**100%**	**100%**	**100%**	**100%**

Source: Guidehouse analysis

Table D-5: Translating Building Climate Zone to Forecast Climate Zone: Residential, Electric – SDG&E Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
12	0%	0%	0%	0%	0%	100%	100%	100%	0%	100%	0%	0%	0%	100%	100%	0%

Source: Guidehouse analysis

Table D-6: Translating Building Climate Zone to Forecast Climate Zone: Residential, Gas

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	0.0%	0.0%	81.4%	91.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	26.3%	0.0%	0.0%	0.0%	0.0%
2	100.0%	100.0%	2.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	26.5%	0.0%	0.0%	0.0%	0.0%	3.2%
4	0.0%	0.0%	1.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	44.7%	28.2%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	59.0%	8.1%	0.0%	2.3%
6	0.0%	0.0%	14.2%	8.1%	93.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7	0.0%	0.0%	0.0%	0.0%	0.0%	59.6%	0.0%	81.9%	42.9%	0.0%	0.0%	0.0%	0.0%	77.0%	0.0%	6.4%
8	0.0%	0.0%	0.0%	0.0%	7.0%	21.8%	0.0%	0.0%	7.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
9	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.0%	6.6%	0.0%	14.1%
10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	27.4%	0.0%	0.0%	0.0%	8.3%	0.0%	56.6%
11	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	33.5%	0.0%	0.0%	0.0%	0.0%	65.1%	0.0%
12	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	39.2%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	32.4%	0.0%	0.0%	0.0%	0.0%
14	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.7%	0.0%	0.0%	0.0%	0.0%
15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	28.7%	5.4%	0.0%	0.0%	0.0%	0.0%
16	0.0%	0.0%	0.0%	0.0%	0.0%	18.6%	0.0%	18.1%	25.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
17	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	18.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	17.4%
18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	34.8%	0.0%
20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
Total	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**	**100.0 %**

Source: Guidehouse analysis

Table D-7: Translating Building Climate Zone to Forecast Climate Zone: Residential, Gas – PG&E Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
1	0%	0%	81%	92%	0%	0%	0%	0%	0%	0%	0%	26%	0%	0%	0%	0%
2	100%	100%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	27%	0%	0%	0%	0%	58%
4	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	45%	28%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	100%	100%	0%	42%
6	0%	0%	14%	8%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	32%	0%	0%	0%	0%
14	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%	0%	0%	0%
15	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	29%	5%	0%	0%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**0%**	**0%**	**0%**	**0%**	**0%**	**100%**	**100%**	**100%**	**100%**	**0%**	**100%**

Source: Guidehouse analysis

Table D-8: Translating Building Climate Zone to Forecast Climate Zone: Residential, Gas – SoCal Gas Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
7	0%	0%	0%	0%	0%	60%	0%	82%	43%	0%	0%	0%	0%	84%	0%	7%
8	0%	0%	0%	0%	100%	22%	0%	0%	8%	0%	0%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	7%	0%	15%
10	0%	0%	0%	0%	0%	0%	0%	0%	0%	45%	0%	0%	0%	9%	0%	60%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	55%	0%	0%	0%	0%	65%	0%
16	0%	0%	0%	0%	0%	19%	0%	18%	25%	0%	0%	0%	0%	0%	0%	0%
17	0%	0%	0%	0%	0%	0%	0%	0%	18%	0%	0%	0%	0%	0%	0%	18%
18	0%	0%	0%	0%	0%	0%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
19	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	35%	0%
20	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	**0%**	**0%**	**0%**	**0%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**0%**	**100%**	**100%**	**100%**	**100%**

Source: Guidehouse analysis

Table D-9: Translating Building Climate Zone to Forecast Climate Zone: Residential, Gas – SDG&E Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
12	0%	0%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	100%	0%

Source: Guidehouse analysis

Table D-10: Translating Building Climate Zone to Forecast Climate Zone: Commercial, Electric

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	0.0%	0.0%	86.8%	93.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	40.7%	0.0%	0.0%	0.0%	0.0%
2	100.0%	100.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	40.7%	0.0%	0.0%	0.0%	0.0%	11.1%
4	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	58.4%	54.8%	0.0%	0.0%	0.0%	11.8%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.5%	85.0%	0.0%	0.0%	2.6%
6	0.0%	0.0%	10.6%	6.3%	93.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7	0.0%	0.0%	0.0%	0.0%	0.0%	70.6%	0.0%	98.4%	87.9%	0.0%	0.0%	0.0%	0.0%	41.6%	0.0%	2.8%
8	0.0%	0.0%	0.0%	0.0%	6.5%	23.6%	0.0%	0.0%	12.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
9	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15.0%	10.1%	0.0%	18.3%
10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	43.8%	0.0%	0.0%	0.0%	46.7%	0.0%	49.9%
11	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	30.4%	0.0%	0.0%	0.0%	0.0%	100.0%	3.4%
12	0.0%	0.0%	0.0%	0.0%	0.0%	5.8%	100.0%	1.6%	0.0%	25.8%	0.0%	0.0%	0.0%	1.7%	0.0%	0.0%
13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
14	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
17	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: Guidehouse analysis

Table D-11: Translating Building Climate Zone to Forecast Climate Zone: Commercial, Electric – PG&E Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
1	0%	0%	87%	94%	0%	0%	0%	0%	0%	0%	0%	41%	0%	0%	0%	0%
2	100%	100%	1%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	41%	0%	0%	0%	0%	43%
4	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	58%	55%	0%	0%	0%	46%
5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	100%	0%	0%	10%
6	0%	0%	11%	6%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**0%**	**0%**	**0%**	**0%**	**0%**	**100%**	**100%**	**100%**	**0%**	**0%**	**100%**

Source: Guidehouse analysis

Table D-12: Translating Building Climate Zone to Forecast Climate Zone: Commercial, Electric – SCE Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
7	0%	0%	0%	0%	0%	75%	0%	100%	88%	0%	0%	0%	0%	42%	0%	4%
8	0%	0%	0%	0%	100%	25%	0%	0%	12%	0%	0%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	10%	0%	25%
10	0%	0%	0%	0%	0%	0%	0%	0%	0%	59%	0%	0%	0%	47%	0%	67%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	41%	0%	0%	0%	0%	100%	5%
Total	**0%**	**0%**	**0%**	**0%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**0%**	**100%**	**100%**	**100%**	**100%**

Source: Guidehouse analysis

Table D-13: Translating Building Climate Zone to Forecast Climate Zone: Commercial, Electric – SDG&E Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
12	0%	0%	0%	0%	0%	100%	100%	100%	0%	100%	0%	0%	0%	100%	0%	0%

Source: Guidehouse analysis

Table D-14: Translating Building Climate Zone to Forecast Climate Zone: Commercial, Gas

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	0.0%	0.0%	84.4%	91.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	23.8%	0.0%	0.0%	0.0%	0.0%
2	100.0%	100.0%	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	24.2%	0.0%	0.0%	0.0%	0.0%	3.2%
4	0.0%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.3%	30.2%	0.0%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	81.3%	8.1%	0.0%	2.3%
6	0.0%	0.0%	13.7%	8.1%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7	0.0%	0.0%	0.0%	0.0%	0.0%	39.5%	0.0%	96.6%	16.7%	0.0%	0.0%	0.0%	0.0%	77.0%	0.0%	6.4%
8	0.0%	0.0%	0.0%	0.0%	0.0%	57.8%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
9	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	18.7%	6.6%	0.0%	14.1%
10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	63.9%	0.0%	0.0%	0.0%	8.3%	0.0%	56.6%
11	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	28.8%	0.0%	0.0%	0.0%	0.0%	65.1%	0.0%
12	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	7.4%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	30.8%	0.0%	0.0%	0.0%	0.0%
14	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.0%	0.0%	0.0%	0.0%	0.0%
15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	34.5%	6.4%	0.0%	0.0%	0.0%	0.0%
16	0.0%	0.0%	0.0%	0.0%	0.0%	2.7%	0.0%	3.4%	66.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
17	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	15.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	17.4%
18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	34.8%	0.0%
20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: Guidehouse analysis

Table D-15: Translating Building Climate Zone to Forecast Climate Zone: Commercial, Gas – PG&E Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
1	0%	0%	84%	92%	0%	0%	0%	0%	0%	0%	0%	24%	0%	0%	0%	0%
2	100%	100%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	24%	0%	0%	0%	0%	58%
4	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	41%	30%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	100%	100%	0%	42%
6	0%	0%	14%	8%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	31%	0%	0%	0%	0%
14	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%	0%	0%
15	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	34%	6%	0%	0%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**0%**	**0%**	**0%**	**0%**	**0%**	**100%**	**100%**	**100%**	**100%**	**0%**	**100%**

Source: Guidehouse analysis

Table D-16: Translating Building Climate Zone to Forecast Climate Zone: Commercial, Gas – SoCal Gas Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
7	0%	0%	0%	0%	0%	39%	0%	97%	17%	0%	0%	0%	0%	84%	0%	7%
8	0%	0%	0%	0%	0%	58%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	7%	0%	15%
10	0%	0%	0%	0%	0%	0%	0%	0%	0%	69%	0%	0%	0%	9%	0%	60%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	31%	0%	0%	0%	0%	65%	0%
16	0%	0%	0%	0%	0%	3%	0%	3%	66%	0%	0%	0%	0%	0%	0%	0%
17	0%	0%	0%	0%	0%	0%	0%	0%	15%	0%	0%	0%	0%	0%	0%	18%
18	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
19	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	35%	0%
20	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	**0%**	**0%**	**0%**	**0%**	**0%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**0%**	**100%**	**100%**	**100%**	**100%**

Source: Guidehouse analysis

Table D-17: Translating Building Climate Zone to Forecast Climate Zone: Commercial, Gas – SDG&E Territory Only

FCZ	BCZ 1	BCZ 2	BCZ 3	BCZ 4	BCZ 5	BCZ 6	BCZ 7	BCZ 8	BCZ 9	BCZ 10	BCZ 11	BCZ 12	BCZ 13	BCZ 14	BCZ 15	BCZ 16
12	0%	0%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	100%	0%

Source: Guidehouse analysis

Table D-18, Table D-19, Table D-20, and Table D-21 show IOU to FCZ mapping based on consumption for the industrial and agricultural sectors. The research team used commercial data as a proxy for industrial electric, industrial gas, and agricultural gas[199] data. Table D-18, Table D-19, Table D-20, and Table D-21 do not show BCZs because none of the savings for the industrial and agriculture sector are weather-sensitive in the Potential and Goals model, so no BCZ level output is available.

Table D-18: Translating Building Climate Zone to Forecast Climate Zone: Industrial, Electric

FCZ	PG&E	SCE	SDG&E
FCZ 0	0.00%	0.00%	0.00%
FCZ 1	52.07%	0.00%	0.00%
FCZ 2	8.81%	0.00%	0.00%
FCZ 3	2.39%	0.00%	0.00%
FCZ 4	14.23%	0.00%	0.00%
FCZ 5	14.91%	0.00%	0.00%
FCZ 6	7.59%	0.00%	0.00%
FCZ 7	0.00%	64.61%	0.00%
FCZ 8	0.00%	7.83%	0.00%
FCZ 9	0.00%	3.65%	0.00%
FCZ 10	0.00%	13.45%	0.00%
FCZ 11	0.00%	10.46%	0.00%
FCZ 12	0.00%	0.00%	100.00%
FCZ 13	0.00%	0.00%	0.00%
FCZ 14	0.00%	0.00%	0.00%
FCZ 15	0.00%	0.00%	0.00%
FCZ 16	0.00%	0.00%	0.00%
FCZ 17	0.00%	0.00%	0.00%
FCZ 18	0.00%	0.00%	0.00%
FCZ 19	0.00%	0.00%	0.00%
FCZ 20	0.00%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**

Source: Guidehouse analysis

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[199] Agricultural electric mapping is available directly from the IOUs with no need for additional analysis.

Table D-19: Translating Building Climate Zone to Forecast Climate Zone: Agricultural, Electric

FCZ	**PG&E**	**SCE**	**SDG&E**
FCZ 0	0.00%	0.00%	0.00%
FCZ 1	0.00%	0.00%	0.00%
FCZ 2	2.68%	0.00%	0.00%
FCZ 3	4.23%	0.00%	0.00%
FCZ 4	15.42%	0.00%	0.00%
FCZ 5	54.92%	0.00%	0.00%
FCZ 6	22.75%	0.00%	0.00%
FCZ 7	0.00%	2.64%	0.00%
FCZ 8	0.00%	20.67%	0.00%
FCZ 9	0.00%	59.26%	0.00%
FCZ 10	0.00%	7.92%	0.00%
FCZ 11	0.00%	9.51%	0.00%
FCZ 12	0.00%	0.00%	100.00%
FCZ 13	0.00%	0.00%	0.00%
FCZ 14	0.00%	0.00%	0.00%
FCZ 15	0.00%	0.00%	0.00%
FCZ 16	0.00%	0.00%	0.00%
FCZ 17	0.00%	0.00%	0.00%
FCZ 18	0.00%	0.00%	0.00%
FCZ 19	0.00%	0.00%	0.00%
FCZ 20	0.00%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**

Source: Guidehouse analysis

Table D-20: Translating Building Climate Zone to Forecast Climate Zone: Industrial, Gas

FCZ	PG&E	SCE	SDG&E
FCZ 0	0.00%	0.00%	0.00%
FCZ 1	51.10%	0.00%	0.00%
FCZ 2	7.30%	0.00%	0.00%
FCZ 3	1.61%	0.00%	0.00%
FCZ 4	11.69%	0.00%	0.00%
FCZ 5	7.66%	0.00%	0.00%
FCZ 6	5.28%	0.97%	0.00%
FCZ 7	0.00%	36.90%	0.00%
FCZ 8	0.00%	6.98%	0.00%
FCZ 9	0.00%	1.57%	0.00%
FCZ 10	0.00%	18.07%	0.00%
FCZ 11	0.00%	9.56%	0.00%
FCZ 12	0.00%	0.00%	100.00%
FCZ 13	8.98%	0.00%	0.00%
FCZ 14	2.32%	0.00%	0.00%
FCZ 15	4.06%	0.00%	0.00%
FCZ 16	0.00%	20.93%	0.00%
FCZ 17	0.00%	4.61%	0.00%
FCZ 18	0.00%	0.41%	0.00%
FCZ 19	0.00%	0.00%	0.00%
FCZ 20	0.00%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**

Source: Guidehouse analysis

Table D-21: Translating Building Climate Zone to Forecast Climate Zone: Agricultural, Gas

FCZ	PG&E	SCE	SDG&E
FCZ 0	0.00%	0.00%	0.00%
FCZ 1	51.10%	0.00%	0.00%
FCZ 2	7.30%	0.00%	0.00%
FCZ 3	1.61%	0.00%	0.00%
FCZ 4	11.69%	0.00%	0.00%
FCZ 5	7.66%	0.00%	0.00%
FCZ 6	5.28%	0.97%	0.00%
FCZ 7	0.00%	36.90%	0.00%
FCZ 8	0.00%	6.98%	0.00%
FCZ 9	0.00%	1.57%	0.00%
FCZ 10	0.00%	18.07%	0.00%
FCZ 11	0.00%	9.56%	0.00%
FCZ 12	0.00%	0.00%	100.00%
FCZ 13	8.98%	0.00%	0.00%
FCZ 14	2.32%	0.00%	0.00%
FCZ 15	4.06%	0.00%	0.00%
FCZ 16	0.00%	20.93%	0.00%
FCZ 17	0.00%	4.61%	0.00%
FCZ 18	0.00%	0.41%	0.00%
FCZ 19	0.00%	0.00%	0.00%
FCZ 20	0.00%	0.00%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**

Source: Guidehouse analysis

APPENDIX E:
Building Stock Description

Building stock data are the total population metrics of a given sector. Residential building stocks are based on the number of households in a utility service territory. Commercial building stocks are represented by total floor space for each commercial building type. Industrial and agricultural building stocks are represented by energy consumption. The residential, commercial, industrial, and agriculture building stock metrics are derived from the CEC's IEPR.

The FSSAT requires building stocks by sector, scenario, and utility for 2013 – 2030. Table E-1 lists the building stocks characterized by IEPR and used in the FSSAT. The FSSAT does not differentiate the industrial and agricultural sectors into building types.

Table E-1: Integrated Energy Policy Report Characterized Building Stock by Sector and Building Type

Sector	Building Type
Residential	Res - Single Family
Residential	Res - Multi Family
Commercial	Com - College
Commercial	Com - Grocery
Commercial	Com - Health
Commercial	Com - Lodging
Commercial	Com - Office (Large)
Commercial	Com - Other
Commercial	Com - Refrig. Warehouse
Commercial	Com - Restaurant
Commercial	Com - Retail
Commercial	Com - School
Commercial	Com - Office (Small)
Commercial	Com - Warehouse

Source: Guidehouse

APPENDIX F:
Fuel Substitution Technology Characterization

Characterization Method

This appendix describes the technology characterization the research team used to develop an analytical framework. The team used this analytical framework to understand the opportunities for fuel substitution in California. The research team completed characterization for two main environments: the existing natural gas technology environment and the existing/emerging electric technology environment. This study considers fuel substitution for building decarbonization in the residential, commercial, agricultural, and industrial sectors. The residential and commercial sectors are characterized at a technology level, while the agricultural and industrial sectors are characterized at an end-use level. For these reasons, the residential and commercial sectors characterization and the agricultural and industrial sectors characterization follow different methods and are discussed separately.

- **Natural gas technology environment:** As part of the 2019 CPUC Potential and Goals study, the research team characterized the natural gas technology environment for the three California natural gas IOUs.[200] This study characterized more than 100 gas technologies spanning the residential, commercial, agricultural, and industrial sectors. The team used this dataset to understand and quantify the natural gas technology environment for this work.
- **Electric technology environment:** The research team used existing electric replacement technology characterization where available in the 2019 CPUC Potential and Goals study. For technologies where no prior characterization was available, the team developed new performance and cost characterizations.

Residential and Commercial Natural Gas Technology

The research used the technology characterization work completed for the 2019 CPUC Potential and Goals study to develop the natural gas technology list and key metrics for this study.

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[200] Navigant Consulting, Inc. July 2019. *2019 Energy Efficiency Potential and Goals Study*, prepared for the California Public Utilities Commission.

Technology List

As part of the Potential and Goals study, the team had characterized the natural gas technologies, provided in Table F-1 and Table F-2, at the sector, end-use, utility, building, and climate zone levels.

Table F-1: Residential Natural Gas Technology List

End Use	Natural Gas Technologies
Space Heating	Furnace*
Space Heating	Condensing Furnace
Water Heating	Gas Storage Water Heater*
Water Heating	Condensing Gas Storage Water Heater
Water Heating	Instantaneous Gas Water Heater
Laundry	Gas Clothes Dryer*

***This technology is characterized at multiple efficiency levels.**

Source: Guidehouse

Table F-2: Commercial Natural Gas Technology List

End Use	Natural Gas Technologies
Space Heating	Furnace*
Space Heating	Condensing Furnace
Space Heating	Boiler*
Space Heating	Condensing Boiler
Water Heating	Gas Storage Water Heater*
Water Heating	Condensing Gas Storage Water Heater
Water Heating	Instantaneous Gas Water Heater
Water Heating	Gas Water Heating Boiler*
Water Heating	Condensing Gas Water Heating Boiler
Cooking	Convection Oven*
Cooking	Steamer*
Cooking	Fryer*
Laundry	Gas Clothes Dryer*

***This technology is characterized at multiple efficiency levels.**

Source: Guidehouse

Key Metrics

Characterizing technologies involves developing the various inputs for each technology to calculate potential impact on electricity and gas consumption as well as the associated costs. Table F-3 summarizes the key metrics the research team used to characterize the gas environment technologies.

Table F-3: Key Metrics for Measure Characterization

Metrics	Brief Description
Technology Description	• Sector • End use • Climate zone • Segment/building type • Replacement type
Energy Use	• Annual gas consumption (therms) • Annual electric consumption (kWh), as applicable
Technology Costs	• Equipment cost • Installation cost
Market Information	• Density associated with the technology group • Saturation for individual technologies
Other Items	• Technology lifetime

Source: Guidehouse

While all characterized metrics are important, the density and saturation are particularly significant for a fuel substitution analytical framework. The residential and commercial gas environments provide the foundation upon which the electric environment is built, so a quantitative understanding of technology density and saturation is essential to determining the amount of available capacity for replacement.

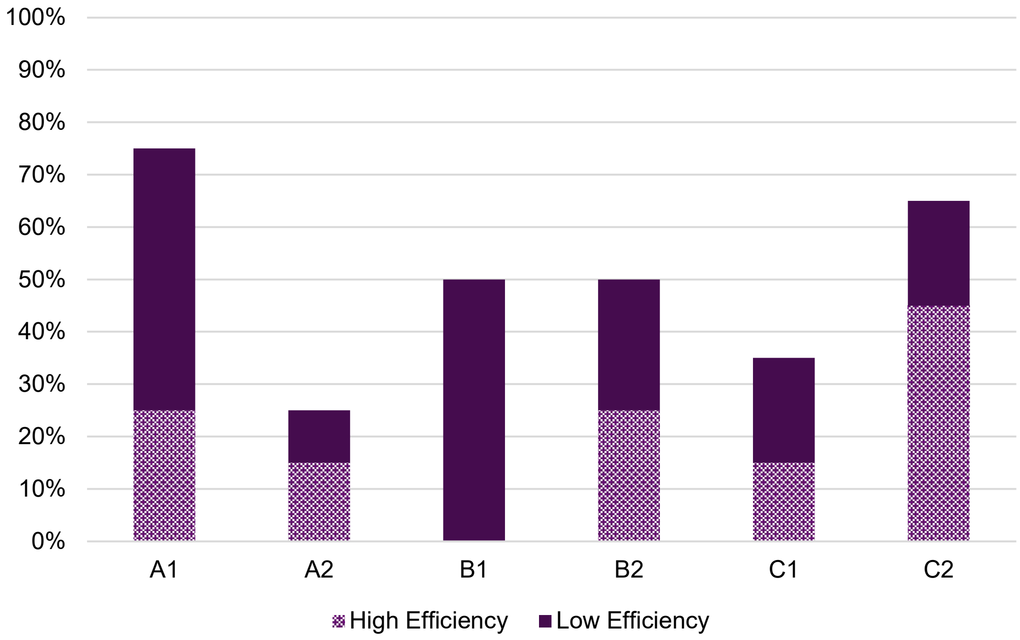
- “Technology density” is defined as the total number of measure units with the scaling basis (residential — per home, commercial — per 1,000 square feet of floor area, industrial and agricultural — per kWh of sector consumption). A residential example would be the number of gas furnaces or the kBtuh of heating per home. These data are derived from market studies and are considered the market average defined by the scaling basis for the sector.
- “Technology saturation” (illustrated in Figure F-1) is defined as the percentage or share of a technology type within the total maximum density. An example would be 70 percent of gas furnaces are standard efficiency, while the other 30 percent are high efficiency. Saturation percentages for each efficiency level of the same technology type sum up to 100 percent.

Equation F-1 shows the calculation for each technology by efficiency. The technology density (unit per household or per 1,000 square feet) is independent of efficiency level.

Equation F-1: Technology Energy Consumption

$$Technology\ Energy\ Consumption = Density \times (Saturation\ Efficiency\ \times Unit\ Energy\ Consumption)_{Efficiency\ Level}$$

Figure F-1: Illustration for Efficiency Saturation by Technology



This stacked bar chart illustrates saturation by technology. For example, Technology A1 has 75 percent penetration in buildings, and Technology A2 has 25 percent. Each technology group adds up to 100 percent.
Source: Guidehouse

The PG study sources of saturation and density values are from a variety of sources. Table F-4 lists the resources used for density and saturation in the residential and commercial sectors in 2017.[201] The research team used primarily California-specific sources for density and saturation data and referred to non-California sources only in cases California-specific sources did not have the required data.

Table F-4: Sources for Potential and Goals Study Density and Saturation Characterization

Sources	**Description**
2012 California Lighting & Appl. Saturation Survey	Residential baseline study of 1,987 homes across California.
2012 Commercial Saturation Survey	Baseline study of 1,439 commercial buildings across California.
2009 Residential Appliance Saturation Study (RASS)[202]	Residential end-use saturations for 24,000 households in California. Planned study update in 2020.

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[201] Even though a more recent Potential and Goals study has been completed since 2017, the research team used the 2017 data because the *2017 IEPR* is the basis for the current scenario analysis. Furthermore, the data sources for the 2019 and 2017 Potential and Goals studies have not changed.

[202] The team referred to this source only in cases where *Commercial Lighting and Appliance Saturation Survey* and *Commercial Saturation Survey* did not have the required data.

Sources	Description
2014 Northwest Energy Efficiency Alliance: • Residential Building Stock Assessment • Comm. Building Stock Assessment	Residential Building Stock Assessment and Commercial Building Stock Assessment survey residential and commercial building stock, respectively, across the Northwest states (Idaho, Montana, Oregon, Washington).
2009 U.S. Department of Energy:* • Res. Energy Consumption Survey (RECS) • Comm. Bldg. Energy Cons. Survey (CBECS)	RECS and CBECS are surveys of residential and commercial building stock in the United States by region. Used west regional data only. Next update is pending for the 2018 CBECS.
Environmental Protection Agency 2003-2016 ENERGY STAR Shipment Database	Unit shipment data of ENERGY STAR-certified products collected to evaluate market penetration and performance.

***Updates for RECS in 2015 and CBECS in 2012 may not have included the data points used for the Potential and Goals study. The Potential and Goals study used only 2009 datasets.**
Source: Guidehouse

Further information about key metrics and data sources for the 2019 CPUC Potential and Goals study are available via the publicly available report.[203]

Residential and Commercial Electric Environment

Technology List

The research team considered a broad set of residential and commercial fuel substitution technologies when developing the final technology list. In coordination with CEC staff, the team prioritized this list to a final technology list (for characterization in this version of the FSSAT) based on the relative impact of a given technology and project capacity. The final technology list is presented in Table F-5 and Table F-6 (split by residential and commercial); the tables include the full reviewed list, noting which technologies are included in the current analytical framework. The final analytical framework will allow adding new technology characterization as they are developed.

Table F-5: Residential Electric Technologies

End Use	Electric Technologies Reviewed	Electric Technologies Included (Y/N)
Space Heating	Standard and High Efficiency Packaged/Split Heat Pump	Y
Space Heating	Standard and High-Efficiency, Variable-Capacity Heat Pump	Y
Space Heating	Radiant Heating	N
Space Heating	Space and Water Heating Combination Systems	N

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[203] Navigant Consulting, Inc. July 2019. *2019 Energy Efficiency Potential and Goals Study*, for the California Public Utilities Commission.

End Use	Electric Technologies Reviewed	Electric Technologies Included (Y/N)
Space Heating	Packaged Terminal Heat Pump	Y
Space Heating	Layered Envelope Improvements [a]	Y
Water Heating	Small Electric Water Heater (0.86, 0.88 and 0.93 EF)	Y
Water Heating	Tankless Resistance Water Heater	Y
Water Heating	Heat Pump Water Heater (>= 2.0 EF)	Y
Water Heating	Solar Water Heater	N
Water Heating	Space and Water Heating Combination Systems	N
Cooking	Electric Cooktop (Resistance)	Y
Cooking	Electric Range (Resistance)	Y
Cooking	Electric Cooktop (Induction Heating)	Y
Laundry	Heat Pump Clothes Dryer	Y

[a] Layered envelope improvements indicate separate technology characterization for each specified space-heating technology operating in a building with an improved envelope.
Source: Guidehouse

Table F-6: Commercial Electric Technologies

End Use	Electric Technologies Reviewed	Electric Technologies Included (Y/N)
Space Heating	Standard and High-Efficiency Variable Capacity Heat Pump	Y
Space Heating	Geothermal Heat Pump	N
Space Heating	Standard and High-Efficiency Packaged Rooftop Unit Heat Pump	Y
Space Heating	Standard and High-Efficiency Split System Heat Pump	Y
Space Heating	Variable-Refrigerant-Flow Systems	N
Space Heating	Packaged Terminal Heat Pump (PTHP)	Y
Space Heating	Layered Envelope Improvement [a]	N
Water Heating	Tankless Electric Resistance Water Heater	Y
Water Heating	Electric Resistance Water Heater (0.86, 0.88 and 0.93 EF)	Y
Water Heating	Heat Pump Water Heater	Y
Water Heating	Pool Heating Equipment	N
Cooking	Electric Fryer/Broiler	Y
Cooking	Electric Stove	N
Cooking	Electric Oven	Y
Cooking	Electric Overhead Broiler	N

End Use	Electric Technologies Reviewed	Electric Technologies Included (Y/N)
Cooking	Electric Griddles	N
Cooking	Combination Oven	N
Laundry	Electric Dryer	N

[a] **Layered envelope improvements indicate separate technology characterization for each specified space-heating technology operating in a building with an improved envelope.**
Source: Guidehouse

The technology list does not include cold climate heat pumps. More than 95 percent of the heating load in California is in climate zones where standard heat pumps perform sufficiently.[204] Cold climate zone heat pumps might be appropriate for parts of California (for example, building Climate Zone 16) but are not included in the scope of this study because of the low impact of the measure compared to other heat pump technologies.

Key Metrics

The key metrics used to characterize the fuel substitution measures include performance characteristics and costs. For electric technologies in the Potential and Goals study, the research team can provide similar characterization as to the gas counterparts. The electric environment for this study is characterized differently, as described here.

- Performance characteristics, such as those included in the sub bullets in this section, define electric technologies in terms of heating value provided compared to heating value of the fuel consumed. The performance characteristics can be used to approximate the expected electric consumption of the electric technology when no consumption data are available. The following bullets are the performance metrics for all electric technologies characterized.
    - Energy factor (EF)
    - Combined energy factor (CEF)
    - Annual fuel utilization efficiency (AFUE)
    - Energy efficiency ratio (EER)
    - Seasonal energy efficiency ratio (SEER)
    - Fuel efficiency
    - Heating seasonal performance factor (HSPF)
    - Coefficient of performance (COP)

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204 Navigant Consulting. *Research, Development, and Demonstration (RD&D) Opportunities for Heat Pump Technologies - DRAFT.* California Energy Commission. Report is not yet published.

Table F-7: Residential and Commercial Electric Technology Performance Metrics

End Use	Performance Metric
Space Heating	HSPF, SEER, EER, COP
Water Heating	EF, COP
Cooking	EF, COP
Laundry	EF, COP

Source: Guidehouse

- Electric technology costs encapsulate equipment costs, installation costs, and contractor overhead and profit.
    - Equipment costs are defined as the capital cost of the specific technology.
    - Installation costs are defined as the cost of labor and additional equipment, including wiring costs where pertinent, needed to install the specific technology.
    - Contractor overhead and profit costs are defined as the additional costs required to allow contractors to sustain their businesses though profits.

Broadly, the research team characterized the performance characteristics and costs using one of two methods:

- For electric measures that existed in the 2019 CPUC Potential and Goals study database, where possible, the team mapped measures in the replacement technology environment to an electric measure for which performance factors (that is, HSPF, EF, and so forth), values, or costs were readily available. For electric measures that were characterized in the Potential and Goals study, all metrics that are referenced in Table F-3 are readily available.
- For measures in the electric technology environment for which there were no performance factors or costs identified in the Potential and Goals study database, the team reviewed reputable alternative sources to develop the characterizations.
    - Performance factors were typically extracted from sources including Title 24 Building Codes and Title 20 Appliance Efficiency Regulations, other state and federal guidance documents, and industry sources and other Web materials. The team compared the materials for consistency of reported values. Commonly used conversion factors for each type of performance factor were then used to convert common performance values to general COPs. The COP represents the ratio of the useful heating value produced by the technology to the heat value of the fuel supplied to the technology.
    - The team developed material costs from a Web market review of retail prices from relevant dealer websites or recent IOU workpapers. See Table F-12 for detailed source(s) by measure.
    - Installation costs (that is, labor costs) were developed from RSMeans estimates of labor hours to complete an installation task multiplied by a labor wage rate for

relevant trade labor. The RSMeans data are indexed to 2019 using the producer price index.[205] See Table F-12 section for detailed source(s) by measure.

- The team estimated contractor overhead and profit by multiplying wage rates by a factor that accounted for applied time (that is, utilization), contractors' overhead on labor, and profit. Separate overhead and profit factors of 2.48 and 3.13 were used for commercial and residential markets, respectively, as shown in Table F-8.

Table F-8: Method for Developing Overhead and Profit Costs

Factor	Commercial	Residential
Average Base Wage Rate	$28.50	$28.50
Applied Time	90%	80%
Direct Labor Cost per Billable Hour	$31.67	$35.63
Contractor Overhead on Labor	90%	100%
Overhead per Billable Hour	$28.50	$35.63
Break Even Labor Cost per Hour	$60.17	$71.25
Profit	15%	20%
Fully Loaded Cost per Hour	$70.78	$89.06
Overhead and Profit Multiplier	2.48	3.13

Source: The Bureau of Labor Statistics for California

Space-Heating Heat Pump Performance Curves

The research team developed space-heating heat pump performance curves to predict more accurately heat pump performance in California climate zones. The performance of the heat pump varies linearly with inlet air temperature for air source heat pumps. Heat pump performance, rated most commonly in HSPF, is rated by the manufacturer according to climate regions defined by the Code of Federal Regulations.[206] Specifically, heat pumps use Region IV to define HSPF. In California, climate zones are typically milder than those defined for Region IV;[207] 43 percent of heating hours in Region IV are above 47ºF, while California's coldest climate zone records 49 percent of heating hours above 47ºF, according to typical meteorological year (TMY3) data.[208] Because heat pump performance improves with higher temperatures, it is expected that effective heat pumps will perform better, on average, in all California climate zones compared to the rated performance based on Region IV.[209]

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[205] "RSMeans" is a cost-estimating database often used in construction or research applications.

[206] "Table 20—Generalized Climatic Region Information, Part 430: Energy Conservation Program for Consumer Products," The Electronic Code of Federal Regulations. Updated as of February 3, 2020.

[207] Pacific Energy Center. October 2006. *The Pacific Energy Center's Guide to California Climate Zones and Bioclimatic Design*.

[208] Typical meteorological year data are weather data for a location generated to reflect the typical range experienced in that location.

[209] "Heat Pump Systems," *Energy Saver*, U.S. Department of Energy, accessed September 2019.

The team used data from manufacturer performance ratings at various temperatures to develop linear regressions of heat pump performance as a function of outdoor air temperature. These performance curves were developed for two residential heat pump technologies and two commercial heat pump technologies, as presented in Table F-9 and Table F-10. Performance curves were developed for heat pump categories to the extent that data were publicly available from manufacturers.

Table F-9: Performance Curve Residential Heat Pump Technology List

Technology Performance Curve	Applicable Technologies
Heat Pump	Packaged/Split Heat Pumps
Heat Pump	Variable Capacity Heat Pump
Heat Pump	Packaged Terminal Heat Pump
Efficient Heat Pump	Efficient Packaged/Split Heat Pumps
Efficient Heat Pump	Efficient Variable Capacity Heat Pump

Source: Guidehouse

Table F-10: Performance-Curve Commercial Heat Pump Technology List

Technology Performance Curve	Applicable Technologies
Packaged Rooftop Unit Heat Pump	Packaged Rooftop Unit Heat Pump – Air Source
Packaged Rooftop Unit Heat Pump	High-Efficiency Packaged Rooftop Unit Heat Pump – Air Source
Split-System Heat Pump	Variable-Capacity Heat Pump
Packaged Rooftop Unit Heat Pump	High-Efficiency Variable-Capacity Heat Pump
Packaged Rooftop Unit Heat Pump	Split-System Heat Pump – Air Source
Packaged Rooftop Unit Heat Pump	High-Eff. Split System Heat Pump – Air Source
Packaged Rooftop Unit Heat Pump	Packaged Terminal Heat Pump

Source: Guidehouse

The research team developed performance curves for a standard heat pump and efficient heat pump in the residential sector and a packaged rooftop unit heat pump and split-system heat pump in the commercial sector. Ideally, unique performance curves are developed for each characterized technology. Because of limited publicly available data, the team developed generalized performance curves applicable to multiple heat pump technologies — for example, variable-capacity heat pumps. As more publicly available manufacturer data become available, the team recommends that more specific performance curves be developed.

The team applied each-heat pump performance curve to California BCZs based on TMY3 weather data.[210] Using TMY3 data, the team translated hourly temperatures to equivalent COP values for each heat pump technology using the developed heat pump performance curves. The team averaged the hourly COP data to develop effective COP values for each California climate zone. The team used the effective COP values to characterize effective heat pump performance values specific to California climate zones for each heat pump space-heating technology.

Agricultural and Industrial Natural Gas and Electric Consumption Baseline

The team characterized the agricultural and industrial sectors differently than the residential and commercial sectors. The characterization of fuel substitution in these sectors was based on a percentage increase of electric consumption coincident with a percentage decrease in gas consumption. As such, the baseline environment consists of the total natural gas and electricity consumption for these sectors. The characterization workbooks use the 2019 CPUC Potential and Goals study global data to build the agricultural and industrial total consumption environment.

Agricultural and Industrial Electric Replacement

The research team identified the highest impact electric replacement end uses in the agricultural and industrial sectors to characterize. The team based the potential for impact according to the percentage of gas consumption by end use in these sectors provided in Figure 10. The end uses chosen for the agricultural sector represent 73 percent of total sector gas consumption, and the end use chosen for industrial represents 39 percent of total sector gas consumption, as presented in Table F-11.

Table F-11: High-Impact Agricultural and Industrial End Uses Selected for Characterization

Sector	End Use	Percentage of End-Use Natural Gas Consumption
Agricultural	Water Heating	38%
Agricultural	HVAC	35%
Industrial	Process Heating	39%

Source: Guidehouse

The Industrial Assessment Center[211] database was used in combination with professional judgement as the primary source to characterize these end uses. The Industrial Assessment Centers are university-based groups that complete audits for the industrial sector. These centers complete hundreds of audits resulting in thousands of measure recommendations each year. These centers have characterized more than 300,000 measures since the 1970s. This

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[210] National Renewable Energy Laboratory. *National Solar Radiation Data Base: 1991—2005 Update: Typical Meteorological Year* 3, accessed 2019.

[211] Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy (DOE). "Industrial Assessment Centers (IACs)," accessed 2019.

database is used to develop gas energy savings, electric energy increases, and the costs associated with electric replacement of technologies in these end-use groups.

- “Gas energy savings” are defined as the percentage of total end-use gas consumption that can be saved per year by installing electric replacement technologies.
- Electric energy savings are defined as the percentage of total end-use electric consumption that will be added per year by installing electric replacement technologies.
- Costs of electric replacement are quantified here on a per-therm-of-total-consumption basis.

In some cases, the electric replacement technologies assumed for a given end use contain emerging technologies not yet prevalent in the market (for example, ohmic heating, ozone cleaning). To account for this, technologies on similar market timelines are put into end-use buckets and are characterized as a unique end-use line item with the average first year available used in the characterization.

Data Sources

Table F-12 summarizes the primary sources used to characterize the installation costs and COPs of each measure.

Table F-12: Data Sources by Technology

Measure	Material Costs	Installation Costs	COP
Res. Packaged/Split Heat Pump (SEER 18)	2019 Potential and Goals Study	2019 Potential and Goals Study	Title 24
Res. Variable-Capacity Heat Pump (SEER 21)	2019 Potential and Goals Study	2019 Potential and Goals Study	Market Review
Res. Variable-Capacity Heat Pump (Code)	Market Review	RSMeans	Market Review
Res. PTHP (7000 Btu/h)	Market Review	RSMeans	Title 24
Res. Electric Resistance Cooktop	Market Review	RSMeans	Title 24
Res. Electric Resistance Oven	Market Review	RSMeans	Market Review
Res. Induction Cooktop	Market Review	RSMeans	Market Review
Res. Small Electric Storage Water Heater (0.86 EF - 50 Gal)	Market Review	Market Review	Market Review
Res. Small Electric Storage Water Heater (0.90 EF - 50 Gal)	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study
Res. High-Eff. Small Electric Storage Water Heater (0.93 EF - 50 Gal)	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study
Res. Heat Pump Water Heater (>= 3.24 EF - 50 Gal)	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study

Measure	Material Costs	Installation Costs	COP
Res. Tankless Electric Water Heater (Code)	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study
Res. Clothes Dryer — 3.01 CEF	Market Review	RSMeans	Market Review
Res. Clothes Dryer — 3.73 CEF	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study
Res. Efficient Clothes Dryer — 3.93 CEF	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study
Res. Heat Pump Clothes Dryer	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study
Res. Tankless Electric Water Heater (Code)	Market Review	Market Review	Market Review
Com. Split System HP — Air Source (SEER 13)	Market Review	RSMeans	Market Review
Com. Split System HP — Air Source (SEER 18)	2019 Potential and Goals Study	2019 Potential and Goals Study	Title 24
Com. Packaged Rooftop Unit Heat Pump — Air Source (EER 10.3)	2019 Potential and Goals Study	2019 Potential and Goals Study	Market Review
Com. Packaged Rooftop Unit Heat Pump — Air Source (IEER 15)	2019 Potential and Goals Study	2019 Potential and Goals Study	Title 24
Com. Packaged Terminal Heat Pump (14,000 Btu/h)	2019 Potential and Goals Study	2019 Potential and Goals Study	Market Review
Com. Variable-Capacity Heat Pump (SEER 13)	Market Review	RSMeans	Title 24
Com. Variable-Capacity Heat Pump (SEER 21)	Market Review	RSMeans	Title 24
Com. Variable Refrigerant Flow Heat Pump	Market Review	RSMeans	Market Review
Com. Energy-Efficient Electric Commercial Fryer	2019 Potential and Goals Study	2019 Potential and Goals Study	Title 24
Com Standard Convection Oven — Electric	Workpaper	RSMeans	Workpaper
Com. Small Electric Storage Water Heater (0.86 EF — 50 Gal)	Workpaper	RSMeans	Workpaper
Com Small Electric Storage Water Heater (0.88 EF - 50 Gal)	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study
Com. High-Eff. Small Electric Storage Water Heater (0.93 EF - 50 Gal)	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study
Com. Heat Pump Water Heater (>= 2.0 EF - 50 Gal)	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study

Measure	Material Costs	Installation Costs	COP
Com. Tankless Electric Water Heater (Code)	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study
Com. Average Existing Electric Clothes Dryer	Market Review	RSMeans	Market Review
Com. Code-Compliant Electric Clothes Dryer	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study
Com. Electric Clothes Dryer — High-Efficiency	2019 Potential and Goals Study	2019 Potential and Goals Study	2019 Potential and Goals Study

Source: Guidehouse

The following provides additional data on various sources:

- The 2019 Potential and Goals study costs for material and installation costs are as recorded in the study database and were obtained from the Itron — 2010–2012 WO017 — Ex Ante Measure Cost Study.[212] The research team did not adjust these costs for inflation as part of the characterization, but they will be adjusted in the model.
- The RSMeans Electrical Cost Data and RSMeans Mechanical Cost Data database provided labor hours for relevant installation tasks.
- The PG&E workpaper PGECOFST102[213] provided the energy efficient electric commercial fryer material costs. Costs represent estimated equipment costs; they are based on list cost data for electric and gas fryers and apply an industry standard 50 percent discount to the manufacturer published list prices, as discussed in the workpaper at Table 12.
- The SDG&E workpaper WPSDGENRCC0006[214] provided the standard convection oven material costs.
- The team conducted a Web market review of equipment providers for various equipment; the most used sites are listed below. List prices were recorded, and the team excluded outliers if cost factors, such as efficiency rating, could not be clearly identified.
  - eComfort.com at https://www.ecomfort.com/
  - Factory Furnace Outlet at https://www.ecomfort.com/
  - HVAC Direct at https://hvacdirect.com/
  - Grainger Industrial Supply at https://www.grainger.com/
  - Sears at https://www.sears.com/
  - The Home Depot at https://www.homedepot.com/

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[212] Itron. May 27, 2014. *2010-2012 WO017 Ex Ante Measure Cost Study Final Report.*

[213] Pacific Gas and Electric, *Commercial Fryer-Electric and Gas* (search for PGECOFST102 with the 2016 date approved at http://www.deeresources.net/workpapers).

[214] San Diego Gas & Electric, *Commercial Convection Oven-Electric and Gas* (search for WPSDGENRCC0006 with the 2016 date approved at http://www.deeresources.net/workpapers).

- The Bureau of Labor Statistics for California (at https://www.bls.gov/oes/current/oes_ca.htma, accessed September 2019) provided the wage rate data. An average hourly wage rate of $28.50 was used for all measures based on the hourly mean wage rate (H_MEAN) for the trades construction laborers, electricians, plumbers, and heating, air conditioning, and refrigeration mechanics and installers.
- Estimates of applied time (that is, utilization), contractors overhead on labor, and profit applicable to California are professional judgment.
- The effect of certain measures that were not well defined in the Industrial Assessment Center database had to be estimated by internal subject matter experts. These measures were typically new or emerging technology and have minimal supporting data. The research used secondary sources where available but often had to use professional judgement when estimating the effect of these measures at the sector level. These measures fed into the end-use level savings used in this study. The subject matter experts leveraged for this work helped develop the industrial section of the Potential and Goals study in California and provided guidance regarding industrial and agriculture energy efficiency for the CEC.

APPENDIX G: Fuel Substitution Load Shapes

Background

Fuel substitution load shapes are developed and used to understand how the implementation of fuel substitution technologies will affect consumption and GHG emissions at an hourly level. The load shapes are developed at an end-use level and then applied to technologies that belong to that end use.

Fuel Substitution Load Shapes

To the extent possible, fuel substitution end-use load shapes leveraged existing load shapes. Existing load shapes were sourced from either the ADM California IOU Electricity Load Shapes study (ADM IOU Load Shape Study) or Navigant's (now Guidehouse's) 2017 Additional Achievable Energy Efficiency (AAEE) Load Shape Analysis.[215,216] This work also developed new load shapes, when necessary. Table G-1 presents a list of load shapes used or developed for each fuel substitution end use.

No existing load shape is available for combined space heating and cooling with a heat pump in the residential and commercial sectors. In the past, the team has approximated a heat pump space heating and cooling load shape by combining a HVAC cooling load shape and a gas furnace load shape.[217] This method, while useful in lieu of a heat pump specific profile, does not capture air source heat pump efficiency fluctuations based on outdoor air temperature. For more accurate load shapes, the research team used the California Building Energy Code Compliance residential and commercial models to generate hourly heat pump load shapes.[218]

Table G-1: Load Shape List by Sector and End Use

Sector	End Use	Load Shape	Source
Residential	Space Heating/Cooling	Residential Heat Pump	Navigant (now Guidehouse) – California Building Energy Code Compliance — Res. Model
Residential	Water Heating	Residential Water Heating	ADM IOU Load Shape Study
Residential	Cooking	Residential Cooking	ADM IOU Load Shape Study
Residential	Laundry	Residential Dryer	ADM IOU Load Shape Study
Residential	Whole Building	Residential Whole Building	ADM IOU Load Shape Study

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[215] ADM Associates, Inc. April 2019*. California Investor-Owned Utility Electricity Load Shapes.*

[216] Navigant Consulting, Inc. January 2018. *Investor Owned Utilities 2017 Additional Achievable Energy Efficiency Savings: Methodology Documentation*.

[217] In this method, the electrified gas furnace is approximated using an assumed fuel efficiency and COP at the end-use level.

[218] "2019 Building Energy Efficiency Standards Approved Computer Compliance Programs," Title 24, California Energy Commission, accessed August 2019.

Sector	End Use	Load Shape	Source
Commercial	Space Heating/Cooling	Commercial Heat Pump	Navigant (now Guidehouse) — California Building Energy Code Compliance — Com. Model
Commercial	Water Heating	Commercial Water Heating	ADM IOU Load Shape Study
Commercial	Cooking	Commercial Cooking	ADM IOU Load Shape Study
Commercial	Laundry	Residential Dryer*	ADM IOU Load Shape Study
Commercial	Whole Building	Commercial Whole Building	ADM IOU Load Shape Study
Agricultural	HVAC	Agricultural Whole Building**	2017 Navigant (now Guidehouse) AAEE Analysis
Agricultural	Water Heating	Agricultural Livestock Whole Building †	ADM IOU Load Shape Study
Agricultural	Whole Building	Agricultural Whole Building	2017 Navigant (now Guidehouse) AAEE Analysis
Industrial	Process Heating	Industrial Whole Building † †	2017 Navigant (now Guidehouse) AAEE Analysis
Industrial	Whole Building	Industrial Whole Building	2017 Navigant (now Guidehouse) AAEE Analysis

***The residential dryer load shape is used as a proxy for the commercial laundry end use.**

****Most agricultural HVAC is devoted to building/greenhouse HVAC. The agricultural whole building shape follows similar seasonal trends as a general HVAC shape and is used as a proxy in lieu of an agricultural HVAC-specific load shape.**

† The ADM livestock facility-level load shape is used as a proxy. Agricultural water heating is driven by dairy cattle, milk production, and other animal production. These end uses are assumed to be primarily process driven and align with the total facility load shape.

† † The industrial whole-building load shape is used as a proxy. Industrial process heating makes up a large share of electric consumption in industrial buildings; so the whole building shape is considered a sufficient approximation in lieu of any end-use-specific data.

Source: Guidehouse

Load Shape Development Standard Methods

Load shape development is typically conducted following one of three methods: end-use metering, prototypical building modeling, or smart meter disaggregation. In many cases, a hybrid approach that combines two or all three approaches is taken.

End-Use Metering

The end-use metering approach is the most intrusive and expensive approach to develop end-use load profiles, but it is also the most accurate. This method collects customer-site data at the end-use circuit level and requires a monitoring device to be installed directly to the load. This approach is used both for developing year-long hourly 8,760 load profiles and performing shorter-term technology evaluations.

Prototypical Building Modeling

Prototypical building modeling uses building models, typically sourced from the U.S. Department of Energy, combined with a weather data file to simulate end-use-level 8,760 load profiles.[219] This technique provides a method for quickly changing weather types and is useful for territories with multiple climates. The Department of Energy building models are not location-specific, so they must be edited to develop regional specificity, such as local building characteristics sourced from California Commercial End-Use Survey.[220] This load-shape-development method does not require any interaction with customer sites nor does it require data requests from load-serving entities. Once output from the model, the load profiles can be made more representative of a region or territory by calibrating to combined load data. Further, the prototypical building models are open source and can be edited to better match the building type of interest.

Smart Meter Disaggregation

This method uses whole building load profiles obtained from advanced metering infrastructure (AMI) [221]15-minute interval data as a starting point and then breaks down these profiles by end-use level. There are many different methods to disaggregate the whole-building load profile, but all methods generally use some simulated or real data to estimate the relative proportions of load contributed by end uses on an hourly basis. These proportions are then applied to the whole-building load profiles to develop the end-use-level load profiles. This method is advantageous because it is based on real and typically recent data and there is no intrusion at the customer site. That said, AMI data can be difficult to obtain, and the overall accuracy of this method rests on the accuracy of the estimated end-use load proportions.

Hybrid Approach

The hybrid approach tries to combine several other approaches to benefit from the advantages and avoid the associated disadvantages. Rarely are any of the other methods used in isolation. For example, building modeling is often used as a starting point to generate load profiles because it requires little input data and all input data are publicly available. Next, the entire output or perhaps a single end use might be calibrated based on an end-use metering study. AMI or meter data may also be used to calibrate the results so that the overall load profile is more representative of reality.

ADM Load Shapes

The ADM IOU Load Shapes study developed the load shapes by using a hybrid approach. The study method employs a combination of end-use metering and prototypical building modeling. AMI load data are also used and disaggregated to an end-use level based on demand forecasts. These techniques are combined into ADM Associates' Hourly Electric Load Model 2.0 model, which uses a similar approach to the CEC's legacy Hourly Electric Load Model used to generate load shapes.[222]

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[219] The U.S. Department of Energy developed and maintains the EnergyPlus whole building simulation program.

[220] Itron, Inc. 2006. *California Commercial End-Use Survey.*

[221] "AMI" refers to the two-way communication between utilities and customers with full measurement and data collection systems.

[222] ADM Associates, Inc. April 2019. *California Investor-Owned Utility Electricity Load Shapes.*

2017 Navigant AAEE Load Shapes

Navigant (now Guidehouse) performed an extensive load shape data search to compile representative 8,760 load profiles for measures in the named end-use categories. Where possible, Navigant sourced California-specific load shapes. Where California-specific data were not available, Navigant used additional secondary resources to fill gaps using load shapes from other states, only for nonweather-sensitive end uses.[223]

California Building Energy Code Compliance Heat Pump Load-Shape Development

While the research team used the best available end-use load shapes for most fuel substitution end uses, no satisfactory load shape was available for an electric heat pump. Residential and commercial electric space heating are high-impact end uses for fuel substitution. Residential space heating represents 45 percent of residential gas use, and commercial space heating represents 36 percent of commercial gas use.[224]

Gas space heating load shapes for the residential and commercial sector are readily available, but these end-use load shapes do not sufficiently approximate electric space-heating load. Electric space heating is expected to be primarily achieved through the use of heat pump space heaters. Unlike a gas furnace, the heating efficiency of an air-source heat pump changes based on outdoor temperature.

The team employed uncalibrated prototypical models in the California Building Energy Code Compliance residential and commercial models for developing hourly heat pump load shape for each sector. As metered heat pump data become available in California, the team recommends that modeled load shapes are updated with calibrated end-use (or whole-building) data.

The research team developed unique heat pump load shapes at the utility, building type, and building vintage level. The following are the load shapes developed:

- Utility: PG&E, SCE, SDG&E, SMUD, LADWP
- Building types: Single-family, multifamily, lodging, office, restaurant, retail, and miscellaneous
- Vintage: Code-compliant[225] and average existing (for residential only). The average existing models use envelope metrics based on the Residential Appliance Saturation Survey (RASS), Title 24 standards, and the average existing building data from the 2019 Navigant Potential & Goals Study.[226]

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[223] Navigant Consulting, Inc. January 2018. Investor Owned Utilities 2017 Additional Achievable Energy Efficiency Savings: Methodology Documentation.

[224] California Energy Commission. 2018. *2018 IEPR Update, Volume II*; California Energy Commission, *California Commercial End-Use Survey.*

[225] The code-compliant models use envelope metrics according to the 2019 California Building Energy Efficiency Standards. California Energy Commission, *2019 Building Energy Efficiency Standards*, accessed August 2019

[226] California Energy Commission. 2009. *Residential Appliance Saturation Survey*; California Energy Commission, *2019 Building Energy Efficiency Standards*; Navigant Consulting, Inc. July 2019. *2019 Energy Efficiency Potential and Goals Study*, California Public Utilities Commission.

To develop unique load shapes by utility and building vintage, the research team ran the prototypical models for the representative BCZs and modified prototypical building envelope characteristics. This study uses representative climate zones available in the California Building Energy Code Compliance models to approximate expected weather in the five utilities modeled.

Climate Zone Selection

The team selected representative climate zone(s) with the highest proportion of electric sales territorywide for each utility territory. Table G-2 presents the climate zone(s) selected for each utility.

Table G-2: Representative Climate Zone(s) by Utility

Utilities	Climate Zone(s)
PG&E	CZ3, CZ12*
SCE	CZ9, CZ10*
SDG&E	CZ7
SMUD	CZ12
LADWP	CZ9

*** Climate zone load shapes are combined using a weighted average of utility-specific electric consumption in each zone.**
Source: Guidehouse

Residential Heat Pump Model Parameters

The research team developed residential heat pump load shapes for single-family and multifamily homes. The team developed unique load shapes for code-compliant and average existing buildings in the residential sector.

- **Code-compliant**. The code-compliant building model envelope metrics use the standard design California Building Energy Code Compliance residential prototypical model. The energy features and envelope metrics of this building model are input to reflect the 2019 California Building Energy Efficiency Standards (Section 150.1 [c] and Table 150.1-A) and is ready-made in the California Building Energy Code Compliance residential software.[227]
- **Average existing.** The average existing building model insulation and air-leakage metrics are based on the insulation and leakage values from each vintage period in the Title 24 Residential Appliance manual[228] and the percentage of homes associated with those vintage periods in the 2009 RASS.[229] The window U-factor (rate of heat loss for

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[227] California Energy Commission. *2019 Residential Alternative Calculation Method Reference Manual (CBECC-Res)*

[228] California Energy Commission. January 2017. *2016 Residential Compliance Manual*, Table 8-1.

[229] California Energy Commission. April 2010. *Residential Appliance Saturation Survey 2009 Banner subset — CEC Forecast Zone and RASS Total.*

windows) and solar heat gain coefficient values of the building model are based on the average existing values in the 2019 Potential and Goals study.[230]

Table G-3 summarizes the building envelope metrics as described in the Potential and Goals study and the associated envelope metrics that are entered in the averaged existing California Building Energy Code Compliance residential building model.

Table G-3: Envelope Metrics for Residential Average Existing Building Model

Parameter	Utility	Average Existing Envelope Metrics
Framing/Insulation *	PG&E	R-Value: 5.6
Framing/Insulation *	SCE	R-Value: 5.5
Framing/Insulation *	SDG&E	R-Value: 5.7
Framing/Insulation *	SMUD	R-Value: 5.6
Framing/Insulation *	LADWP	R-Value: 3.6
Attic Type/Insulation *	PG&E	R-Value: 17.6
Attic Type/Insulation *	SCE	R-Value: 17.5
Attic Type/Insulation *	SDG&E	R-Value: 17.6
Attic Type/Insulation *	SMUD	R-Value: 17.6
Attic Type/Insulation *	LADWP	R-Value: 13.9
Internal Insulation *	PG&E	R-Value: 5.6
Internal Insulation *	SCE	R-Value: 5.5
Internal Insulation *	SDG&E	R-Value: 5.7
Internal Insulation *	SMUD	R-Value: 5.6
Internal Insulation *	LADWP	R-Value: 3.6
Air Leakage *	All	7.7 ACH at 50Pa
Windows **	All	U-Factor: 1.19 Btuh/ft^2-F
Solar Heat Gain Coefficient **	All	0.83
Duct Leakage †	All	5%

*** Sourced from Title 24 and CEC RASS.**
**** Sourced from market data analysis conducted for the 2019 Navigant Potential and Goals study.**
† Duct leakage is not a user editable input in the model.
Source: Guidehouse

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[230] Navigant Consulting, Inc. July 2019. *2019 Energy Efficiency Potential and Goals Study*. California Public Utilities Commission.

Commercial Heat Pump Model Parameters

The research team developed commercial heat pump load shapes for lodging, office, restaurant, retail, and miscellaneous building types. The commercial buildings selected for modeling are building types with the most opportunity for heat pump adoption in the commercial sector.[231]

The team modeled commercial heat pumps using code-compliant prototypical building models in the California Building Energy Code Compliance commercial model. While researchers believe the load shape from this vintage is enough for approximating heat pump hourly load in the commercial sector at this level of effort, understanding heat pump hourly load and performance in the average existing building as well will become more important as commercial heat pump penetration grows in the existing commercial building stock.

Table G-4 displays the envelope metrics used to develop the code-compliant building models for the commercial sector. These models are run in different climate zone conditions to approximate heat pump hourly load by utility.

Table G-4: Envelope Metrics for Commercial Code-Compliant Building Model

Parameter	Lodging	Office	Restaurant	Retail	Miscellaneous
Exterior Wall	R-Value: 14	R-Value: 14	R-Value: 14	R-Value: 14	R-Value: 14
Roof	R-Value: 14	R-Value: 14	R-Value: 14	R-Value: 14	R-Value: 14
Exterior Floor	R-Value: 10	N/A*	R-Value: 10	N/A*	N/A*
Interior Wall	N/A*	N/A*	N/A*	R-Value: 11	N/A*

***There is no option to modify this parameter in the California Building Energy Code Compliance commercial 2019 model.**

Source: Guidehouse

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[231] Navigant. 2019. *Research, Development, and Demonstration (RD&D) Opportunities for Heat Pump Technologies,* delivered to the California Energy Commission.

APPENDIX H:
Hourly Impacts Method

The primary purpose of the hourly impacts tool is to break down annual electrical energy savings (load additions) or GHG emissions abated to an hourly impacts level based on available load shapes at a utility, sector, and end-use level. To complete this work, research team staff worked with the CEC to:

1. Map available load shapes to utility, sector, and end-use combinations.
2. Tailor existing load shapes where needed at the utility, sector, and end-use levels to complete the load shape library.
3. Develop a tool that automates the process of applying annual values to hourly load shapes and produces an hourly impacts output.

The development of this tool originated to break down AAEE savings to hourly impacts. The description in this appendix applies to the AAEE hourly impact analysis and fuel substitution hour load increase impacts.

Hourly Impacts Segmentation and Mapping

Segmentation

The research team worked with CEC staff to develop a set of named end uses at the utility and sector levels deemed representative of AAEE savings and fuel substitution. The representative set of utility, sector, and end-use combinations are included in Table H-1. This set also aligns with the SB 350 beyond-utility-savings segmentation. No specific load shapes were developed for the POUs, except for SMUD and LADWP. The representative set of sector and end-use combinations apply to PG&E, SCE, SDG&E, LADWP, SMUD, and a general POU category.

Table H-1: AAEE Hourly Impacts Segmentation

Sector	End Use
Commercial	Whole Building
Commercial	HVAC – Cooling
Commercial	HVAC – Heating
Commercial	HVAC – Ventilation
Commercial	HVAC – Controls
Commercial	HVAC – General
Commercial	HVAC – Heat Pump
Commercial	Cooking
Commercial	Lighting – General
Commercial	Lighting – Indoor Equipment

Sector	End Use
Commercial	Lighting Indoor Controls
Commercial	Lighting Outdoor
Commercial	Office Equipment
Commercial	Refrigeration
Commercial	Water Heating
Commercial	Heat Pump Water Heater
Commercial	Machine Drive
Commercial	Behavior
Commercial	Miscellaneous
Residential	HVAC – Cooling
Residential	HVAC – Heating
Residential	HVAC – General
Residential	HVAC – Heat Pump
Residential	Whole Building
Residential	Plug Load – Appliance
Residential	Plug Load – Consumer Electronics
Residential	Refrigerator/Freezer
Residential	Miscellaneous
Residential	Behavior
Residential	Water Heating
Residential	Heat Pump Water Heater
Residential	Lighting – Indoor Controls
Residential	Lighting – General
Residential	Lighting – Indoor Equipment
Residential	Lighting Outdoor
Agricultural	Lighting
Agricultural	Machine Drive
Agricultural	Process Refrigeration
Agricultural	Whole Building
Agricultural	Miscellaneous
Industrial	Lighting
Industrial	Machine Drive
Industrial	HVAC
Industrial	Process Heat
Industrial	Whole Building
Industrial	Miscellaneous

Sector	End Use
Mining	Oil & Gas Extraction
Streetlighting	Streetlighting

Source: Guidehouse

To develop hourly impacts for the POUs, the research team mapped each POU to an IOU based on its geographic proximity. Table H-2 shows the mapping used to develop POU hourly impacts.

Table H-2: IOU to POU Map

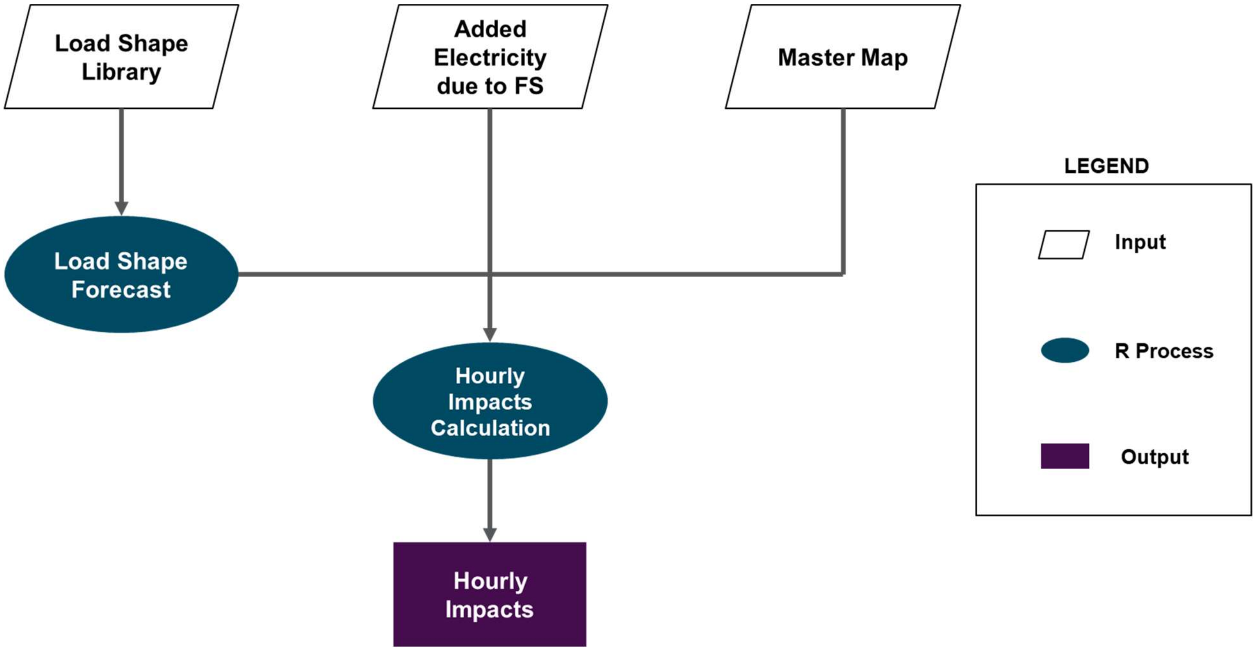
POU	IOU
Modesto	PG&E
Roseville	PG&E
Palo Alto	PG&E
San Francisco	PG&E
Santa Clara	PG&E
Turlock	PG&E
Redding	PG&E
NorCal Other	PG&E
Glendale	SCE
Burbank	SCE
Anaheim	SCE
Imperial	SCE
Riverside	SCE
Pasadena	SCE
Vernon	SCE
SoCal Other	SCE

Source: Guidehouse

Tool Inputs, Calculations, and Outputs

The hourly impacts tool takes in a set of load shape, savings, and mapping inputs; calculates hourly impacts; and outputs the resultant impacts to an Excel workbook. This process is shown at a high level in Figure H-1 and detailed throughout this section.

Figure H-1: Overall Hourly Impacts Tool Structure



Flow chart on how the hourly impacts tool maps the savings or consumption values from the annual fuel substation analysis to the load shape library to calculate hourly impacts.
Source: Guidehouse

Hourly Impacts Tool Inputs

The hourly impacts tool calculated the hourly impacts of a set of energy efficiency measures over a given forecast period. To accomplish this calculation, this tool uses three main inputs:

1. **AAEE savings values or fuel substitution electrical load increase.** This dataset contains annual values at the utility, sector, and end-use levels of granularity.
2. **Normalized load shapes.** Each normalized load shape contains hourly normalized load data for a representative year at the utility, sector, and end-use levels of granularity.
3. **Mapping inputs.** This dataset contains information that maps a given savings value to the load shape that will be used to develop the hourly impacts for that savings value.

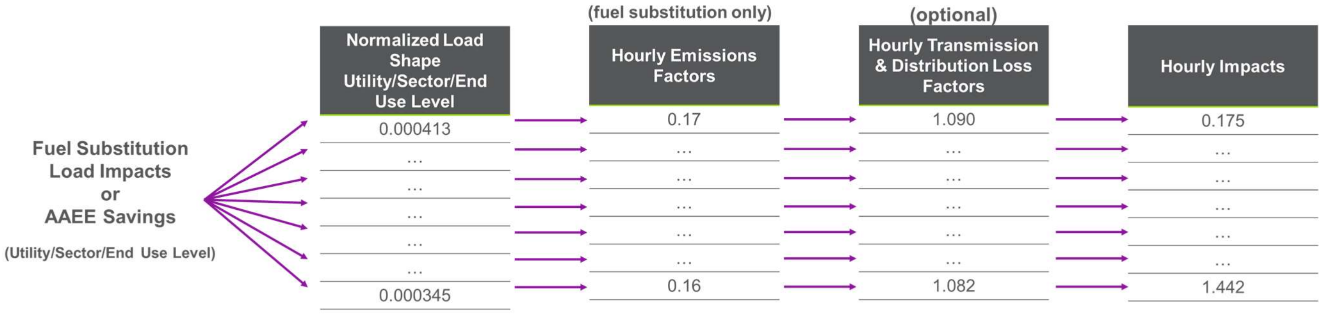
Other additional inputs that the tool uses are:

- **Forecast period length.** These user input data define the length of the hourly impacts forecast period output by the tool.
- **T&D loss factors.** The tool also has the capability to account for transmission and distribution losses associated with the hourly impacts. These calculations are based on T&D loss input values provided by the user.

Hourly Impacts Tool Calculations

The hourly impacts tool applies an annual savings value at the utility, sector, and end-use levels to a normalized load shape specific to the utility, sector, or end-use level associated with the savings value. Figure H-2 shows the general data flow completed in the tool to develop the hourly impacts output.

Figure H-2: The Data and Calculation Flow of the Hourly Impacts Tool



Note: Values are illustrative.
Visual depiction of the hourly impacts tool calculation where the annual value is disaggregated to the hourly value using the normalized load shape. Then the calculator multiples the hourly value with the transmission and distribution loss factors to calculate the hourly impact.
Source: Guidehouse

The tool is written in the R programming language, so all data flow and calculations are completed in the R Foundation for Statistical Computing environment. As the number of values and associated load shapes grow, the data handling associated with developing hourly impacts become too intensive for traditional data handling programs like Microsoft Excel. Handling these calculations in the R environment is more efficient and, in part, automates the process of developing the hourly impacts.

Hourly Impacts Tool Outputs

The output of the hourly impacts tool is provided at the utility, sector, or end-use level by year based on the output selected by the user. The tool produces either a simple output or a detailed output based on a user's selection.

- **Simple output.** The simple output provides the hourly impacts at a scenario, utility, and sector level aggregation. This output is less computationally intensive; it is preferable if all quality control/review is complete, and the user would like to quickly output finalized results. The simple output also prints all inputs to the tool as a record for the output run.
- **Detailed output.** The detailed output contains all the same information provided in the simple output but also includes hourly impacts at the end-use level. This output is more computationally intensive but is useful for quality control/review. The detailed output is expected to take longer than five minutes to process for most savings inputs.

APPENDIX I:
Glossary

A	Amperes: Unit of electric current or the rate of electron flow
AAEE	Additional achievable energy efficiency: An accounting for future potential installed energy efficiency savings in the California energy demand forecast.
AB	Assembly Bill
AC	Air conditioning
AFUE	Annual fuel utilization efficiency: AFUE is a measure of gas furnace efficiency.
AMI	Advanced metering infrastructure: AMI refers to the two-way communication between utilities and customers with full measurement and data collection systems. AMI also enables collecting consumption data at the subhourly level.
BCZ	Building climate zone: There are 16 in California based on energy use, temperature, weather, and other factors. Each one has unique conditions that dictates which minimum efficiency requirements are needed.
Benefit-cost ratio	Most utility programs are measured by a benefit-cost ratio. The benefits are typically energy savings, and the costs can be the measure installation costs and program administrator costs.
Berkeley Lab	Lawrence Berkeley National Laboratory
BUILD	Building Initiative for Low-Emissions Development by providing incentives for electric space and water heat pumps, solar hot water with electric backup, heat pump dryers, and induction cooktops with a specific allocation to income-eligible energy users, too.
Btu	British thermal unit: Btu is a measurement of heat energy. One Btu of heat is required to raise the temperature of one pound of water 1° Fahrenheit.
Capital recovery factor	Ratio of the present value of a series of equal annual cost allocation.
CBECS	Commercial Buildings Energy Consumption Survey: CBECS is a national survey on the commercial building stock, including their energy-related building characteristics and energy usage data.
CCA	Community choice aggregator: Local governments that procure power on behalf of their residents, businesses, and municipal properties from a non-investor-owned utility supplier.

CEC	California Energy Commission
CEF	Combined energy factor: The CEF is the energy performance metric for clothes dryers.
CHP	Combined heat and power: CHP is also known as cogeneration. It is the simultaneous production of electricity and useful thermal energy.
CO_2	Carbon dioxide: Carbon and greenhouse gas (GHG) are used interchangeably. Carbon dioxide is one type of GHG. GHG emissions are typically quantified in terms of metric ton of carbon dioxide equivalent ($mtCO_2e$). The conversation of emissions for each GHG to $mtCO_2e$ uses a global warming potential (GWP) factor.
COP	Coefficient of performance: COP is the ratio of useful heating or cooling provided to work required.
CPUC	California Public Utilities Commission
Demand-side	Term used to describe customer energy use on the customer side of the utility meter.
Density	The scaling to identify the quantity of the technology or the capacity within the population. Typically, it is per household for homes and per square foot for commercial.
DER	Distributed energy resources, "defined as distribution-connected distributed generation resources, energy efficiency, energy storage, electric vehicles, and demand response technologies."[232]
DOE	U.S. Department of Energy
DR	Demand response: DR is a voluntary program that end users may participate in to reduce their electricity usage during a period of higher prices.
EER	Energy efficiency ratio: EER is the ratio of output cooling energy (in Btu) to input electrical energy (in watts).
Emissions intensity factor or emissions factor	Representative value to relate emissions of a pollutant, for example carbon dioxide, to an activity, for example electricity generation.
EF	Energy factor: Measurement of the energy efficiency of a water heater where the amount of energy the water heater makes divided by the total amount of energy that powered the unit.
End user	Consumers of utility electricity or natural gas.

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232 California Public Utilities Commission. May 2017. "California's Distributed Energy Resources Action Plan: Aligning Vision and Action."

EUI	Energy use intensity: EUI refers to the energy use intensity at the building or end-use level, typically expressed as an energy unit per household for residential and per square feet for nonresidential.
EUL	Effective useful life: EUL is characterized as the median length of time (in years) that an energy efficiency measure is in place and operable.
EV	Electric vehicle
FCZ	Forecasting climate zone: 20 electricity planning areas to support demand forecasting.
FSSAT	Fuel substitution scenario analysis tool: FSSAT is a software tool that implements a framework to assess the following impacts of fuel substitution on the five largest California electric utilities: decreased natural gas use, increased electricity use, emissions impacts, and cost implications.
GHG	Greenhouse gas
GWh	Gigawatt hours (1,000,000 kWh) — unit of electricity use
GWP	Global warming potential compares the global warming impacts of one ton of different gases relative to one tonne of CO_2. CO_2 has a GWP of 1.
HERS	Home energy rating system
HFC	Hydrofluorocarbon is a greenhouse gas typically used as a refrigerant.
HSPF	Heating seasonal performance factor
HVAC	Heating, ventilation, and air conditioning
IEPR	Integrated Energy Policy Report: The IEPR assesses the major energy trends in California.
IOU	Investor-owned utility. An IOU is a private electricity and/or natural gas provider.
kBtu	1,000 British thermal units
kWh	kilowatt hours — unit of electricity use
LADWP	Los Angeles Department of Water and Power
$mTCO_2e$	Metric ton of carbon dioxide equivalent. One metric ton is 1,000 kilograms.
$MMTCO_2e$	Million metric tons of carbon dioxide equivalent.
Net-to-gross	Net-to-gross is the ratio of the changes in energy use directly attributable to the program intervention to the changes in energy consumption calculated by the program activities.
NG	Natural gas
NREL	National Renewable Energy Laboratory

PG&E	Pacific Gas and Electric
POU	Publicly owned utility: A POU is subject to local public control and regulation.
PTHP	Packaged terminal heat pump: PTHPs are a through the wall, ductless, all-in-one heating and cooling unit.
PV	Photovoltaic
RASS	Residential Appliance Saturation Survey: RASS is a comprehensive look at residential energy use collected by surveys of residents.
RECS	Residential Energy Consumption Survey: RECS is a national survey on housing units, including their energy-related characteristics, usage patterns, and demographics.
Real discount rate	Rate of return used to discount to the present value of future cash flows. The real discount rate removes the effects of inflation to reflect the real cost and is typically the nominal discount rate minus inflation rate.
ROI	Return on investment
Saturation	Defines the fraction of the stock that is represented by the efficient technology.
SB	Senate Bill
SCE	Southern California Edison
SDG&E	Sand Diego Gas & Electric
SEER	Seasonal energy efficiency ratio: SEER is an efficiency rating at which air conditioners produce cooling. It is the ratio of the amount of cooling produced (Btu) divided by the amount of electricity (watts) used.
SMUD	Sacramento Municipal Utility District
SoCal Gas	Southern California Gas
T&D	Transmission and distribution
TECH	The Technology and Equipment for Clean Heating goal is to deploy low-emissions space and water heating equipment for new and existing homes, mostly through the upstream market, consumer education, and contractor and vendor training via incentives to the upstream and midstream channels.
therms	Unit of heat used to measure gas consumption. It is equivalent to 100,000 Btu.

Time-dependent valuation (TDV)	Metric to incorporate nonenergy impacts into the cost of energy during a given hour of the year. The resulting TDV aligns energy savings for the end users with the cost of producing and delivering energy to consumers.
Unit basis	Value depends on referenced technology — for example, dishwasher is per unit and heat pumps are capacity tons.

APPENDIX J:
Reference List

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