Fuel Substitution Behind the Meter Infrastructure Market Study

Final Report

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Executive Summary

Fuel substitution measures[1] for energy efficiency programs are designed to be one of the primary mechanisms for achieving California's building decarbonization goals. Unlike conventional same-fuel energy efficiency measures, fuel substitution measures primarily address the conversion of direct-fired gas devices to electric devices. However, because decarbonization/electrification will likely necessitate electrical panel and other behind the meter infrastructure upgrades among the existing residential and nonresidential building stock, the California Public Utilities Commission (CPUC) deemed it necessary to conduct a study to assess the infrastructure needs and costs associated with fuel substitution measures in California among market-rate customers.[2] The CPUC contracted with Guidehouse and Opinion Dynamics (hereafter referred to as 'the team') to complete the Fuel Substitution Infrastructure Market Study beginning in the Spring of 2023. Note there is comparable study for equity customers currently underway; that study will be completed in the summer of 2024.

Notably, the CPUC issued Decision (D.) 23-04-035[3] in April 2023 and eliminated non-exempt[4] natural gas energy efficiency in new construction projects in the residential and commercial sectors to complement the long-term building decarbonization policy framework developed as part of Rulemaking (R.) 19-01-011. Despite being issued after the team began work on the Market Rate Fuel Substitution Infrastructure Costs Study, D.23-04-35 reinforced the need for research on the infrastructure costs associated with fuel substitution. The Decision was in response to an Energy Division staff proposal recommending the "phasing out [of] ratepayer-funded incentives for non-exempt gas efficiency measures with viable electric alternatives (VEA) over approximately ten years, beginning in program year 2024." Other parties also urged the CPUC to take steps to reduce incentives for gas efficiency measures to avoid the ongoing installation of long-lived, GHG-emitting appliances. The Decision noted that the CPUC's "authority to eliminate ratepayer funding for cost-effective gas efficiency measures or to redirect gas ratepayer funds towards incentivizing electric efficiency measures, [required] further consideration." In particular, the CPUC called for "further examination of the bill impacts, infrastructure costs, and the customer decision-making issues, which will inform future decisions related to gas efficiency measures." The research presented in this paper provides an examination of the infrastructure costs that are required to pursue fuel substitution for gas measures with a VEA.

The results of this market study for frequency of fuel substitution infrastructure upgrades two types of results related to customers' infrastructure upgrade needs: (1) Technical Engineering Needs Assessment results and (2) Workforce Implementation Likelihood results. The Technical Engineering Needs Assessment results detail customers' infrastructure needs based solely on our engineering-based analysis of whether a given fuel substitution scenario would necessitate additional panel capacity and/or breaker slots. The Workforce Implementation Likelihood results attempt to account for the fact that, in the field, electricians may do or recommend something different based on their own practices that may not follow the method we used to determine technical needs. This change was estimated using the results of our survey of electricians. The

[1] https://www.cpuc.ca.gov/about-cpuc/divisions/energy-division/building-decarbonization/fuel-substitution-in-energy-efficiency

[2] For the purposes of this report, market rate customers are considered residential customers that are not on a CARE or FERA electric rate. This study did not screen nonresidential customers for market rate or equity status.

[3] https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF

[4] Non-exempt measures are considered direct-fired gas measures. Exempt measures include those such as air sealing, which may be associated with gas savings but are gas-fired measures.

results presented in this report highlight the Technical Engineering Needs Assessment results; however, the FS Infra MS Data Tool in Appendix F. FS Infra MS Data Tool includes a second type of results related to infrastructure need outcomes called the Workforce Implementation Likelihood results.

This report includes results from a two-phase study that included a secondary research effort (Phase 1) to assess existing data on the subject, and to set assumptions in the 2023 EE Potential and Goals Study. This was followed by additional primary research involving extensive surveys (Phase 2). **Table 1** summarizes the specific tasks undertaken as part of this research. Detailed descriptions of methods are available in Chapter 2, while detailed results are available in Chapter 3.

Table 1. Overview of Infrastructure Upgrade Research Tasks and Achieved Survey Targets

Research Task	Task Description
Program Coordination and Scenario Development	Conducted a detailed review of publicly available reports and data to inform the development of various fuel substitution scenarios for application to primary research. Additionally, conducted outreach with various organizations within and outside California to understand what information may be available to inform an assessment of infrastructure upgrade needs and the associated costs. This effort built upon a literature review that was conducted in 2022 and fed into the 2023 Potential and Goals (PGS) study. The documents associated with these efforts can be found in Appendix A. Scenario Development and Literature Review Memos.
Residential Occupant Survey	Conducted a web survey of 642 PG&E/SDG&E/SCE residential electric customers residing in individually metered single-family or multifamily properties (555 included in the analysis, 87 excluded).[5] The original goal was 640 completions. The survey included questions about current equipment in the home and electric panel conditions to determine what proportion of the residential housing stock will require electrical panel or other infrastructure upgrades to pursue fuel substitution measures. Survey questions also explored the impacts of other electrification measures on the need for infrastructure upgrades.
Nonresidential Customer Survey	Conducted a web survey of 579 PG&E/SDG&E/SCE nonresidential electric accounts representing occupied buildings. The original goal was 600 completions. The survey asked questions about current equipment in the building and electric panel conditions to determine what proportion of the nonresidential building stock will require panel upgrades or other infrastructure upgrades to pursue fuel substitution upgrades. Survey questions also Survey questions also explored the impacts of other electrification measures on the need for infrastructure upgrades.
Electrician Survey	A web survey of 56 electricians located throughout California was conducted to answer key questions regarding the costs associated with the electric panel and related infrastructure upgrades that are sometimes necessary when installing fuel substitution measures. Electricians who worked in both the residential and nonresidential sectors were permitted to select which sections of the survey they would like to answer (questions regarding residential jobs, nonresidential jobs, or both). The final analysis included 45 residential survey completions and 33 nonresidential survey completions. The original goal was to complete surveys with 35 residential electricians and 35 nonresidential electricians.
Reporting	Used the information from each research task to develop an Excel-based tool (FS Infra MS Data Tool) that maps the results of the panel upgrade needs assessment and cost assessment to the residential housing and nonresidential building stock in California. Completed univariate and multivariate regression analyses to identify which building/occupant characteristics to prioritize in the Excel tool. In addition to this report, drafted a short memo detailing the study methods and key results associated with each research task.

Key Findings

Table 2 presents the key findings associated with this study. The findings are separated by the residential and Nonresidential market segments considered in the research.

Table 2. Summary of Key Findings

Research Area	Residential	Nonresidential
Existing Panel Sizes	Average panel sizes were 175 amps and 136 amps for single-family and multifamily housing units, respectively.	Existing panel sizes range from 100 amps to 4,000 amps, with an overall average of 326 amps.
Existing Panel Capacity Constraints	Single-family homes have slightly higher electric panel capacity (i.e., amperage) constraints than multifamily housing units. These constraints are lowest in the 'Space Heating Only' scenario.	Nonresidential buildings had the greatest capacity (i.e., amperage) constraints in the 'Cooking' scenario, where 34% of the relevant sites have capacity issues. Capacity constraints were much lower in the 'Space Heating Only' and 'Water Heating Only' scenarios.
Existing Panel Space Constraints	Electric panel space constraints (i.e., breaker slot availability) present a far greater barrier than capacity constraints in both single-family and multifamily properties.	In all scenarios, the proportion of sites with space constraint (i.e., breaker slot availability) issues exceeds the capacity constraint issues.
Drivers of Infrastructure Upgrade Needs	Compared to newer homes, slightly older homes had a higher likelihood of requiring panel upgrades or optimization services.	For the nonresidential sector, compared to the cold region, being in the hot-dry region decreased the likelihood of requiring a panel upgrade across all included scenarios
Infrastructure Upgrade Costs	Panel upgrade costs range from around $6,000 to $8,000. Panel optimization prices vary depending on the approach being used. Sub-panels were the most popular reported approach and cost ~$2,200.	Scenarios involving a 400-amp panel upgrade are typically in the $15,000 range, while scenarios involving a 600-amp panel upgrade are typically in the $20,000 range. Sub-panels were the most popular report optimization approach and cost ~$2,600.
Current Penetration of Electrification Equipment	The most common electrification measures for single-family respondents were solar panels (48%), HVAC heat pumps (35%), electric vehicles (EVs) (26%), and EV charging (25%). For multifamily, the most common electrification measures were HVAC heat pumps (26%), EVs (16%), and EV charging (10%).	Ownership of electrification measures was low among nonresidential survey respondents, with the most common electrification measures at buildings being HVAC heat pumps (11%), solar panels (8%), and HPWHs (6%).
Preference for Future	Both single-family and multifamily respondents were most interested in battery storage (65% single-family,	Nonresidential customers indicated they were most interested in solar

[5] The 87 excluded respondents were identified as equity customers and will be included in a separate study focused on the infrastructure needs and costs for equity customers.

Research Area	Residential	Nonresidential
Electrification Equipment	47% multifamily), EVs (58% single-family, 56% multifamily), solar panels (57% single-family, 50% multifamily), and HVAC heat pumps (51% single family, 42% multifamily).	panels (35%), followed by HVAC Heat Pumps (23%) and EV chargers (13%).

Below we provide a more detailed narrative of the results presented in Table 2.

Existing Panel Sizes

Overall, the average existing electric panel size was larger for single-family homes (175 amps) than it was for multifamily housing units (136 amps). Existing panel sizes did not vary all that much by climate region or home age (Table 21). Almost one-third of single-family respondents (31%) indicated that they had previously received a panel upgrade, which would at least partially explain why older homes have average existing panel sizes that are in line with newer homes (Table 22).

The existing panel sizes in nonresidential buildings range from 100 amps to 4,000 amps, with the overall average being 326 amps. The cold climate region (237 amps) displayed a smaller average panel size than the hot-dry (327 amps) and marine (337 amps) climate regions (Table 49). Only 14% of nonresidential customers indicated their building had previously received a panel upgrade (Table 51).

Existing Panel Capacity Constraints

Panel upgrade needs generally fall under two categories when reviewing the panel size. One is the capacity or amp rating of the panel which would result in a panel upgrade. The other is the space constraints to accommodate additional equipment (breaker slots) which would result in panel optimization.

Electric panel capacity (i.e., amperage) constraints are one of the primary barriers to fuel substitution measure adoption. When pursuing the switch from natural gas-fired equipment to electric equipment, customers' electrical panels must be able to accommodate the new all-electric measures. This requires available capacity in the existing electrical panel or a panel upgrade. The constraints associated with electric panel capacity vary depending on the fuel substitution scenario that is being considered. For example, a single-family home may have the available capacity to accommodate Heating, Ventilation, and Air Conditioning (HVAC) heat pumps but not HVAC heat pumps and Heat Pump Water Heaters (HPWHs).

- **Residential**: Overall, single-family homes have slightly greater electric panel capacity constraints than multifamily housing units across each of the fuel substitution scenarios considered. Capacity constraints are greatest in the 'Space Heating and Water Heating' and 'All Electric' scenarios for both single-family and multifamily buildings. One-fifth (21%) of single-family homes displayed capacity constraints under the 'Space Heating and Water Heating' scenario, while 14% of multifamily housing units displayed capacity constraints for the same scenario. Capacity constraints are lowest for the 'Space Heating Only' scenario, where 5% of single-family homes and 1% of multifamily housing units displayed capacity issues when trying to accommodate all-electric HVAC heat pumps. These results are shown in Section 3.1.3.

- **Nonresidential**: Nonresidential buildings had the greatest capacity constraints in the 'Cooking' scenario, where 34% of the relevant sites in our sample would have capacity issues trying to accommodate all-electric cooking equipment. Capacity constraints for nonresidential properties were relatively low in the 'Space Heating Only' (6%) and 'Water Heating Only' (1%) scenarios. Detailed results for each of the nonresidential scenarios, presented overall and by climate region, can be found in Section 3.2.3.

Existing Panel Space Constraints

Electric panel space constraints are another considerable barrier to fuel substitution adoption. It is possible to have excess capacity available in the electric panel but not enough (or any) available breaker slots to accommodate new electric measures. These are scenarios where it may be technically feasible to pursue panel optimization as opposed to a full panel upgrade.

- **Residential**: As shown in Section 3.1.3, space constraints present a far greater barrier than capacity constraints in both single-family and multifamily properties, regardless of the fuel substitution scenario being considered. Overall, 6% to 33% of single-family sites and 21% to 50% of multifamily sites displayed space constraints in the various fuel substitution scenarios. This represents a much larger proportion of sites than those with capacity issues discussed above.
- **Nonresidential**: The same story is true for nonresidential buildings, where the percentage of sites with space constraint issues in their panels ranges from 13% to 44%, depending on the scenario. In all scenarios, the proportion of sites with space constraint issues exceeds the capacity constraint issues except for the cooking scenario.

Drivers of Infrastructure Upgrade Needs

The team conducted a regression analysis to assess the combined relationship between variables of interest and the panel upgrade/optimization outcome.

- **Residential**: For the residential sector, we observed a consistent relationship between the age of the home and the likelihood of a panel upgrade/panel optimization being required across the four scenarios. Compared to newer homes, slightly older homes had a higher likelihood of requiring panel upgrades. This was particularly true for homes built between 1976 and 1999, in comparison to the homes built in 2000 or later. Compared to the cold region, being in the marine region increased the likelihood of requiring a panel upgrade across all four scenarios. In an all-equipment electrification scenario, being in the hot-dry region increased the likelihood of requiring a panel upgrade compared to the cold region.
- **Nonresidential**: For the nonresidential sector, compared to the cold region, being in the hot-dry region decreased the likelihood of requiring a panel upgrade across all included scenarios. In the 'Water Heating Only' and 'Space Heating and Water Heating' equipment scenarios, being in the marine region compared to the cold region also decreased the likelihood of requiring a panel upgrade. More details on the regression analyses can be found in Section 3.2.3.

Infrastructure Upgrade Costs

- **Residential**: The infrastructure upgrade costs associated with the residential sector are detailed in Section 3.1.5. The costs vary widely depending on the scenario in question and the extent of infrastructure work that is required. Simple connection costs, which may include installing a 240-volt (V) circuit and a disconnect for the equipment being installed, can range from around $1,500 to $3,000. Typically, scenarios that involve upgrading the electrical panel to 200 amps and connecting fuel substitution equipment fall in the $6,000 to $8,000 range. The costs associated with panel optimization vary depending on the optimization approach. Smart panels (~$4,500) were the most expensive approach, with sub-panels (~$2,200) being the second most expensive approach and also the approach that is most commonly used by electricians (Table 40 and Table 41).[6]

- **Nonresidential:** The nonresidential sector infrastructure upgrade costs are presented in Section 3.2.5. Overall, the infrastructure costs associated with nonresidential projects are substantially higher than they are for residential projects. This is, in part, due to the size of the electric panels associated with panel upgrades in the nonresidential fuel substitution scenarios. Scenarios involving a 400-amp panel upgrade are typically in the $15,000 range, while scenarios involving a 600-amp panel upgrade are typically in the $20,000 range. The panel optimization results were comparable between the residential and nonresidential sectors. Nonresidential electricians noted that sub-panels were the most commonly used optimization approach, and the typical cost is around ~$2,600 (Table 70).

Please note that the costs presented in this report may vary from those presented in the FS Infra MS Data Tool, which removed the outliers associated with cost estimates for each scenario. The team recommends that the data tool be the ultimate source of cost data for this study.

Current Penetration of Electrification Equipment

- **Residential**: The most common electrification measures among single-family respondents were solar panels (48%), HVAC heat pumps (35%), electric vehicles (EVs) (26%), and EV charging (25%). Among multifamily respondents, the most common electrification measures were HVAC heat pumps (26%), EVs (16%), and EV charging (10%). The least common measures across all respondents were battery storage, HPWHs, and heat pump clothes dryers. Table 28 depicts the percentage of respondents who indicated owning each electrification measure by housing type.

- **Nonresidential**: Ownership of electrification measures was low among nonresidential survey respondents, with the most common electrification measures at buildings being HVAC heat pumps (11%), solar panels (8%), and HPWHs (6%). Table 57 depicts the percentage of respondents who indicated having each electrification measure at their building.

Preference for Future Electrification Equipment

Respondents were asked to indicate which electrification measures they would be interested in purchasing in the future, assuming they had enough money to get everything they wanted.

- **Residential**: Both single-family and multifamily respondents were most interested in battery storage (65% single-family, 47% multifamily), EVs (58% single-family, 56% multifamily), solar panels (57% single-family, 50% multifamily), and HVAC heat pumps (51% single family, 42% multifamily). Both single-family and multifamily respondents were least interested in HPWHs (33% single-family, 26% multifamily) and heat pump clothes dryers (26% single-family, 22% multifamily).

[6] For the purposes of this study a smart panel is considered a panel optimization technique as it is not associated with a service amperage upgrade.

- Table 31 presents the percentage of residential respondents interested in each measure by housing type.
- **Nonresidential**: Nonresidential customers were asked the same question – which electrification measures would they be interested in if money were no object? Nonresidential customers indicated they were most interested in solar panels (35%), followed by HVAC Heat Pumps (23%) and EV chargers (13%) (Table 60).

Considerations for Future Research

The team documented the limitations associated with this study in Section2.7. Below, we present a few considerations for future research that would help to validate the findings presented in this report. Future research efforts could focus on measures and/or building types that are associated with the largest infrastructure needs in this study.

Conduct site visits to refine the electrical panel size findings and the remaining capacity load calculations.

As documented in this report, the team used self-report surveys and pictures of electrical panels to assess the size of the existing electrical panel and to calculate the current load associated with the existing electrical equipment at each site. The team used this information to make bottom-up load calculations for the residential sector. The team used 2022 electric peak demand values for nonresidential customers to estimate the current electrical load and calculate the remaining capacity available in the electrical panel.

On the residential side, onsite inspections would help validate the wattage assumptions used when calculating current electric loads. On the nonresidential side, onsite inspections would allow for electrical equipment to be documented in detail (e.g., type, quantity, wattage) so that bottom-up load calculations can be used instead of the peak demand approach used in this study.

Conduct more thorough cost research with electricians and HVAC contractors.

The scope of the panel upgrade and panel optimization cost research for this study was somewhat limited. Given the nature of the data collection approach, self-report web surveys, it was not possible to provide electricians with all the information they would typically need to develop pricing estimates. The team suggests that the CPUC consider conducting cost research with electricians using mystery shopping visits, where researchers act as homeowners in search of fuel-sub measures and receive bids from multiple contractors, or contractor bid templates that provide all of the unique building characteristics needed for detailed cost quotes, in the future. These approaches would provide electricians with much more detail regarding the location of equipment, the state of the building, the location of the electrical panel, and the state of the wiring, among other considerations that typically factor into cost estimates.

Update study results every three years.

The CPUC should consider updating these study results every three years. There is a lot happening in the building decarbonization space right now, and this could lead to major market shifts in a relatively short period of time. This is especially true with the introduction of the Inflation Reduction Act (IRA) funds expected in 2024. The CPUC should update these results, ideally leveraging some of the approaches mentioned above, to track the market needs with respect to infrastructure upgrades and to ensure that stakeholders understand how electrician approaches are evolving over time.

Coordinate with implementation teams about collecting detailed information for sites receiving fuel substitution measures.

The CPUC should consider developing a data collection form or series of questions that can be provided to all implementation contractors working with programs that are processing fuel substitution measures. The data collection form could ensure that the CPUC has access to consistent and accurate data regarding existing electrical panel sizes, existing capacity and/or space constraint issues in the electrical panel, infrastructure upgrade strategies, and infrastructure upgrade costs. These data points will help refine ongoing strategies around fuel substitution incentives and training opportunities for market actors.

1. Introduction

1.1 Background

In September 2018, Governor Brown signed two bills into law aimed at reducing greenhouse gas (GHG) emissions from buildings: Senate Bill (SB) 1477 and Assembly Bill (AB) 3232. SB 1477 called for the development of two programs aimed at increasing the adoption of low/near-zero-emission technologies in new and existing homes, known as the Building Initiative for Low-Emissions Development Program (BUILD) and Technology and Equipment for Clean Heating Initiative (TECH).[7] AB 3232 called for the California Energy Commission to, by 2021, "assess the potential for the state to reduce the emissions of greenhouse gases from the state's residential and nonresidential building stock by at least 40% below 1990 levels by January 1, 2030."[8]

The California Energy Commission (CEC) submitted the final California Building Decarbonization Assessment in August 2021. The assessment outlined seven GHG emission reduction strategies, listing building end-use electrification (e.g., replacing a gas-fueled appliance with an electric appliance, i.e., fuel substitution) as the top strategy in terms of feasibility and potential. However, the authors noted that, given the age of the existing housing stock in California, "it is reasonable to assume that some portion will require electric panel upgrades from 100 amps to 200 amps or larger to support new electric loads."[9]

Fuel substitution measures[10] for energy efficiency programs are designed to be one of the primary mechanisms for achieving California's building decarbonization goals. Unlike conventional same-fuel energy efficiency measures, fuel substitution measures primarily address the conversion of direct-fired gas devices to electric devices and save energy on a "source energy" rather than "site energy" basis. However, because decarbonization/electrification in many cases may necessitate electrical panel and other infrastructure upgrades among the existing residential and nonresidential building stock, the CPUC deemed it necessary to conduct a study to assess the infrastructure needs and costs associated with fuel substitution measures in California among market-rate customers.[11] The CPUC contracted with Guidehouse and Opinion Dynamics (hereafter referred to as 'the team') to complete the Fuel Substitution Infrastructure Market Study beginning in the Spring of 2023. Note there is comparable study for equity customers currently underway; that study will be completed in the summer of 2024.

Notably, the CPUC issued Decision 23-04-035[12] in April 2023 to complement the long-term building decarbonization policy framework developed as part of Rulemaking (R.) 19-01-011. Despite being issued after the team began work on the Market Rate Fuel Substitution Infrastructure Costs Study, Decision 23-04-35 reinforced the need for research on the infrastructure costs associated with fuel substitution. The Decision was in response to an

[7] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB1477

[8] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180AB3232

[9] https://www.energy.ca.gov/publications/2021/california-building-decarbonization-assessment

[10] https://www.cpuc.ca.gov/about-cpuc/divisions/energy-division/building-decarbonization/fuel-substitution-in-energy-efficiency

[11] For the purposes of this report, market rate customers are considered residential customers that are not on a CARE or FERA electric rate. This study did not screen nonresidential customers for market rate or equity status.

[12] https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF

Energy Division staff proposal recommending the "phasing out [of] ratepayer-funded incentives for non-exempt gas efficiency measures with viable electric alternatives (VEA) over approximately ten years, beginning in program year 2024."[13] Other parties also urged the CPUC to take steps to reduce incentives for gas efficiency measures to avoid the ongoing installation of long-lived, GHG-emitting appliances. The Decision noted that the CPUC's "authority to eliminate ratepayer funding for cost-effective gas efficiency measures or to redirect gas ratepayer funds towards incentivizing electric efficiency measures, [required] further consideration." In particular, the CPUC called for "further examination of the bill impacts, infrastructure costs, and the customer decision-making issues, which will inform future decisions related to gas efficiency measures." The research presented in this paper provides an examination of the infrastructure costs that are required to pursue fuel substitution for gas measures with a VEA.

1.2 Study Overview

This report includes results from a two-phase study that included a secondary research effort (Phase 1) and extensive follow-up primary research surveys (Phase 2). Table 3 summarizes the specific tasks undertaken as part of this research. Detailed descriptions of methods are available in Chapter 3, while detailed results are available in Chapter 4. Interim deliverables, survey instruments, and the FS Infra MS Data Tool are available in the Appendices at the end of this report.

Table 3. Overview of Infrastructure Upgrade Research Tasks and Achieved Survey Targets

Research Task	Task Description
Program Coordination and Scenario Development	Conducted a detailed review of publicly available reports and data to inform the development of various fuel substitution scenarios for application to primary research. Additionally, conducted outreach with various organizations within and outside California to understand what information may be available to inform an assessment of infrastructure upgrade needs and the associated costs. This effort built upon a literature review that was conducted in 2022 and fed into the 2023 Potential and Goals (PGS) study. The documents associated with these efforts can be found in Appendix A. Scenario Development and Literature Review Memos.
Residential Occupant Survey	Conducted a web survey of 642 PG&E/SDG&E/SCE residential electric customers residing in individually metered single-family or multifamily properties (555 included in the analysis, 87 excluded).[14] The original goal was 640 completions. The survey included questions about current equipment in the home and electric panel conditions to determine what proportion of the residential housing stock will require electrical panel or other infrastructure upgrades to pursue fuel substitution measures. Survey questions also explored the impacts of other electrification

[13] Non-exempt measures are considered direct-fired gas measures. Exempt measures include those such as air sealing, which may be associated with gas savings but are gas-fired measures.

[14] The 87 excluded respondents were identified as equity customers and will be included in a separate study focused on the infrastructure needs and costs for equity customers.

Research Task	Task Description
	measures on the need for infrastructure upgrades (i.e., fractional attribution).
Nonresidential Customer Survey	Conducted a web survey of 579 PG&E/SDG&E/SCE nonresidential electric accounts representing occupied buildings. The original goal was 600 completions. The survey asked questions about current equipment in the building and electric panel conditions to determine what proportion of the nonresidential building stock will require panel upgrades or other infrastructure upgrades to pursue fuel substitution upgrades. Survey questions also explored fractional attribution.
Electrician Survey	A web survey of 56 electricians located throughout California was conducted to answer key questions regarding the costs associated with the electric panel and related infrastructure upgrades that are sometimes necessary when installing fuel substitution measures. Electricians who worked in both the residential and nonresidential sectors were permitted to select which sections of the survey they would like to answer (questions regarding residential jobs, nonresidential jobs, or both). The final analysis included 45 residential survey completions and 33 nonresidential survey completions. The original goal was to complete surveys with 35 residential electricians and 35 nonresidential electricians.
Reporting	Used the information from each research task to develop an Excel-based tool (FS Infra MS Data Tool) that maps the results of the panel upgrade needs assessment and cost assessment to the residential housing and nonresidential building stock in California. Completed univariate and multivariate regression analyses to identify which building/occupant characteristics to prioritize in the Excel tool. In addition to this report, drafted a short memo detailing the study methods and key results associated with each research task.

2. Methodology

2.1 Program Coordination and Scenario Development

The team conducted extensive outreach with various stakeholders engaged in programs or research activities that targeted measures or research priorities related to those considered in this study. Outreach included contact with staff at California Investor Owned Utilities (IOUs), national laboratories, California-based universities, stakeholder working groups, and evaluation contractors, among others.

One of the goals of the outreach and coordination efforts was to determine if any other programs or studies had data regarding panel upgrade needs and associated costs that could be leveraged for this study. Although the team identified studies and groups that were investigating electrical panel upgrade needs, none of the contacts the team connected with had data that would be sufficient to reduce the scope of the planned survey tasks; however, the team identified a number of resources that could be used to contextualize the results of primary research tasks.

Another primary goal of this research task was to define the scenarios that would be considered in the fuel substitution infrastructure upgrade needs analysis. In the context of this research, a “fuel substitution scenario” is defined as the full elemental characterization of a unique fuel substitution measure or package of measures and the existing infrastructure (i.e., behind-the-meter electrical, structural, permitting, etc.) and technology baseline conditions that determine the necessary panel/infrastructure upgrades. Fuel substitution scenarios included items such as connecting equipment to the electrical panel, installing a 240-volt circuit, installing an equipment disconnect, upgrading wiring, and installing a 200-amp panel upgrade, among others.

Table 4 presents a summary of the residential and nonresidential fuel substitution measures currently included in the California eTRM documentation. These represent the measures that were considered for fuel substitution applications in the analysis phase of this study.

Table 4. eTRM Fuel Substitution Measures

Fuel Substitution Measures
Residential Measures
Ductless HVAC, Residential, Fuel Substitution (SWHC044)
Heat Pump HVAC, Residential, Fuel Substitution (SWHC045)
Heat Pump Water Heater, Residential, Fuel Substitution (SWWH025)
Cooking Appliances, Residential, Fuel Substitution (SWAP013)
Heat Pump Clothes Dryer, Residential, Fuel Substitution (SWAP014)
Heat Pump Pool Heater, Residential, Fuel Substitution (SWRE005)
Nonresidential Measures
Packaged Heat Pump Air Conditioner, Nonresidential, Fuel Substitution (SWHC046)
Heat Pump Water Heater, Nonresidential, Fuel Substitution (SWWH027)
Fryer, Nonresidential, Fuel Substitution (SWFS021)
Convection Oven, Nonresidential, Fuel Substitution (SWFS022)

Large Heat Pump Water Heater, Nonresidential and Multifamily, Fuel Substitution (SWWH028)

The next two sections describe the scenarios used for data collection in the surveys. The full residential and nonresidential memos associated with this task, including the resulting residential and nonresidential fuel substitution scenarios, are available in Appendix A. Scenario Development and Literature Review Memos.

2.1.1 Residential Scenario Development

For the residential sector measures, the team evaluated the state of current fuel substitution measure installations among residential homes by conducting a detailed review of the CPUC CEDARS EE program tracking data and the TECH Clean California program tracking database by housing type (single-family vs. multifamily). This review included an analysis of which baseline conditions and upgrade scenarios were most common, as well as what type of scenarios received a panel upgrade. Based on this review, the team developed four residential fuel substitution scenarios.

- **Fuel Substitution Scenario 1**. Gas space heating equipment to HVAC heat pump
  - *Baseline Equipment:* Space Heating fueled by natural gas
  - *Fuel Substitution Measure:* Central air source heat pump (ASHP) or mini/multi-split heat pump
  - *Application of Fuel Substitution Measure*: Number of units and capacity of units dependent on baseline equipment; central air source heat pumps applied to units with existing duct systems
- **Fuel Substitution Scenario 2.** Gas water heating to HPWH
  - *Baseline Equipment:* Water heating fueled by natural gas
  - *Fuel Substitution Measure:* HPWH
  - *Application of Fuel Substitution Measure:* Number of units and capacity of units dependent on baseline equipment
- **Fuel Substitution Scenario 3**. Combination of space heating and water heating fuel substitution measures
  - Combination of Scenario 1 and Scenario 2
- **Fuel Substitution Scenario 4.** All-electric housing unit
  - Combination of Scenario 1 and Scenario 2 with the addition of induction cooktops, heat pump dryers, and heat pump pool heaters where applicable (i.e., when they would be placing the equivalent technology fueled by natural gas).

The team used the scenarios to inform the residential occupant and electrician surveys. Once data collection for the residential occupant survey was complete, the team used the responses and electrical panel photos to characterize customers' baseline equipment and their remaining electric panel capacity (i.e., amperage). The team then applied the residential fuel substitution scenarios identified in this task, based on customers' baseline equipment, to identify which fuel substitution measures, or combination of measures, were likely to trigger the need for infrastructure upgrades given a customer's remaining available panel capacity. Further details on the application of the scenarios to the residential occupant data are available in Section 2.2.2.

2.1.2 Nonresidential Scenario Development

On the nonresidential side, the team reviewed the nonresidential fuel substitution measure uptake in the CPUC's California Energy Data and Reporting System (CEDARS) data set. Additionally, the team examined nonresidential sector building type distributions and end-use energy uses reported in the CEC's Commercial End-Use Survey (CEUS) studies. The team analyzed these data sources to understand the diversity of nonresidential buildings (building type, business size, electrical service type, end-use technology, and systems, etc.) and identify the fuel substitution measures with the largest impact and the nonresidential building types likely to be most impacted by decarbonization/electrification. Based on this review, the team developed 11 nonresidential fuel substitution scenarios, which are depicted in Table 5.

Table 5. Nonresidential Fuel Substitution Measure Scenarios for Infrastructure Upgrade Scenarios

FSM Scenario Label	Fuel Substitution Measure Scenario Description	Gas Baseline	Additional Criteria	Fuel Substitution Measure
HVHP_1	Package AC/Gas Furnace converted to Package HP	PSZ AC/GF	Predominant HVAC Type	PSZ HP
HVHP_2	Split-system AC/Gas Furnace converted to Split-system HP	Split-system AC/GF	Predominant HVAC Type	Split-system HP
HPWH_1	Individual gas storage WHs converted to HPWHs	Storage WH	Resid/Large HPWH	Resid & Large HPWH
HPWH_2	Individual gas instantaneous WHs converted to HPWHs	Instantaneous WH	Resid/Large HPWH	Resid & Large HPWH
HPWH_3	Central gas storage WH system converted to Central HPWH system	Storage WH System	Only Multifamily	Large HPWH
HPWH_4	Central boiler WH system converted to Central HPWH system	Boiler System	Only Multifamily	Large HPWH
COOK_1	Gas Fryers to Electric Fryers	Gas Fryer	Only for Restaurants	Elec Fryer
COOK_2	Gas convection ovens to electric convection ovens	Gas Conv Oven	Only for Restaurants	Elec Conv Oven
COOK_3	Gas fryers and convection ovens all electrified	Gas Fryers + Conv Oven	Only for Restaurants	Elec Fryer & Conv Oven
FS_HTG	Gas HVAC and WH to HVAC HP and HPWHs	Gas SpaceHtg + WaterHtg	Only applicable if both HVAC and WH gas baseline	HVAC HP & HPWH
FS_ALL	All applicable fuel substitution measures for the site	All applicable gas	None	All applicable fuel substitution

The team used the nonresidential customer survey results to identify gas measures with a fuel substitution alternative to be included in the scenario analysis. Additional details regarding the nonresidential analysis methodology can be found in Section 2.3.2.

2.2 Residential Occupant Survey

The primary objective of the residential occupant survey was to gather information on the existing equipment from single-family and multifamily customers' homes and to assess their electrical panel capacity (amps) and physical space available for fuel substitution measures. The team leveraged the existing equipment details and the panel capacity information to assess whether a given fuel substitution measure scenario would necessitate an infrastructure upgrade. The full residential occupant survey is available in Appendix C. Survey Instruments.

2.2.1 Sampling and Completes

The CA electric IOUs provided contact information for just over 20,000 single-family electric customers and 11,000 individually metered multifamily electric customers. The team supplemented the IOU customer data with records from the TECH Clean California program tracking data flagged as receiving a panel upgrade as part of their TECH-incented heat pump installation.

The team developed separate single-family and multifamily stratified random samples, stratifying by building standards climate zone (climate zone) to ensure representativeness among customer groups. All customers within each climate zone stratum had an equal chance of being randomly selected, except for the TECH panel upgrade recipients, who were all purposely included. For each stratum, the team included every TECH customer who had a panel upgrade and then supplemented the stratum with a random sample of customers proportional to the number of customers from each IOU in that climate zone.

Assuming a response rate of 5%, the team developed a sample of 8,540 single-family customers. At the time of sampling, the team expected that response rates would be similar in each climate zone and IOU territory, apart from TECH participants, whom the team expected to respond at a higher rate. Table 6 shows the full single-family sample frame, as well as the number of customers invited/sampled and the expected and actual number of survey completes. The final response rate among single-family customers was 4.6%.[15]

Table 6. Single-Family Sample and Completes

Climate Zone	Sample Frame					Total Invited (Sample)	Completes Expected	Completes Actual
	PG&E	SCE	SDG&E	TECH Panel Upgrade Recipient	Total Population			
1	1,223	0	0	0	1,223	501	25	32
2	1,223	0	0	31	1,254	514	26	38
3	1,223	0	0	64	1,287	528	26	49
4	1,223	0	0	8	1,231	505	25	44
5	1,223	813	0	2	2,038	836	42	36
6	0	800	0	16	816	355	18	12
7	0	0	500	33	533	250	13	12

[15] The response rate is slightly higher if we account for the equity customers that were removed from the analysis.

Climate Zone	Sample Frame					Total Invited (Sample)	Completes Expected	Completes Actual
	PG&E	SCE	SDG&E	TECH Panel Upgrade Recipient	Total Population			
8	0	790	0	25	815	355	18	9
9	0	794	0	35	829	355	18	12
10	0	799	500	24	1,323	542	27	15
11	1,223	0	0	15	1,238	521	26	20
12	1,223	0	0	90	1,313	538	27	31
13	1,223	801	0	12	2,036	835	42	9
14	0	811	500	8	1,319	541	27	23
15	0	796	500	17	1,313	538	27	24
16	1,223	790	0	2	2,015	826	41	29
Total	**11,007**	**7,194**	**2,000**	**382**	**20,583**	**8,540**	**427**	**395**

Note: The team invited all TECH panel upgrade recipients to the survey.

Table 7 depicts the multifamily sample frame, stratified sample, and expected and actual survey completions. Like the single-family sample, the team assumed a 5% response rate and developed a sample of 4,260 multifamily customers. The team did not include the eight multifamily customers who received a panel upgrade through TECH because the contact information on file was associated with the landlord or property owner, not the occupant. The final response rate among multifamily customers was 3.8%.[16]

The full residential occupant survey sampling plan is available in Appendix D. Sampling Plans.

[16] The response rate is slightly higher if we account for the equity customers that were removed from the analysis.

Table 7. Multifamily Sample and Completes

Climate Zone	Sample Frame				Total Invited (Sample)	Completes Expected	Completes Actual
	PG&E	SCE	SDG&E	Total			
1	667	0	0	667	253	13	18
2	667	0	0	667	253	13	10
3	667	0	0	667	253	13	22
4	667	0	0	667	253	13	26
5	667	454	0	1,121	426	21	13
6	0	453	0	453	172	9	2
7	0	0	250	250	128	6	2
8	0	466	0	466	177	9	6
9	0	457	0	457	180	9	1
10	0	454	250	704	268	13	12
11	667	0	0	667	253	13	5
12	667	0	0	667	253	13	8
13	667	453	0	1,120	426	21	6
14	0	454	250	704	268	13	6
15	0	460	250	710	270	13	9
16	667	454	0	1,121	426	21	14
Total	**6,003**	**4,105**	**1,000**	**11,108**	**4,260**	**213**	**160**

2.2.2 Analysis

Data Cleaning

The data cleaning process for the residential survey contained three steps: 1) identifying relevant questions and responses in the survey, cleaning those responses, and storing them in new variables for later use; 2) filling in missing panel size information using respondent-submitted images of the electrical panel, or, if this information was unclear from the image, by using cross-segmented average panel sizes by building type and square footage, and 3) dropping equity customers from the dataset because the focus of this study is on market rate customers.

The new variables created in the first step of the cleaning process were used to segment the data during the analysis. The team created the following variables: Climate Region, Utility, Building Type, Panel Size, Open Slots, Building Square Footage, Equipment Purchase Order, Equipment Purchase Cost, and Equipment Purchase Preference. The team created the climate region variable to account for geographic variation in our analyses while maintaining reasonable sample sizes, which was not possible using the CA climate zones. The team used the climate region mapping that was developed as part of the Potential and Goals study and is documented below in Table 8.

Table 8. California Climate Zone to Climate Region Mapping from 2023 Potential and Goals Study

Climate Zone	2023 PG Study CZ Reference Location	Mapping CZ to Climate Region
1	CZ01 - Arcata	Marine
2	CZ02 - Santa Rosa	Marine
3	CZ03 - Oakland	Marine
4	CZ04 - Sunnyvale	Marine
5	CZ05 - Santa Maria	Marine
6	CZ06 - Los Angeles	Marine
7	CZ07 - San Diego	Hot-Dry
8	CZ08 - El Toro	Hot-Dry
9	CZ09 - Pasadena	Hot-Dry
10	CZ10 - Riverside	Hot-Dry
11	CZ11 - Red Bluff	Hot-Dry
12	CZ12 - Sacramento	Hot-Dry
13	CZ13 - Fresno	Hot-Dry
14	CZ14 - China Lake	Hot-Dry
15	CZ15 - El Centro	Hot-Dry
16	CZ16 - Mount Shasta	Cold

For the second step, the team assigned electrical panel size estimates to records with missing panel sizes (i.e., sites where the respondent did not know the existing panel size and a photo was not submitted or it was illegible). The team calculated the average panel size by building type and building square footage among the sites with known existing panel sizes. The average panel sizes within the building type and square footage strata were rounded to the nearest commercially available residential panel sizes: 100, 125, 150, and 200 amps. These values were then assigned to each site with missing panel size information based on the relevant building type and square footage strata.

Data Analysis

The process for analyzing data from the residential survey involved four key steps. The team first gathered information on the quantity and fuel types of all equipment installed in the surveyed homes. We then researched and assigned typical wattages for each piece of electrical equipment. Next, we calculated the remaining panel capacity by comparing the maximum electrical load of all installed equipment against the full panel capacity. Finally, we identified all eligible fuel substitution measures that would require a gas-to-electric equipment replacement, calculated the impact the electric measures would have on the existing panel load, and identified the proportion of sites that would require substantial infrastructure upgrades through either a panel upgrade or panel optimization services.

Mapping Installed Equipment for Each Site: The team used the results of the residential occupant survey to document the quantity and fuel types of installed equipment at each study participant's home. Table 71 in Appendix E. Detailed Data Cleaning and Analysis Methodsdisplays the system and fuel types that respondents could choose from in the survey. The team also asked respondents to indicate the quantity of each system type in their home.

Typical Wattage Values for Installed Equipment: The team relied on information from industry research products, academic articles, DOE studies, and online product listings to find reasonable wattage assumptions for existing electrical equipment. When we could not find wattage information from such sources, we performed general online research and used a minimum of two reliable online sources to produce an estimated wattage assumption. A summary of our research and typical values is provided in Table 71 in Appendix E. Detailed Data Cleaning and Analysis Methods, including our notes for each confirmed wattage value and the source.

Calculating the Remaining Panel Capacity: Calculating the remaining panel capacity involves calculating the existing load and subtracting it from the existing panel size. The team calculated the existing load by following the protocols laid out in the latest version of the National Electrical Code.[17] This involves addressing HVAC and non-HVAC loads separately. For non-HVAC equipment, the NEC recommends adding loads up to 10,000 watts (W) and adding 40% of the remaining load above 10,000 W. An additional 75% demand factor is to be applied if the total quantity of non-HVAC equipment exceeds three. For HVAC equipment, we take the maximum of the cooling load OR the heat pump space heating load and other space heating HVAC loads combined. Cooling HVAC equipment loads are based entirely on a home's square footage.[18] Heat pump space heating loads are the same as cooling loads according to the equations in Table 72. Other space heating loads have a demand factor applied to them that is based on the number of space heating units. The maximum of either the cooling load OR the heat pump space heating and other space heating loads is the total HVAC load. The sum of the general and HVAC loads is divided by 240V to obtain the existing load in amps for residential electrical equipment, and the remaining panel capacity is obtained by subtracting this load from the existing panel size.

Scenario Analysis: The scenario analysis involved creating multiple flags for sites that 1) are eligible for a fuel substitution measure (i.e., the sites that have gas-fueled equipment with a viable electric alternative) and 2) require a panel upgrade based on the remaining panel capacity calculated in the previous step, the number of open slots, or both, alongside the introduced load of the fuel substitution measure. If the introduced load of the substituted measure for a certain building is greater than the remaining panel capacity of that building, then the building is flagged as a site that requires a panel upgrade based on capacity only. If the building has enough capacity but the number of open slots in the existing panel is less than the number of open slots required to add all of the introduced electrical equipment, then the building is flagged as a site that requires a panel optimization upgrade based on space only. Another flag is added for sites that need either a capacity-based upgrade, a panel space-based upgrade, or both. This amounts to the sum of the other two flags.

2.3 Nonresidential Occupant Survey

The primary objective of the nonresidential customer survey was to gather information on the baseline equipment in customers' buildings and their remaining capacity for electrification

[17] *NFPA 70, National Electrical Code* 2023, Article 220

[18] As shown in Table 69, the team assumed one ton of cooling for every 500 square feet of conditioned floor area in residential housing units and one ton of cooling for every 300 square feet of condition floor area in nonresidential buildings.

measures, given the status of their current electrical panel. The team leveraged the baseline equipment details to apply the correct electrification measures in each fuel substitution scenario. Subsequently, the team used respondents' 2022 peak electric demand (as provided by the IOUs) and panel capacity information to assess whether a given fuel substitution scenario would necessitate a panel upgrade. The full nonresidential customer survey is available in Appendix C. Survey Instruments.

2.3.1 Sampling and Completes

The CA electric IOUs provided contact information for 10,978 large nonresidential customers (more than 300,000 kWh usage in 2022) and 20,503 small nonresidential customers (less than 300,000 kWh usage in 2022). The team removed residential accounts, unsuitable accounts for study objectives (e.g., unlikely to be pursuing fuel substitution measures), and sufficiently large and complex business types (such that the amount of questioning needed to determine the equipment, load, and panel configuration would be too onerous) from the sample frame. Due to the lower-than-expected response rate to initial outreach, the team invited the entire sample frame (minus the removed accounts) to complete the survey, leveraging email invitations for all contacts with an email on file and mail outreach for the remaining customers.

After exhausting the initial sample frame, the team requested contact information from the IOUs for an additional 100,000 nonresidential accounts (66,678 small, 33,322 large). Like with the initial sample, the team removed residential, unsuitable, and sufficiently large/complex accounts from the sample frame. The team elected to send outreach to all accounts with a unique email and no mailed outreach.

In total, the team sent 51,333 accounts an invitation to complete the survey. The team achieved 579 responses for a response rate of 1.1%; however, only 476 of the responses were included in the fuel substitution scenario analyses. The team dropped 103 responses from analyses because they either (1) were missing important peak demand data or (2) had a negative remaining capacity value after applying existing electric technology to overall panel capacity. The latter is a limitation of this study, where assumptions were necessary to populate existing panel sizes for all sites and to estimate the wattages associated with electrical equipment.

The full nonresidential customer survey sampling plan is available in Appendix D. Sampling Plans.

2.3.2 Analysis

The data cleaning and analysis processes used by the team are described below.

Data Cleaning

The team largely followed the same data cleaning steps for the nonresidential survey as it did for the residential survey, absent the need to remove equity customers from the analysis. One difference within the nonresidential dataset is that the team had to assign missing square footage values. To assign these values, the team created square footage bins by building type and square footage for the sites with known information. We created the bins, following U.S. Census bin sizes[19], from survey responses to the building square footage question, and we

[19] U.S. Census Bureau; *Statistical Abstract of the United States, Table 1006*

cross-tabulated them with the building type to understand the frequency distribution of existing building size bins by building type. We used the known building size distributions by building type, to assign the unknown records to an appropriate building size bin. To get a numerical square footage value for these unknown records, we averaged the known square footages within each bin and assigned those average values to the unknown building sizes according to the bins they have been assigned. A detailed example of this process is presented in Appendix E. Detailed Data Cleaning and Analysis Methods.

As with the residential analysis, the team assigned electrical panel size estimates to records with missing panel sizes (i.e., sites where the respondent did not know the existing panel size and a photo was not submitted or it was illegible). The team calculated the average panel size by building type and building square footage among the sites with known existing panel sizes. The team then rounded those mean panel sizes to the closest available nonresidential panel sizes. The range of panel sizes applied to those with missing values includes the following: 100, 125, 200, 225, 250, 300, 400, 600, 800, 1,000, 2,000, 3,000 and 4,000 amps.

Data Analysis

Data analysis of the nonresidential survey was identical to the residential survey, except that the equipment that survey respondents can choose from and the wattage assumptions are different. These are tracked in Table 71 and Table 72 in Appendix E. In addition, we were provided with an electric peak demand value for each nonresidential site, which allowed us to size the maximum existing load on the panel - and consequently, determine the remaining panel capacity - without needing to know all the installed electrical equipment on site. To calculate the remaining panel capacity, we divide the peak demand value by 240V to get the maximum existing load on the panel in amps and then subtract the result from the existing panel size to obtain the remaining panel capacity value that is essential for the scenario analysis.

2.4 Electrician Survey

The primary objective of the electrician survey was to gather estimates on the project costs for the residential and nonresidential electrical upgrades that could be necessitated by each of the fuel substitution scenarios. Additionally, given the diversity and complexity of panel and wiring configurations in nonresidential buildings, the survey asked nonresidential electricians to characterize the typical electrical configurations of different business types they worked in (office, retail, restaurant, etc.). The full electrician survey is available in Appendix C. Survey Instruments.

2.4.1 Sampling and Completes

The team drew electrician contacts from the Dunn and Bradstreet Hoovers Database, exporting records from licensed electrician companies in California with emails on file. All companies exported did electrical work in either the residential sector, nonresidential sector, or both. The team spot-checked individual electrician's websites to ensure they were the correct target for the electrician survey. The data export often had multiple emails for a single company. To avoid inundating companies with emails, we split survey outreach into "waves" and only sent up to three emails to a single company at each time. Additionally, the team supplemented the sample with contractors registered as part of the TECH Clean California program.

The initial target for survey completions was 70. Across the outreach waves, the team sent 1,734 unique emails associated with electricians in CA. Overall, 56 electricians completed the survey with a response rate of 3.2%. Electricians who worked in both the residential and nonresidential sectors were permitted to select which sections of the survey they would like to answer (questions regarding residential jobs, nonresidential jobs, or both). The final analysis included 45 residential and 33 nonresidential survey completions.

2.4.2 Analysis

The electrician survey asked electricians to estimate the cost for them to connect select fuel substitution measures, given the existing technology and what electrical work would be needed (based on the current condition of a customer's electric panel, wiring, and circuits). The electricians separated their cost estimates by labor, materials, and miscellaneous for each scenario. The team averaged the estimates for each cost scenario across electricians to calculate the minimum, maximum, and mean costs associated with each scenario. The team isolated the costs associated with individual pieces of electrical work by calculating the difference between cost scenarios with the same fuel substitution scenario but varying electrical work needs. Table 9 presents the combinations of residential fuel substitution scenarios and electrical work needed for which the surveyed electricians provided cost estimates.

Table 9. Electrician Survey Residential Fuel Substitution Electrical Work Cost Scenarios

Electrical Work Cost Scenario	
Fuel Substitution Scenario	**Electrical Work Required Based on Condition of Panel/Wiring/Circuit**
Gas furnace and CAC to central ASHP	Connect ASHP
Gas furnace and CAC to central ASHP	Connect ASHP and upgrade wiring
Gas furnace, no CAC, to central ASHP	200A panel upgrade, 240V circuit and disconnect, connect ASHP
Gas wall furnace to ductless ASHP	Install 240V circuit and disconnect, connect ductless ASHP
Gas wall furnace to ductless ASHP	200A panel upgrade, 240V circuit and disconnect, connect ductless ASHP
Gas wall furnace to ductless ASHP	200A panel upgrade, 240V circuit and disconnect, wiring upgrade, connect ductless ASHP
Replace 50-gallon gas DHW with 240V HPWH	Install 240V circuit and disconnect, connect ASHP
Replace 50-gallon gas DHW with 240V HPWH	200A panel upgrade, 240V circuit and disconnect, connect HPWH
Replace 50-gallon gas DHW with 240V HPWH	200A panel upgrade, 240V circuit, wiring upgrade, connect HPWH
Gas furnace and CAC to central ASHP and gas DHW to 240V HPWH	Install 240V circuit and disconnect HPWH, connect ASHP and HPWH
Gas furnace and CAC to central ASHP and gas DHW to 240V HPWH	200A panel upgrade, 240V circuit and disconnect, connect ASHP and HPWH
Gas furnace and CAC to central ASHP and gas DHW to 240V HPWH	200A panel upgrade, 240V circuit and disconnect, wiring upgrade, connect ASHP and HPWH
Gas-powered range to induction range	Connect induction range
Gas-powered range to induction range	200A panel upgrade, connect induction range
Gas-powered range to induction range	200A panel upgrade, 240V circuit and disconnect, wire upgrade, connect induction range

Table 10 presents the combination of nonresidential fuel substitution scenarios and electrical work needed for which the surveyed electricians provided cost estimates.

Table 10. Electrician Survey Nonresidential Fuel Substitution Electrical Work Cost Scenarios

Electrical Work Cost Scenario	
Fuel Substitution Scenario	Electrical Work Required Based on Condition of Panel/Wiring/Circuit
Replace packaged AC/gas furnace with package HP and electric resistance back-up	Connect HP
Replace packaged AC/gas furnace with package HP and electric resistance back-up	600A panel upgrade, connect HP
Replace packaged AC/gas furnace with package HP and electric resistance back-up	200A panel upgrade, connect HP
Replace packaged AC/gas furnace with package HP and electric resistance back-up	600A panel upgrade, wiring upgrade, connect HP
Replace 60-gallon gas DHW with 80-gallon HPWH	Install 240V circuit and disconnect, connect HPWH
Replace 60-gallon gas DHW with 80-gallon HPWH	400A panel upgrade, 240V circuit and disconnect, connect HPWH
Replace 60-gallon gas DHW with 80-gallon HPWH	400A panel upgrade, 240V circuit and disconnect, wiring upgrade, connect HPWH
Replace nonresidential gas fryer with 12kW electric fryer	Add circuit and disconnect, connect fryer
Replace nonresidential gas fryer with 12kW electric fryer	400A panel upgrade, add circuit and disconnect, connect fryer
Replace nonresidential gas fryer with 12kW electric fryer	200A panel upgrade, add circuit and disconnect, connect fryer
Replace nonresidential gas fryer with 12kW electric fryer	400A panel upgrade, add circuit and disconnect, upgrade wiring, connect fryer
Replace nonresidential gas oven with 11kW electric convection oven	Add circuit and disconnect, connect oven
Replace nonresidential gas oven with 11kW electric convection oven	600A panel upgrade, add circuit and disconnect, connect oven
Replace nonresidential gas oven with 11kW electric convection oven	200A panel upgrade, add circuit and disconnect, connect oven
Replace nonresidential gas oven with 11kW electric convection oven	600A panel upgrade, add circuit and disconnect, upgrade wiring, connect oven
Replace nonresidential gas oven with 11kW electric convection oven and nonresidential gas fryer with 12kW electric fryer	Add circuit and disconnect, connect oven and fryer
Replace nonresidential gas oven with 11kW electric convection oven and nonresidential gas fryer with 12kW electric fryer	600A panel upgrade, add circuit and disconnect, connect oven and fryer

Electrical Work Cost Scenario	
Fuel Substitution Scenario	Electrical Work Required Based on Condition of Panel/Wiring/Circuit
Replace nonresidential gas oven with 11kW electric convection oven and nonresidential gas fryer with 12kW electric fryer	200A panel upgrade, add circuit and disconnect, connect oven and fryer
Replace nonresidential gas oven with 11kW electric convection oven and nonresidential gas fryer with 12kW electric fryer	600A panel upgrade, add circuit and disconnect, upgrade wiring, connect oven and fryer
Replace forced-air-gas-fired furnace with ASHP and 60-gallon DHW with 80-gallon HPWH	Add circuit and disconnect, connect HPWH and ASHP
Replace forced-air-gas-fired furnace with ASHP and 60-gallon DHW with 80-gallon HPWH	400A panel upgrade, add circuit and disconnect, connect HPWH and ASHP
Replace forced-air-gas-fired furnace with ASHP and 60-gallon DHW with 80-gallon HPWH	200A panel upgrade, add circuit and disconnect, connect HPWH and ASHP
Replace forced-air-gas-fired furnace with ASHP and 60-gallon DHW with 80-gallon HPWH	400A panel upgrade, add circuit and disconnect, upgrade wiring, connect HPWH and ASHP

2.5 Regression Analysis

The team conducted a regression analysis on the residential occupant and nonresidential customer survey data in two stages. The first stage was a correlation analysis in which we leveraged univariate methods to assess the extent and direction of the **individual** relationships between each of the variables of interest and the panel upgrade outcome. We chose to complete the correlation analysis first because it allowed us to provide timely preliminary findings, formulate preliminary hypotheses, and identify if there were any relationships that warranted a regression analysis. Based on the results of the correlation analysis, the second stage was a multivariate regression analysis conducted to assess the **combined** relationship between the variables of interest and the panel upgrade outcome. Compared to correlation analysis, multivariate regression analysis is more appropriate for trying to explain or predict a given customer's need for a panel upgrade because it accounts for how a variety of unique customer characteristics interact to affect that outcome.

2.5.1 Residential Data

The team conducted a univariate analysis to assess the relationship between each variable and the need for a panel upgrade. Subsequently, we conducted a multivariate regression analysis based on the results of the univariate analyses, summarized in Table 11. We completed a multivariate regression analysis for each scenario. The independent variables included all variables that had a statistically significant correlation with the outcome variable across **any** of the univariate analyses. We chose this approach because variables reported as insignificant in a single scenario's univariate analysis may be meaningful predictors in a multivariate regression analysis once you control for other possible predictors of the panel upgrade outcome. We chose to include climate region (from the potential and goals study) rather than CEC building climate zone in our multivariate regression analyses. We could not include both variables due to their correlation with one another.[20]

Table 11. Residential Occupant Survey Multivariate Regression Results

Characteristic	Space Heating Only		Water Heating Only		Space Heating and Water Heating		All Applicable Equipment	
	Direction	Adjusted Odds Ratio	Direction	Adjusted Odds Ratio	Direction	Adjusted Odds Ratio	Direction	Adjusted Odds Ratio
Age of Home (Reference: 2000 or later)								
Before 1950								
1950-1975	Positive	2.1						
1976-1999	Positive	2.1	Positive	1.6			Positive	1.7
Unsure								
Climate Region (Reference: Cold)								
Hot-Dry							Positive	2.4
Marine	Positive	2.3	Positive	2.1	Positive	2.9	Positive	3.8
Baseline Equipment & Systems								
Electrical Cooling System[21]	Positive	1.3	Positive	1.2	Positive	1.4	Positive	1.3
Electrical Space Heating System	Negative	0.6			Negative	0.4	Negative	0.7
Electrical Water Heating System			Negative	0.1	Negative	0.1		
Panel Size	Negative	0.99	Negative	0.99	Negative	0.99	Negative	0.99
Solar Panels								
Electric Vehicle								

Included in multivariate analysis and effect is significant (p < 0.10)
Included in multivariate analysis but effect not significant (p > 0.10)
Excluded from multivariate analysis because effect not significant in univariate analysis

The team produced adjusted odds ratios to aid in the interpretation of the results. In a multivariate regression, an adjusted odds ratio represents the relative likelihood of the outcome happening when a given factor is true while holding all the other independent variables in the analysis constant. For categorical variables, we needed to choose one category to be the "reference." The results represent whether being in another category makes you more or less likely to need the upgrade than being in the reference category (e.g. if having a home built

[20] This analysis is based on the available relevant data and does not perfectly explain the need for a panel upgrade, suggesting that there are other factors that affect a customer's need for a panel upgrade beyond those observed in the currently available data. The pseudo-adjusted R-squared across the four models ranged from 0.06 to 0.13, which means that the models explain 6% to 13% of the variation in panel upgrade outcomes.

[21] Between univariate analysis and multivariate analysis, the direction of the relationship for the existing number of electrical cooling system changed from negative to positive. The potential sources of the reversal can be multi-collinearity or suppression effect after we controlled for other covariates. While multi-collinearity requires further statistical exploration, the suppression effect in itself is not problematic.

between 1976 and 1999 makes you more or less likely to need a panel upgrade than having a home built in 2000 or later). It is possible to obtain a different result with a different reference category; however, we tried to choose logical reference categories where they existed (e.g., being in the coldest region or having the newest home).

The results of this analysis can be used to identify customers that are particularly likely or unlikely to require a panel upgrade. That said, the observed variables only partially explain the need for a panel upgrade, and there are likely other factors that affect the need for a panel upgrade but are not available for analysis currently given data limitations.

Overview of Multivariate Regression Analysis findings

Age of Home: In general, we observed a consistent relationship between the age of the home and the likelihood of a panel upgrade being required across the four scenarios. Compared to newer homes, slightly older homes had a higher likelihood of requiring panel upgrades. This was particularly true for homes built between 1976 and 1999, in comparison to the homes built in 2000 or later.

Climate Region: Compared to the cold region, being in the marine region increased the likelihood of requiring a panel upgrade across all four scenarios. In an all-equipment scenario, being in the hot-dry region increased the likelihood of requiring a panel upgrade compared to the cold region.

Baseline Equipment and Systems:

- In general, age of home and climate region have a stronger relationship with the panel upgrade outcome than do existing baseline systems, but there are still some relationships.
- Across all scenarios, customers were more likely to require panel upgrades if they had an existing electrical cooling system.
- Having existing electric space heating and/or electric water heating made customers less likely to need a panel upgrade.
- Having a larger panel size makes customers slightly less likely to need a panel upgrade across all scenarios; however, this effect is very small.

2.5.2 Nonresidential Data

Similar to the procedure used for the residential data, the team completed a multivariate regression analysis based on the results of the univariate analyses, including all variables that were significant across **any** of the univariate analyses as independent variables. The results of the multivariate regression analysis are summarized in Table 12. For two specific scenarios-Space Heating Only and Cooking Equipment, we were unable to conduct a robust multivariate regression due to limited variation in survey responses, particularly with respect to the building type variable. [22]

[22] This analysis is based on the available relevant data and does not perfectly explain the need for a panel upgrade, suggesting that there are other factors that affect a customer's need for a panel upgrade beyond those observed in the currently available data. The pseudo-adjusted R-squared across the four models ranged from 0.05 to 0.26, which means that the models explain 5% to 26% of the variation in panel upgrade outcomes.

Table 12. Nonresidential Customer Survey Multivariate Regression Results

Characteristic	Water Heating Only		Space Heating and Water Heating Equipment		All Applicable Equipment	
	Direction	Adjusted Odds Ratio	Direction	Adjusted Odds Ratio	Direction	Adjusted Odds Ratio
Building Type (Reference: Retail, Restaurant & Supermarket)						
Agriculture, Automotive & Industrial					Negative	0.3
Education, Lodging & Offices						
Healthcare						
Miscellaneous, Religious & Storage						
Climate Region (Reference: Cold)						
Hot-Dry	Negative	0.2	Negative	0.3	Negative	0.3
Marine	Negative	0.3	Negative	0.3		
Baseline Equipment & Systems						
Electrical Cooling System						
Electrical Space Heating System	Positive	1.3	Negative	0.4		
Electrical Water Heating System	Negative	0.1	Negative	0.4	Negative	0.5
Panel Size						
Solar Panels						
EV Chargers						

Included in multivariate analysis and effect is significant (p < 0.10)
Included in multivariate analysis but effect not significant (p < 0.10)
Excluded from multivariate analysis because effect not significant in univariate analysis

Overview of Multivariate Regression Analysis Findings

Building Type: For the all equipment scenario, we found that compared to the retail, restaurants & supermarkets category, customers in the agriculture, automotive & industrial category were slightly less likely to require a panel upgrade after controlling for other building types, climate region, and baseline equipment and systems. However, this was not consistent across all three included scenarios.

Climate Regions: Compared to the cold region, being in the hot-dry region decreased the likelihood of requiring a panel upgrade across all included scenarios. In the water heating only and space heating and water heating equipment scenarios, being in the marine region compared to the cold region also decreased the likelihood of requiring a panel upgrade.

Baseline Equipment and Systems:

- In general, climate regions have a more consistent relationship with the panel upgrade outcome than do existing baseline systems, but there are still some relationships.
- Across all scenarios, customers are less likely to require a panel upgrade if they have an existing electric water heating system.
- Having existing electric space heating does not exhibit a consistent relationship with the need for a panel upgrade across all three scenarios. For the water heating only scenario, customers were more likely to require a panel upgrade if they had existing electric space heating. On the other hand, customers were less likely to require a panel upgrade under the space heating & water heating equipment scenario if they had existing electric space heating.
- Having a larger baseline panel size, EV charger, or solar panels does not change the likelihood of the panel upgrade outcome.

Application of Results to FS Infra MS Data Tool

The team used the results of the residential and nonresidential multivariate regression analyses to identify how to best present the study results in the FS Infra MS Data Tool and this report.

2.6 FS Infra MS Data Tool

The team used the residential occupant and nonresidential customer surveys to understand the level of infrastructure upgrades that would be needed to support fuel substitution and the electrician survey to estimate the costs associated with said upgrades. The team incorporated the results of all three survey efforts into an Excel-based FS Infra MS Data Tool. The final workbook, found in Appendix G. FS Infra MS Data Tool, includes residential infrastructure upgrade and pricing results by fuel substitution scenario, climate region, building type, and building vintage and nonresidential infrastructure upgrade and pricing results by fuel substitution scenario, climate region, and building type. The workbook also includes overall weighted statewide results by sector, fuel substitution scenario, building type, and a summary of the electrician pricing estimates from the residential and nonresidential electrician surveys.

The team applied a number of adjustments to the survey results in the development of the FS Infra MS Data Tool; these adjustments are discussed at a high-level below. The team provided a separate memo fully detailing the development of the workbook. This memo is included in Appendix H. FS Infra MS Data Tool Memo.

Adjusted Workforce Implementation Results – The FS Infra MS Data Tool includes two types of results related to customers' infrastructure upgrade needs: (1) Technical Engineering Needs Assessment results and (2) Workforce Implementation Likelihood results. The Technical Engineering Needs Assessment results detail customers' infrastructure needs based solely on our engineering-based analysis of whether a given fuel substitution scenario would necessitate additional panel capacity and/or breaker slots. The Technical Engineering Needs Assessment results closely align with infrastructure need data from TECH Clean California program data.

The Workforce Implementation Likelihood results were an added exercise that attempted to account for the fact that, in the field, electricians may do or recommend something different based on their own practices that may not follow the method we used to determine technical needs. Specifically, surveyed electricians reported not always using panel optimization when technically feasible to create space in a panel with no open breaker slots but remaining capacity, instead electing to do a full panel upgrade regardless in some cases.

Residential and nonresidential electricians reported the frequency with which they optimized rather than upgraded panels, indicating they “never,” “rarely,” “sometimes,” “often,” or “always” optimized. Nonresidential electricians provided responses by business type and the team calculated the average response distribution across types. The team assigned percentages to each of these selections (never – 0%, rarely – 25%, sometimes – 50%, often – 75%, always – 100%) and used the distribution of electricians’ responses to calculate a weighted average representing the percentage of the time electricians apply optimization strategies when it is technically feasible (52% for residential, 53% for nonresidential). The results of these calculations are detailed in Section 3.1.5 for residential electricians and Section 3.2.5 for nonresidential electricians. The team then multiplied the Technical Engineering Needs Assessment results for optimization by the adjustment factor to estimate the percentage of customers requiring optimization that would likely receive optimization given electrician practices, adding the percentage of customers requiring optimization but more likely to receive an upgrade to the infrastructure upgrade category. As such, compared to the Technical Engineering Needs Assessment results, the Workforce Implementation Likelihood results have higher rates of upgrade needs and lower rates of optimization needs. The FS Infra MS Data Tool Memo included in Appendix G. FS Infra MS Data Tool Memo provides an example of how this adjustment was implemented.

Typical Panel Optimization Cost – Given that electricians cited sub-panels as the primary optimization approach used most frequently, the team elected to apply the average cost associated with a sub-panel as a proxy for the average panel optimization cost. Panel optimization pricing in the workbook also accounts for the simple connection costs associated with the fuel substitution measure, in addition to the price of the subpanel.

Multifamily Adjustment Factor – The electrician survey found that, on average, multifamily projects are typically 13% more expensive than a comparably scoped single-family project. The team applied a 113% adjustment factor to the single-family cost estimates to develop cost estimates for each scenario for multifamily buildings.

Electrician Cost Estimates – The team applied the cost estimates from the electrician survey to specific fuel substitution scenarios. A full list of scenarios and the associated price mapping is detailed in Appendix H. FS Infra MS Data Tool Memo. Prior to finalizing total cost estimates for the data tool, the team removed outliers from each electrician scenario analysis by removing values that fell outside high and low thresholds equal to 1.5 times the interquartile range (IQR).

Accounting for Multiple Applicable Measures – The electrician survey asked electricians to provide cost estimates for connecting a single heater or water heating system and the cost of connecting both a space heating system and a water heating system. The electrician survey scenarios did not account for the fact that a home or business may have multiple measures eligible for fuel substitution, even within the same end-use. To account for this limited full-electrification scenario, the team asked electricians how costs would change if an additional heat pump technology was connected during the same visit. The team used these responses to adjust the scenario pricing estimates provided by electricians.

2.7 Study Limitations

As with any research, it is important that we consider the methodological limitations of this research when interpreting the results.

- **Self-Report Customer Surveys:** The residential occupant and nonresidential customer surveys asked customers technical questions about the equipment in their homes/businesses as well as specific details such as the equipment's fuel source and age, among other things. Additionally, the surveys asked respondents a series of questions about their electrical panel. The surveys requested that respondents provide a photo of their electrical panel, but it was not required. The team leveraged panel photos to confirm respondents' survey answers when provided; however, not all respondents provided a panel photo. The team used respondents' self-report answers to estimate the remaining panel capacity and determine how to apply the relevant fuel substitution scenarios; as such, the validity of the analyses is deeply dependent on respondents' ability to accurately answer technical questions about their equipment and panel.
- **Low Response Rates:** Both the residential occupant and nonresidential customer surveys achieved lower-than-expected response rates (3.8% for single-family residential and 1.1% for nonresidential). In the case of nonresidential customers, the response rate was so low that the team requested additional sample. Low response rates raise questions about the representativeness of respondents compared to the broader population of interest.
- **Small Sample Sizes:** The data tool associated with this report provides the relative precision, at the 90% confidence level, for the scenario results associated with a wide range of strata for both residential and nonresidential customers. Many strata have relative precision results that are greater than 10% at the 90% confidence level due to small sample sizes. This varies based on the sector, strata, and fuel substitution scenario being considered. While there are some key strata that display relative precisions below 10% at the 90% confidence level, users should understand there are statistical limitations associated with some of these results.
- **Equipment and Wattage Assumptions:** The team used the existing electrical panel information (total amperage, available slots) and equipment information (type, quantity, fuel type, age) to calculate an estimate of the remaining available panel capacity. Given the limited details about the equipment the team felt respondents could accurately self-report, the team had to make equipment and wattage assumptions to estimate the amount of wattage occupied by the existing systems.
- **Estimating Remaining Panel Capacity in Nonresidential Buildings Via Peak Demand:** Due to the complexity of nonresidential buildings, the team determined it would not be possible to build bottom-up electrical load calculations as was done on the residential side. Instead, the team used electrical peak demand values provided by the IOUs to estimate the total electrical load associated with each nonresidential site. The team believes this is a reasonable approach given the scope of the study, but it is highly unlikely that the electrical load estimated using peak demand values is equivalent to those that would have been calculated using bottom-up NEC calculations.
- **Electrician Estimates Based on Generic Scenarios:** The team drafted the electrician survey to include cost scenarios that covered the fuel substitution scenarios developed as part of the fuel substitution scenario development task. The survey split each fuel substitution scenario into multiple cost scenarios that varied in the electrical work needed to connect the electrification measure given the condition (or existence) of the panel, wiring,

240V circuit, and disconnect. The team attempted to include a robust number of scenarios to collect as much information as possible but limited the survey to generic scenarios to avoid respondent burnout.

- **Lack of Data on Key Infrastructure Items Influencing Pricing:** The team leveraged existing data from the IOUs' customer databases and the residential occupant and nonresidential customer surveys to capture as much information as possible for contextualizing customers' baseline equipment and electrical needs; however, the team lacked a number of details that affect the cost for an electrician to connect a given fuel substitution measure. These missing details included wiring quality, distance of equipment from the panel, and presence of disconnect/required circuits. The IOUs do not collect this information, and the team deemed this information too technical for respondents to provide reliably.

3. Results

This section of the report provides detailed results associated with both the residential and nonresidential sector analyses. This includes the fuel substitution scenario results, supplemental survey analyses, and electrician survey results. *Please note that the electrician survey results presented here do not exclude outliers, while the cost data presented in the FS Infra MS Data Tool does*. Some of the fuel substitution scenario results presented in the data tool, notably those that account for the adjustment factors presented in Section 2.6, are not presented here and are only captured in the data tool. The data tool is intended to provide additional usability and flexibility for readers, which is why it includes additional details.

3.1 Residential Sector Results

Below, we present the results of the residential occupant and electrician surveys, along with the results of the residential fuel substitution scenario analysis.

3.1.1 Home Characteristics

The following section details the key home characteristics of the 555 residential occupant survey respondents included in the analysis.

Table **13** shows the breakdown of respondents by housing type and the relative precision achieved for each segment.

Table 13. Residential Housing Type

Housing Type	Respondents		Relative Precision @ 90% Confidence
	Count	Percentage	
Single-family	395	71%	±4%
Multifamily	160	29%	±7%
Total	**555**	**100%**	**±4%**

The team also examined responses by climate region. Table 14 depicts the distribution of respondents across the climate regions by housing type. More than half of the respondents for single-family (53%) and multifamily (57%) building types came from the marine climate region.

Table 14. Residential Climate Region by Housing Type

Climate Region	Single-Family		Multifamily	
	Count	Percentage	Count	Percentage
Cold	29	7%	14	9%
Hot-Dry	155	39%	55	34%
Marine	211	53%	91	57%
Total	**395**	**100%**	**160**	**100%**

Table 15 depicts the distribution of respondents by building vintage and housing type.

Table 15. Residential Building Vintage by Housing Type

Building Vintage	Single-Family		Multifamily	
	Count	Percentage	Count	Percentage
Before 1950	65	16%	10	6%
1950-1975	114	29%	26	16%
1976-1999	136	34%	44	28%
2000 or Later	74	19%	38	24%
Unsure	6	2%	42	26%
Total	**395**	**100%**	**160**	**100%**

Table 16 depicts the distribution of respondents across gas utility by housing type.

Table 16. Residential Gas Utility by Housing Type

Gas Utility	Single-Family		Multifamily	
	Count	Percentage	Count	Percentage
Pacific Gas & Electric (PG&E)	171	43%	88	55%
Southern California Gas (SoCalGas/SCG)	82	21%	26	16%
San Diego Gas & Electric (SDG&E)	30	8%	10	6%
Another Provider	11	3%	5	3%
Don’t Have Natural Gas	97	25%	26	16%
Unsure	4	1%	5	3%
Total	**395**	**100%**	**160**	**100%**

Table 17 depicts the fuel types other than electricity and natural gas that residential survey respondents reported using to heat their home/water or cook by housing type. As shown, propane was the most common fuel type mentioned amongst both single-family (30%) and multifamily (14%) respondents.

Table 17. Residential Fuel Types Other Than Electricity/Gas by Housing Type

Fuel Besides Electricity/Gas	Single-Family (n=395)	Multifamily (n=160)
None of These	57%	73%
Propane	30%	14%
Wood	18%	8%
Diesel/Gas Generator	4%	2%
Wood Pellets	3%	3%

Fuel Besides Electricity/Gas	Single-Family (n=395)	Multifamily (n=160)
Other Fuel Source	4%	2%
Unsure	0%	5%
Kerosene	1%	1%

Note: Responses do not sum to 100%, as multiple responses were permitted.

Table 18 depicts the distribution of the square footage of respondents' homes by housing type.

Table 18. Residential Square Footage by Housing Type

Square Footage	Single-Family		Multifamily		Total	
	Count	Percentage	Count	Percentage	Count	Percentage
Less than 250 sq. ft.	0	0%	1	1%	1	<1%
Between 250 and 500 sq. ft.	1	<1%	10	6%	11	2%
Between 501 and 750 sq. ft.	7	2%	33	21%	40	7%
Between 751 and 1,000 sq. ft.	27	7%	33	21%	60	11%
Between 1,001 and 1,250 sq. ft.	37	9%	27	17%	64	12%
Between 1,251 and 1,500 sq. ft.	61	15%	17	11%	78	14%
Between 1,501 and 2,000 sq. ft.	109	28%	14	9%	123	22%
Between 2,001 and 2,500 sq. ft.	64	16%	9	6%	73	13%
Between 2,501 and 3,000 sq. ft.	42	11%	2	1%	44	8%
Between 3,001 and 4,000 sq. ft.	38	10%	2	1%	40	7%
Between 4,001 and 5,000 sq. ft.	5	1%	1	1%	6	1%
Greater than 5,000 sq. ft.	1	<1%	0	0%	1	<1%
Unsure	3	1%	11	7%	14	3%
Total	**395**	**100%**	**160**	**100%**	**555**	**100%**

Table 19 depicts the average number of levels/stories, bedrooms, and bathrooms in respondents' homes by housing type.

Table 19. Residential Average Number of Stories, Bedrooms, and Bathrooms by Housing Type

Characteristic	Single-Family		Multifamily		Total	
	Count	Average	Count	Average	Count	Average
Number of Levels/Stories	383	1.5	154	1.5	537	1.5
Number of Bedrooms	395	3.1	160	1.9	555	2.8
Number of Bathrooms	395	2.4	160	1.7	555	2.2

Note: The number of levels/stories was not asked of those residing in a mobile/manufactured home, a boat/RV motorhome, or a camper.

Table 20 depicts the distribution of residential respondents with knob and tube wiring in their homes by housing type. Overall, nearly one-quarter (23%) of all respondents were unsure if their home had knob and tube wiring. The presence of knob and tube wiring has the potential to significantly increase the infrastructure costs associated with fuel substitution measure adoption.

Table 20. Residential Presence of Knob and Tube Wiring and Housing Type

Presence of Knob and Tube Wiring	Single-Family		Multifamily		Total	
	Count	Percentage	Count	Percentage	Count	Percentage
Yes	11	3%	1	1%	12	2%
No	322	82%	96	60%	418	75%
Unsure	62	16%	63	39%	125	23%
Total	**395**	**100%**	**160**	**100%**	**555**	**100%**

3.1.2 Condition of Existing Electric Panel

The condition of a customer's existing electric panel is a determinate of whether their home can support an electrification measure without additional amperage or slots. Table 21 presents the average total and available capacity of respondents' existing panels overall and by housing type, climate region, and building vintage. Single-family homes had greater total and available capacity than multifamily homes (175 amp vs. 136 amp total capacity and 85 amp vs. 59 amp available capacity). For single-family homes, homes in the hot-dry region had the greatest total and available capacity (178 amps and 87 amps), followed closely by those in the marine region (174 amps and 86 amps) and lastly, the cold region (171 amps and 71 amps). In contrast, multifamily homes in the cold region had the highest total capacity (148 amps). Despite this, among multifamily respondents, the marine region had the highest available capacity (63 amps). Regarding building vintage, homes built in 2000 or later had the highest total capacity for both single-family and multifamily homes (195 amps and 145 amps); however, single-family and multifamily homes built before 1950 had the highest available capacity (99 amps and 66 amps). The average panel capacity and remaining available capacity results suggest that a large portion of homes built in the older vintage categories have already received a panel upgrade at some point.

Table 21. Residential Panel Capacity by Housing Type, Climate Region, and Building Vintage

Segment	Single-Family			Multifamily		
	n	Average Panel Capacity	Average Panel Capacity Available	n	Average Panel Capacity	Average Panel Capacity Available
Overall	395	175	85	160	136	59
Climate Region						
Cold	29	171	71	14	148	54
Hot-Dry	155	178	87	55	136	52
Marine	211	174	86	91	134	63
Home Age						
Before 1950	65	170	99	10	138	66
1950-1975	114	169	88	26	131	49
1976-1999	136	172	75	44	138	60
2000 or Later	74	195	85	38	145	60
Unsure	6	183	122	42	128	61

Table 22 depicts the average number of total and available slots on respondents' electrical panels by housing type. Single-family home electric panels had more panel slots and more empty slots available than multifamily electric panels. Single-family respondents in marine regions had the most panel slots (23.2 slots), followed by those in the cold region (23.0 slots) and hot-dry region (22.2 slots); however, single-family respondents in the hot-dry region had the most empty panel slots available (4.5 slots). Among multifamily respondents, those in the cold region had the most total and available panel slots (23.1 slots total, 5.9 slots available), followed by the marine region (16.9 slots total, 4.1 slots available) and hot-dry region (16.3 slots total, 2.8 slots available). Homes built in 2000 or later had the most slots overall (25.4 slots single-family, 24.4 slots multifamily) and the most empty slots (4.7 slots single-family, 5.2 slots multifamily).

Table 22. Residential Panel Slots by Housing Type, Climate Region, and Building Vintage

Segment	Single-Family			Multifamily		
	n	Average Panel Slots	Average Empty Panel Slots Available	n	Average Panel Slots	Average Empty Panel Slots Available
Overall	395	22.8	4.2	160	17.3	3.8
Climate Region						
Cold	29	23.0	4.3	14	23.1	5.9
Hot-Dry	155	22.2	4.5	55	16.3	2.8
Marine	211	23.2	3.9	91	16.9	4.1
Home Age						
Before 1950	65	22.9	4.2	10	16.8	3.5
1950-1975	114	20.7	4.5	26	14.6	2.3
1976-1999	136	23.3	3.6	44	16.5	3.3
2000 or Later	74	25.4	4.7	38	24.4	5.2
Unsure	6	19.5	4.0	42	13.4	4.1

Figure 1 depicts customers' number of open slots by remaining capacity by housing type. Notably, many homes (both single-family and multifamily) have remaining panel capacity but have no available slots on their electric panel. These results indicate a larger portion of respondents' homes are suitable for panel optimization services.

Figure 1. Open Slots by Remaining Capacity (amps) by Housing Type

Table 23 depicts the percentage of respondents that indicated completing a panel upgrade or other upgrade/modification in the past by housing type. Approximately 31% of single-family and 5% of multifamily respondents indicated they completed a panel upgrade in the past.

Table 23. Residential Past Panel Upgrade

Previous Electrical Panel Upgrade to Expand Capacity/Amperage	Single-Family (n=395)	Multifamily (n=160)
Yes	31%	5%
No	57%	79%
Other upgrade or modification	9%	2%
Don't know	6%	14%

Note: Responses do not sum to 100%, as multiple responses were permitted.

3.1.3 Panel Upgrade Outcomes

The following section details the Technical Engineering Needs Assessment results given the application of the residential fuel substitution scenarios to customers' baseline equipment and panel conditions. The results display the percentage of single-family and multifamily customers that, based on the condition of the panel, current electrical load, and existing equipment, (1) do not have enough availability capacity and would require a panel upgrade, (2) have enough capacity but not enough breaker slots and would require panel optimization, and (3) fall under categories one and two, i.e. require either a panel upgrade or panel optimization.

As previously mentioned, **the results presented in this report highlight the Technical Engineering Needs Assessment results**; however, the FS Infra MS Data Tool in Appendix F. FS Infra MS Data Tool includes a second type of results related to infrastructure need outcomes called the Workforce Implementation Likelihood results. The Workforce Implementation Likelihood results attempt to adjust the Technical Engineering Needs Assessment results to account for current electrician practices in terms of their usage of optimization vs. full upgrades. Additional notes on the nature of these adjusted results and the methods behind the adjustment are discussed in Section 2.6 and the FS Infra MS Data Tool Memo included in Appendix G. FS Infra MS Data Tool Memo.

Table 24 presents the panel upgrade outcomes resulting from substituting residential respondents' gas-fueled space heating system with the electric-fueled equivalent. As mentioned previously, some of the fuel substitution scenario results presented in the data tool, notably those that account for the adjustment factors presented in Section 2.6 are not presented here and are only captured in the data tool. The data tool is intended to provide additional usability and flexibility for readers, which is why it includes additional details.

Table 24. Residential Space Heating Upgrade Scenario Panel Upgrade Outcome

Segment	Single-Family				Multifamily			
	n	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade – Capacity + Panel Space	n	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade – Capacity + Panel Space
Overall	243	5%	6%	11%	72	1%	21%	22%
Climate Region								
Cold	16	6%	6%	12%	5	0%	40%	40%
Hot-Dry	84	4%	2%	6%	23	0%	17%	17%
Marine	143	10%	21%	31%	44	7%	32%	39%
Building Vintage								
Before 1950	32	6%	25%	31%	4	0%	25%	25%
1950-1975	62	15%	15%	30%	10	0%	30%	30%
1976-1999	91	7%	13%	20%	25	0%	40%	40%
2000 or Later	55	0%	5%	5%	16	6%	0%	0%
Unsure	3	33%	33%	67%	17	12%	35%	47%

Table 25 presents the panel upgrade outcomes resulting from substituting residential respondents’ gas-fueled water heating system with the electric-fueled equivalent.

Table 25. Water Heating Upgrade Scenario Panel Upgrade Outcome

Segment	Single-Family				Multifamily			
	n	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade – Capacity + Panel Space	n	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade – Capacity + Panel Space
Overall	278	14%	30%	44%	78	13%	41%	54%
Climate Region								
Cold	19	11%	21%	32%	5	20%	20%	40%
Hot-Dry	109	14%	29%	43%	28	14%	43%	57%
Marine	150	15%	37%	52%	45	4%	40%	44%
Building Vintage								
Before 1950	39	5%	44%	49%	5	20%	20%	40%
1950-1975	74	16%	31%	47%	8	25%	38%	63%
1976-1999	99	18%	32%	51%	27	7%	44%	52%
2000 or Later	62	11%	29%	40%	23	9%	30%	39%
Unsure	4	0%	50%	50%	15	0%	53%	53%

Table 26 presents the panel upgrade outcomes resulting from substituting residential respondents' gas-fueled space and water heating systems with the electric-fueled equivalents.

Table 26. Space Heating and Water Heating Upgrade Scenario Panel Upgrade Outcome

Segment	Single-Family				Multifamily			
	n	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade – Capacity + Panel Space	n	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade – Capacity + Panel Space
Overall	210	21%	28%	49%	58	14%	42%	56%
Climate Region								
Cold	13	23%	15%	38%	3	0%	33%	33%
Hot-Dry	72	19%	26%	46%	20	15%	40%	55%
Marine	125	29%	41%	70%	35	14%	54%	69%
Home Age								
Before 1950	24	17%	42%	58%	3	33%	33%	67%
1950-1975	52	37%	35%	71%	7	14%	43%	57%
1976-1999	80	29%	34%	63%	21	5%	57%	62%
2000 or Later	51	12%	31%	43%	15	27%	27%	53%

Unsure	3	33%	33%	67%	12	8%	67%	75%

Table 27 presents the panel upgrade outcomes resulting from substituting all of the residential respondents' gas-fueled systems/equipment with the electric-fueled equivalents.

Table 27. All Electric Upgrade Scenario Panel Upgrade Outcome

Segment	Single-Family				Multifamily			
	n	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade – Capacity + Panel Space	n	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade – Capacity + Panel Space
Overall	329	19%	33%	51%	99	15 %	50%	65%
Climate Region								
Cold	23	13%	17%	30%	7	14%	43%	57%
Hot-Dry	129	18%	33%	50%	33	15%	52%	67%
Marine	177	24%	41%	65%	59	14%	46%	59%
Home Age								
Before 1950	52	8%	48%	56%	7	14%	43%	57%
1950-1975	88	27%	30%	57%	12	17%	58%	75%
1976-1999	114	28%	35%	63%	31	16%	45%	61%
2000 or Later	71	11%	37%	48%	28	14%	39%	54%
Unsure	4	25%	25%	50%	21	10%	57%	67%

3.1.4 Fractional Attribution

Ownership of all electrification measures was the same or higher among single-family respondents compared to multifamily respondents. The most common electrification measures among single-family respondents were solar panels (48%), HVAC heat pumps (35%), electric vehicles (EVs) (26%), and EV charging (25%). Whereas 48% of single-family respondents indicated owning solar panels, only 9% of multifamily respondents indicated they had solar on their property. The most common electrification measures among multifamily respondents were HVAC heat pumps (26%), EVs (16%), and EV charging (10%). The least common measures across all respondents were battery storage, heat pump water heaters, and heat pump clothes dryers. Table 28 depicts the percentage of respondents who indicated owning each electrification measure by housing type.

Table 28. Residential Ownership of Electrification Measures by Housing Type

Measure	Single-Family (n=395)	Multifamily (n=160)
Solar Panels	48%	9%
HVAC Heat Pump	35%	26%
EV	26%	16%

Measure	Single-Family (n=395)	Multifamily (n=160)
EV Charger	25%	10%
Level 2 Charger	18%	4%
Level 1 Charger	6%	6%
Induction Stove/Ranges	11%	7%
Battery Storage	10%	2%
Heat Pump Water Heater	10%	0%
Heat Pump Clothes Dryer	3%	3%

Of the respondents with any of the above electrification measures at their home, 256 out of 555 respondents purchased at least one of the measures after moving into the home. Of these 256 respondents, 143 purchased more than one electrification measure after moving in.

Table 29 depicts the frequency with which respondents reported certain measures as their first purchase, second purchase, etc. For example, 39% of respondents who purchased at least one of the measures after moving into their home reported their first purchase was solar panels. This result suggests that respondents prioritized purchasing solar technology before other electric measures. After solar, respondents prioritized purchasing EV home charging and HVAC heat pumps.

Table 29. Residential Purchase Order of Existing Electrification Measures by Housing Type

Measure	First Purchase Was… (n=256)	Second Purchase Was… (n=143)	Third Purchase Was… (n=61)	Fourth Purchase Was (n=23)	Fifth Purchase Was… (n=5)	Sixth Purchase Was (n=2)
Solar Panel	39%	35%	16%	35%	20%	N/A
EV with Home Charger	21%	13%	21%	30%	40%	50%
HVAC Heat Pump	18%	20%	21%	13%	0%	50%
Induction Stove/Range	11%	8%	7%	9%	N/A	N/A
Battery for Solar Panel	5%	13%	15%	9%	20%	N/A
Heat Pump Water Heater	4%	10%	20%	0%	20%	N/A
Heat Pump Clothes Dryer	3%	1%	0%	4%	N/A	N/A

Respondents were asked to provide the pricing associated with their existing electrical equipment, assuming it was purchased after they occupied the property. *Note that the survey did not ask about the scope of the projects (e.g., the quantity of HVAC heat pumps installed, the* *size of the solar array, etc.),* so readers should proceed with caution when interpreting these results. The mean cost associated with these measures is presented in Table 30**.**

Table 30. Residential Pre-Existing Electrical Equipment Costs

Measure	n	Average Cost
Solar Panel	143	$22,192
EV with Home Charger	84	$25,345
HVAC Heat Pump	74	$15,255
Induction Stove/Range	41	$1,897
Battery for Solar Panel	37	$16,651
Heat Pump Water Heater	36	$5,683
Heat Pump Clothes Dryer	8	$1,588

Respondents were asked to indicate which electrification measures they would be interested in purchasing in the future, assuming they had enough money to get everything they wanted. Both single-family and multifamily respondents were most interested in battery storage (65% single-family, 47% multifamily), EVs (58% single-family, 56% multifamily), solar panels (57% single-family, 50% multifamily), and HVAC heat pumps (51% single family, 42% multifamily). Both single-family and multifamily respondents were least interested in heat pump water heaters (33% single-family, 26% multifamily) and heat pump clothes dryers (26% single-family, 22% multifamily).

Table **31** presents the percentage of residential respondents interested in each measure by housing type.

Table 31. Residential Interest in Electrification Measures by Housing Type

Measure	Single-Family		Multifamily	
	n	% Interested	n	% Interested
Battery Storage	354	65%	157	47%
EV	291	58%	135	56%
Solar Panels	206	57%	146	50%
HVAC Heat Pump	258	51%	118	42%
Level 2 Charger	323	44%	154	38%
Induction Stove/Ranges	352	36%	149	32%
Heat Pump Water Heater	356	33%	160	26%
Heat Pump Clothes Dryer	385	26%	155	22%

Note: n-sizes vary as respondents were not asked about their interest in technologies they already owned. Percents do not sum to 100% as multiple responses were permitted.

Respondents ordered the measures they were interested in by the sequence in which they would prioritize the purchases. Table 32 depicts the frequency with which respondents reported certain measures would be their first purchase, second purchase, etc. For example, 33% of respondents who indicated they were interested in at least one measure indicated their first purchase would be battery storage. The results suggest that if money were not a barrier, respondents would prioritize purchasing battery storage, EVs, and solar panels.

Table 32. Purchase Order of Future Electrification Measures Among Residential Survey Respondents

Equipment	First Purchase Would Be… (n=359)	Second Purchase Would Be… (n=359)	Third Purchase Would Be… (n=292)	Fourth Purchase Would Be… (n=209)	Fifth Purchase Would Be… (n=136)	Sixth Purchase Would Be… (n=75)	Seventh Purchase Would Be… (n=49)	Eighth Purchase Would Be… (n=17)
Battery Storage	33%	26%	21%	18%	20%	8%	16%	29%
EV	26%	10%	14%	10%	10%	18%	6%	0%
Solar Panel	23%	10%	11%	9%	4%	5%	8%	0%
HVAC Heat Pump	17%	11%	10%	9%	8%	5%	2%	6%
Induction Stove/Range	11%	7%	12%	12%	15%	15%	10%	6%
Heat Pump Water Heater	8%	9%	15%	12%	10%	13%	16%	0%
Heat Pump Clothes Dryer	3%	7%	8%	10%	21%	19%	14%	41%
Level 2 Charger	3%	20%	9%	20%	12%	17%	27%	18%

Respondents rated how important it was for them to have natural gas for specific end uses. Table 33 depicts the responses by housing type. Across both single-family and multifamily respondents, more respondents indicated having gas was “very” or “somewhat” important for indoor cooking (51% single-family, 49% multifamily) and water heating (46% single-family, 57% multifamily) than they did for clothes drying (32% single-family, 32% multifamily) and space heating (36% single-family, 42% multifamily). Compared to single-family respondents, a larger percentage of multifamily respondents indicated it was “very” or “somewhat” important to have gas across all end-uses.

Table 33. Residential Respondents Importance of Gas for End-Uses by Housing Type

End Use	Single-Family		Multifamily	
	Count	%	Count	%
Importance of having natural gas in home for space heating.				
Very important	92	24%	41	26%
Somewhat important	47	12%	26	16%
Not very important	33	8%	14	9%
Not at all important	194	50%	62	39%
Don't know	25	6%	16	10%
Importance of having natural gas in home for water heating.				
Very important	128	33%	62	39%
Somewhat important	52	13%	28	18%
Not very important	34	9%	9	6%
Not at all important	158	40%	43	27%
Don't know	19	5%	17	11%
Importance of having natural gas in home for indoor cooking.				
Very important	145	37%	54	34%
Somewhat important	56	14%	24	15%
Not very important	29	7%	17	11%
Not at all important	147	37%	54	34%
Don't know	16	4%	9	6%
Importance of having natural gas in home for clothes drying.				
Very important	30	19%	85	22%
Somewhat important	21	13%	41	10%
Not very important	20	13%	38	10%
Not at all important	69	44%	209	53%
Don't know	18	11%	19	5%

Note: Total n-values vary as the question was not a forced response.

3.1.5 Electrician Survey Outcomes

Electrical Work Cost Outcomes

The following section presents the costs associated with residential fuel substitution scenarios given the existing systems and required electrical work averaged across electrician survey respondents. In some cases, the costs reported in these tables may misalign with the costs listed in the FS Infra MS Data Tool. As part of the development of the FS Infra MS Data Tool, the evaluation team removed electrician cost estimates that appeared to be outliers using the IQR. Further details on the team-identified outliers are covered in Appendix H. FS Infra MS Data Tool Memo.

Table 34 presents the average costs associated with an electrician connecting an air source heat pump at a residence with a preexisting gas-fired furnace and central air conditioner, overall and by cost type.

Table 34. Electrical Work Cost Scenarios – Gas Fired Furnace with Central Air Conditioning to Air Source Heat Pump

Electrical Work Scenario	Sample Size	Average Cost			
		Labor	Materials	Miscellaneous	Total
Connect ASHP to panel	45	$1,108	$425	$291	$1,846
Upgrade wiring and connect ASHP to panel	45	$1,544	$713	$219	$2,476

Table 35 presents the average costs associated with an electrician connecting an air source heat pump at a residence with a preexisting gas-fired furnace but no preexisting central air conditioner, overall and by cost type.

Table 35. Electrical Work Cost Scenarios – Gas Fired Furnace without Central Air Conditioning to Air Source Heat Pump

Electrical Work Scenario	Sample Size	Average Cost			
		Labor	Materials	Miscellaneous	Total
Install 200A panel, install 240V circuit and disconnect, connect ASHP to panel	45	$3,987	$1,826	$481	$6,294

Table 36 presents the average costs associated with an electrician connecting a mini-split air source heat pump at a residence with a preexisting gas wall furnace but no preexisting central air conditioner, overall and by cost type.

Table 36. Electrical Work Cost Scenarios – Gas Wall Furnace without Central Air Conditioning to Mini-Split Air Source Heat Pump

Electrical Work Scenario	Sample Size	Average Cost			
		Labor	Materials	Miscellaneous	Total
Install 240V circuit and disconnect, connect ASHP to panel	45	$1,638	$764	$269	$2,671
Install 200A panel, install 240V circuit and disconnect, connect ASHP to panel	45	$4,082	$1,884	$397	$6,363
Install 200A panel, install 240V circuit and disconnect, upgrade wiring, connect ASHP to panel	45	$4,454	$2,180	$426	$7,060

Table 37 presents the average costs associated with an electrician connecting a heat pump water heater at a residence with a preexisting gas domestic hot water heater, overall and by cost type.

Table 37. Electrical Work Cost Scenarios – 50 Gallon Gas Domestic Hot Water Heater to Heat Pump Water Heater

Electrical Work Scenario	Sample Size	Average Cost			
		Labor	Materials	Miscellaneous	Total
Install 240V circuit and disconnect, connect HPWH to panel	45	$1,644	$851	$226	$2,722
Install 200A panel, install 240V circuit and disconnect, connect HPWH to panel	45	$4,251	$2,186	$458	$6,894
Install 200A panel, install 240V circuit and disconnect, upgrade wiring, connect HPWH to panel	45	$4,767	$2,345	$463	$7,576

Table 38 presents the average costs associated with an electrician connecting an air source heat pump and heat pump water heater at a residence with a preexisting gas domestic hot water heater, central air conditioner, and gas domestic hot water heater.

Table 38. Electrical Work Cost Scenarios – Gas Furnace with Central Air Conditioning and Gas Domestic Hot Water Heater to Air Source Heat Pump and Heat Pump Water Heater

Electrical Work Scenario	Sample Size	Average Cost			
		Labor	Materials	Miscellaneous	Total
Install 240V circuit and disconnect for HPWH, connect both ASHP and HPWH to panel	45	$2,692	$1,539	$283	$4,514
Install 200A panel, install 240V circuit and disconnect for HPWH, connect both ASHP and HPWH to panel	45	$5,136	$2,646	$551	$8,332
Install 200A panel, install 240V circuit and disconnect for HPWH, upgrade wiring, connect both ASHP and HPWH to panel	45	$5,607	$2,747	$546	$8,900

Table 39 presents the average costs associated with an electrician connecting an induction range at a residence with a preexisting gas-powered range, overall and by cost type.

Table 39. Electrical Work Cost Scenarios – Gas Powered Range to Induction Range

Electrical Work Scenario	Sample Size	Average Cost			
		Labor	Materials	Miscellaneous	Total
Connect induction range to panel	45	$1,177	$588	$179	$1,944
Install 200A panel and connect induction range to panel	45	$4,066	$1,865	$537	$6,468
Install 200A panel, install 240V circuit and disconnect for new induction range, upgrade wiring, connect induction range to panel	45	$4,789	$2,303	$468	$7,560

FS Infra MS Data Tool Adjustments

Below, we detail the survey results that were used to inform adjustment factors used in the FS Infra MS Data Tool.

Use and Cost of Panel Optimization Strategies

Residential electricians reported how often it is possible to optimize space in an electrical panel rather than upgrade the panel to a high amperage. Table 40 depicts the distribution of responses. The team used these responses to calculate an adjustment factor that estimated the proportion of sites requiring panel optimization that were likely to receive panel optimization services given current electrician practices. As detailed in Section 2.6, we calculated that residential electricians use optimization when technically feasible about 52% of the time and applied this adjustment factor to the Technical Engineering Needs Assessment results to calculate adjusted Workforce Implementation Likelihood results. Although this report focuses on the Technical Engineering Needs Assessment results, the FS Infra MS Data Tool includes both outcomes.

Table 40. Residential Feasibility of Panel Optimization

	n	Always	Often	Sometimes	Rarely	Never	Don't know
How often is it possible to optimize the panel rather than upgrade?	45	0%	24%	60%	16%	0%	0%

The team asked the residential electricians how often they used different panel optimization options when they had a space-constrained panel. Table 41 depicts the distribution of responses. Subpanels were by far the strategy electricians used most frequently. The team used this information to inform the pricing values associated with panel optimization approaches in the data tool.

Table 41. Residential Panel Optimization Options

Optimization Option	n	Always	Often	Sometimes	Rarely	Never	Don't know
Sub-Panel	45	31%	40%	29%	0%	0%	0%
Load-Sharing	45	7%	9%	20%	22%	40%	2%
Smart Circuit Breakers	45	4%	4%	13%	24%	48%	4%
Circuit Pausers	45	2%	4%	9%	18%	58%	9%
Smart Panel	45	0%	4%	18%	24%	51%	2%
Meter Collars	45	0%	2%	2%	18%	67%	11%
Other	45	11%	7%	4%	13%	20%	44%

The team asked residential electricians about the typical costs associated with the panel optimization strategies they had experience with.

Table 42 depicts the average costs. The team used this information and the results presented in Table 41 to inform the pricing values associated with panel optimization approaches in the data tool.

Table 42. Residential Panel Optimization Option Costs

Optimization Option	n	Average Cost
Smart panel	21	$4,424
Sub-panel	45	$2,211
Meter collars	10	$1,831
Circuit pausers	15	$1,435
Load-sharing	26	$1,186
Other	16	$1,077
Smart circuit breakers	21	$1,064

Multifamily Adjustment

The team asked residential electricians who indicated they service multifamily properties how their cost estimates would change if they were installing a heat pump at an apartment with its own in-unit electrical panel versus a single-family home. Of the 35 residential electricians who service multifamily properties, 14 (40%) indicated the price would likely decrease, 12 (34%) indicated the price would increase, and nine indicated the price would stay the same.

Those who indicated the price would likely decrease indicated it would decrease by 16% on average (n=12, two respondents unsure). Those who indicated the price would likely increase indicated it would increase by 56% on average (n=10, two respondents unsure). This information was used to adjust the pricing associated with multifamily properties in the data tool.

Multiple Measure Adjustment

The team asked residential electricians how much the electrical project cost to connect a mini-split air source heat pump at a single-family home would increase if they were to connect two mini-split air source heat pumps. On average, electricians reported it would cost an additional $1,185 (n=45). This information was used to adjust the pricing estimates in the data tool to account for multiple measures.

3.2 Nonresidential Sector Results

Below, we present the results of the nonresidential customer and electrician surveys, along with the results of the nonresidential fuel substitution scenario analysis.

3.2.1 Building Characteristics

The following section details the key building characteristics of the 476 nonresidential customer survey respondents included in the analysis.

Like with the residential respondents, and consistent with the PGS, the team simplified respondents' climate zones into climate regions to allow for larger sample sizes across subsegments. Table 43 depicts the distribution of respondents across climate zones. As shown, only 6% of the sample was located in the cold climate region, which includes only one of the 16 climate zones (CZ16).

Table 43. Nonresidential Climate Zone

Climate Region	Count	Percent
Cold	27	6%
Hot-Dry	230	48%
Marine	219	46%
Total	**476**	**100%**

Table 44 depicts the distribution of respondents by gas utility. PG&E represents the largest share (43%) of respondents with natural gas. Approximately one-quarter of respondents (26%) did not have natural gas. These customers were included in the survey to inform our research on existing systems, existing electrical panel sizes, and fractional attribution.[23]

Table 44. Nonresidential Gas Utility

Gas Utility	Count	Percent
Pacific Gas and Electric Company (PG&E)	207	43%
Southern California Gas (SoCalGas/SCG)	77	16%
San Diego Gas & Electric (SDG&E)	48	10%
Another Provider	13	3%
None/Don't Have Natural Gas	124	26%
Don't Know	7	1%
Total	**476**	**100%**

Table 45 depicts the distribution of respondents by building structure. As shown, nearly half of the businesses surveyed (48%) were part of a larger building, while 35% were in a standalone building. Note that all respondents had their own electrical service panel.

[23] The Team struggled to complete surveys with nonresidential customers. Non-gas customers were necessary to get close to the initial target number of completes for the nonresidential customer survey.

Table 45. Nonresidential Building Structure

Building Structure	Count	Percent
Part of a Larger Building	230	48%
Standalone Building	168	35%
Part of a Campus of Buildings	47	10%
Other	31	7%
Total	**476**	**100%**

Table 46 depicts the distribution of the number of stories/floors in respondents' buildings.

Table 46. Nonresidential Number of Levels/Stories

Stories/Floors	Count	Percent
One Story (No Basement)	300	63%
Two Stories/Floors	142	30%
Three Stories/Floors	23	5%
Four Stories/Floors	6	1%
Five or More Stories/Floors	5	1%
Total	**476**	**100%**

Table 47 depicts the distribution of businesses by type as reported by the survey respondents. There was a wide range of business types represented by the survey, led by offices (24%) and restaurants (13%).

Table 47. Nonresidential Business Type

Business Type	Count	Percent
Offices	115	24%
Restaurant	64	13%
Miscellaneous	60	13%
Retail	48	10%
Healthcare	39	8%
Education	29	6%
Industrial	26	5%
Lodging	23	5%
Storage	23	5%
Automotive	17	4%
Religious	15	3%
Supermarket/Grocery	11	2%
Agricultural	6	1%
Total	**476**	**100%**

Table 48 depicts the average square footage of respondents' buildings overall and by business type. As shown, the small sample of agricultural businesses had the largest average square footage, followed by education and lodging business types.

Table 48. Nonresidential Average Square Footage Overall and by Business Type

Segment	n	Average Square Footage
Overall	394	12,012
Business Type		
Agricultural	5	76,660
Education	22	58,924
Lodging	15	52,511
Industrial	22	17,335
Offices	94	8,035
Storage	20	7,156
Religious	7	7,071
Miscellaneous	51	6,954
Automotive	15	6,010
Retail	43	4,803
Healthcare	33	3,055
Restaurant	57	2,762
Supermarket/Grocery	10	2,669

Note: n-values vary from counts in Table 47 as some respondents did not know the square footage of their building.

3.2.2 Condition of Existing Electric Panel

Table 49 presents the average total and available capacity of respondents' existing panels overall and by climate region. The average nonresidential panel capacity was 326 amps, with 248 amps available. Buildings in the marine region had the most total capacity and available capacity (337 amps and 258 amps), followed by those in the hot-dry region (327 amps and 244 amps) and cold region (237 amps and 193 amps).

Table 49. Nonresidential Panel Capacity by Climate Region

Segment	n	Average Panel Capacity	Average Panel Capacity Available
Overall	476	326	248
Climate Region			
Cold	27	237	193
Hot-Dry	230	327	244
Marine	219	337	258

Table 50 presents the average number of total and empty panel slots overall and by climate region. Buildings in the hot-dry region had the most total panel slots and empty panel slots (28.6 slots and 5.9 slots), followed by those in the marine region (25.9 slots and 5.7 slots) and cold region (20.1 slots and 3.9 slots).

Table 50. Nonresidential Panel Slots by Climate Region

Segment	n	Average Panel Slots	Average Empty Panel Slots Available
Overall	476	26.9	5.7
Climate Region			
Cold	27	20.1	3.9
Hot-Dry	230	28.6	5.9
Marine	219	25.9	5.7

Table 51 depicts the percentage of respondents who indicated completing a panel upgrade or other upgrade/modification at their building in the past. Approximately 14% of respondents indicated they completed a panel upgrade in the past.

Table 51. Nonresidential Past Panel Upgrade

Previous Electrical Panel Upgrade to Expand Capacity/Amperage	Nonresidential Respondents (n=476)
Yes	14%
No	68%
Other upgrade or modification	5%
Don't know	14%

Note: Responses do not sum to 100%, as multiple responses were permitted

3.2.3 Panel Upgrade Outcomes

The following section details the Technical Engineering Needs Assessment results given the application of the nonresidential fuel substitution scenarios to customers' baseline equipment and panel conditions. The results display the percentage of nonresidential customers that, based on the condition of the panel, current electrical load, and existing equipment, (1) do not have enough availability capacity and would require a panel upgrade, (2) have enough capacity but not enough breaker slots and would require panel optimization, and (3) fall under categories one and two, i.e. require either a panel upgrade or panel optimization.

As previously mentioned, the results presented in this report highlight the Technical Engineering Needs Assessment results; however, the FS Infra MS Data Tool in Appendix F. FS Infra MS Data Tool includes a second type of results related to infrastructure need outcomes called the Workforce Implementation Likelihood results. The Workforce Implementation Likelihood results attempt to adjust the Technical Engineering Needs Assessment results to account for current electrician practices in terms of their usage of optimization vs. full upgrades. Additional notes on the nature of these adjusted results and the methods behind the adjustment are discussed in Section 2.6 and the FS Infra MS Data Tool Memo included in Appendix G. FS Infra MS Data Tool Memo.

Table 52 presents the panel upgrade outcomes resulting from substituting nonresidential respondents' gas-fueled space heating system with an HVAC heat pump heating system.

Table 52. Nonresidential Space Heating Upgrade Scenario Panel Upgrade Outcome

Segment	Sample Size	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade - Capacity + Panel Space
Overall	143	6%	8%	14%
Climate Region				
Cold	12	-	8%	8%
Hot-Dry	64	-	5%	5%
Marine	67	16%	10%	26%

Table 53 presents the panel upgrade outcomes resulting from substituting nonresidential respondents' gas-fueled water heating system with a HPWH.

Table 53. Nonresidential Hot Water Upgrade Panel Upgrade Outcome

Segment	Sample Size	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade - Capacity + Panel Space
Overall	149	1%	45%	46%
Climate Region				
Cold	11	0%	64%	64%
Hot-Dry	67	6%	28%	34%
Marine	71	0%	46%	46%

Table 54 presents the panel upgrade outcomes resulting from substituting nonresidential respondents' gas-fueled nonresidential fryers and ovens with their electric-fueled equivalents.

Table 54. Nonresidential Cooking Upgrade Scenario Panel Upgrade Outcome

Segment	Sample Size	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade - Capacity + Panel Space
Overall	66	34%	28%	62%

Climate Region				
Cold	1	100%	0%	100%
Hot-Dry	32	22%	31%	53%
Marine	33	18%	33%	52%

Table 55 presents the panel upgrade outcomes resulting from substituting nonresidential respondents' gas-fueled space and water heating systems with the electric-fueled equivalents.

Table 55. Nonresidential Space Heating and Hot Water Upgrade Scenario Panel Upgrade Outcome

Segment	Sample Size	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade - Capacity + Panel Space
Overall	73	16%	46%	62%
Climate Region				
Cold	7	0%	71%	71%
Hot-Dry	33	9%	30%	39%
Marine	33	24%	33%	58%

Table 56 presents the panel upgrade outcomes resulting from substituting all of the nonresidential respondents' fuel substitution eligible gas-fueled systems/equipment with the electric-fueled equivalents.

Table 56. Nonresidential All Electric Upgrade Scenario Panel Upgrade Outcome

Segment	Sample Size	% Panel Upgrade – Capacity Constraint	% Panel Optimization– Space Constraint	% Total Infrastructure Upgrade - Capacity + Panel Space
Overall	239	7%	28%	36%
Climate Region				
Cold	16	6%	50%	56%
Hot-Dry	109	8%	22%	30%
Marine	114	15%	32%	47%

3.2.4 Fractional Attribution

Ownership of electrification measures was low among nonresidential survey respondents, with the most common electrification measures at buildings being HVAC heat pumps (11%) and solar panels (8%). Table 57 depicts the percentage of respondents who indicated having each electrification measure at their building.

Table 57. Nonresidential Ownership of Electrification Measures

Measure	Nonresidential Respondents (n=476)
HVAC Heat Pump	11%
Solar Panel	8%
Heat Pump Water Heater	6%
EV Charger	5%
Any Nonresidential Cooking Equipment (Not Necessarily Electric – For Context)	22%
Electric Convection Oven	5%
Electric Fryer	1%

Of the respondents with any of the above electrification measures at their building, 62 purchased at least one of the measures after moving into the building. Only eight respondents purchased more than one type of electrification measure after moving in, and no respondents purchased more than two. Table 58 depicts the frequency with which respondents reported certain measures as their first purchase, second purchase, etc. For example, 39% of respondents who purchased at least one of the measures after moving into their building reported their first purchase was EV charging. The results suggest the businesses prioritized purchasing EV charging before other electrification measures.

Table 58. Nonresidential Purchase Order of Existing Electrification Measures

Measure	First Purchase Was… (n=62)	Second Purchase Was… (n=8)
EV Charger	39%	38%
Solar Panel	18%	38%
Heat Pump Water Heater	16%	N/A
Electric Convection Oven	15%	13%
HVAC Heat Pump	13%	13%
Electric Fryer	N/A	N/A

Respondents were asked to provide the pricing associated with their existing electrical equipment, assuming it was purchased after they occupied the property. *Note that the survey did not ask about the scope of the projects (e.g., the number of heat pumps installed, size of the solar array, etc.), so readers should proceed with caution when interpreting these results.* The mean cost associated with these measures is presented in Table 59.

Table 59. Nonresidential Pre-Existing Electrical Equipment Costs

Measure	n	Average Cost
EV Charger	13	$97,770
Solar Panel	26	$215,148
Heat Pump Water Heater	7	$3,819
Electric Convection Oven	10	$12,170

HVAC Heat Pump	7	$46,434
Electric Fryer	N/A	N/A

Respondents were asked to indicate which electrification measures they would be interested in purchasing in the future, assuming they had enough money to get everything they wanted. As shown in Table 60, customers were most interested in solar panels (35%), followed by HVAC Heat Pumps (23%) and EV chargers (13%).

Table 60. Nonresidential Interest in Future Electrification Measures

Measure	n	Percent Interested
Solar Panels	439	35%
HVAC Heat Pump	426	23%
EV Charger	453	13%
Heat Pump Water Heater	447	12%
Electric Convection Oven	430	5%
Electric Fryer	439	2%

Note: n-sizes vary as respondents were not asked about their interest in technologies they already owned. In the case of ovens and fryers, those with nonresidential cooking equipment who indicated they had no ovens or fryers were not asked about interest in the electric variations of those technologies. Percents do not sum to 100% as multiple responses were permitted.

Respondents ordered the measures they were interested in by the sequence in which they would prioritize the purchases.

Table 61 shows that customers were most interested in first purchasing solar panels and HVAC heat pumps. Those measures were followed by EV chargers and HPWHs in terms of purchase order preference.

Table 61. Purchase Order of Future Electrification Measures Among Nonresidential Survey Respondents

Measure	First Purchase Would Be… (n=111)	Second Purchase Would Be… (n=111)	Third Purchase Would Be… (n=45)	Fourth Purchase Would Be… (n=15)	Fifth Purchase Would Be… (n=1)	Sixth Purchase Would Be… (n=1)
Solar Panels	41%	23%	13%	N/A	N/A	N/A
HVAC Heat Pump	39%	35%	11%	13%	100%	N/A
EV Charger	9%	20%	22%	27%	0%	100%
Heat Pump Water Heater	8%	15%	33%	33%	N/A	N/A
Electric Convection Oven	3%	6%	11%	20%	N/A	N/A
Electric Fryer	0%	1%	9%	7%	N/A	N/A

3.2.5 Electrician Survey Outcomes

Electrical Work Cost Outcomes

The following section presents the costs associated with nonresidential fuel substitution scenarios given the existing technology and what electrical work would be needed, averaged across electrician survey respondents. *In some cases, the costs reported in these tables may misalign with the costs listed in the FS Infra MS Data Tool. As part of the development of the FS Infra MS Data Tool, the evaluation team removed electrician cost estimates that appeared to be outliers using the IQR*. Further details on the team-identified outliers are covered in Appendix H. FS Infra MS Data Tool Memo.

Table 62 presents the average costs associated with an electrician connecting a packaged heat pump with electric resistance backup at a nonresidential building with a preexisting packaged air conditioner and gas furnace, overall and by cost type.

Table 62. Electrical Work Cost Scenarios – Packaged Air Conditioner and Gas Furnace to Packaged Heat Pump with Electric Resistance Back-Up

Electrical Work Scenario	Sample Size	Average Cost			
		Labor	Materials	Miscellaneous	Total
Connect packaged HP to panel	33	$2,582	$1,781	$264	$4,627
Install 600A panel and connect packaged HP to panel	33	$8,794	$9,664	$1,353	$19,811
Add 200A panel and connect packaged HP to panel	27	N/A	N/A	N/A	$6,700
Install 600A panel, upgrade wiring, connect packaged HP to panel	33	$9,468	$9,858	$1,462	$20,788

Table 63 presents the average costs associated with an electrician connecting an 80-gallon heat pump water heater at a nonresidential building with a preexisting 60-gallon gas domestic hot water heater, overall and by cost type.

Table 63. Electrical Work Cost Scenarios – 60 Gallon Gas Domestic Hot Water Heater to 80 Gallon Heat Pump Water Heater

Electrical Work Scenario	Sample Size	Labor	Materials	Miscellaneous	Total
Install 240V circuit and disconnect, connect HPWH to panel	33	$1,877	$1,332	$221	$1,535
Install 400A panel, install 240V circuit and disconnect, connect HPWH to panel	33	$6,155	$4,954	$855	$11,965
Add 200A panel and connect packaged HP to panel	24	N/A	N/A	N/A	$7,297

Electrical Work Scenario	Sample Size	Labor	Materials	Miscellaneous	Total
Install 400A panel, install 240V circuit and disconnect, upgrade wiring, connect HPWH to panel	32	$7,901	$6,243	$956	$14,642

Table 64 presents the average costs associated with an electrician connecting electric fryers at a nonresidential building with preexisting gas fryers, overall and by cost type.

Table 64. Electrical Work Cost Scenarios – Gas Fryer to Electric Fryer

Electrical Work Scenario	Sample Size	Labor	Materials	Miscellaneous	Total
Add circuit and disconnect, connect fryer to panel	33	$1,698	$960	$158	$2,816
Install 400A panel, add circuit and disconnect, connect fryer to panel	33	$6,639	$5,184	$936	$12,760
Add 200A panel, add circuit and disconnect, connect fryer to panel	25	N/A	N/A	N/A	$7,934
Install 400A panel, upgrade wiring, add circuit and disconnect, connect fryer to panel	33	$8,251	$6,080	$806	$15,137

Table 65 presents the average costs associated with an electrician connecting electric convection ovens at a nonresidential building with preexisting gas ovens, overall and by cost type.

Table 65. Electrical Work Cost Scenarios – Gas Oven to Electric Convection Oven

Electrical Work Scenario	Sample Size	Labor	Materials	Miscellaneous	Total
Add circuit and disconnect, connect oven to panel	33	$2,078	$1,598	$164	$3,840
Install 600A panel, add circuit and disconnect, connect oven to panel	33	$8,843	$8,371	$1,183	$18,397
Add 200A panel, add circuit and disconnect, connect oven to panel	28	N/A	N/A	N/A	$8,084
Install 600A panel, upgrade wiring, add circuit and disconnect, connect oven to panel	33	$9,417	$9,245	$822	$19,484

Table 66 presents the average costs associated with an electrician connecting electric fryers and electric convection ovens at a nonresidential building with preexisting gas fryers and gas ovens.

Table 66. Gas Oven and Gas Fryer to Electric Convection Oven and Electric Fryer

Electrical Work Scenario	Sample Size	Labor	Materials	Miscellaneous	Total
Add circuit and disconnect, connect oven and fryer to panel	33	$3,634	$2,289	$331	$6,253
Install 600A panel, add circuit and disconnect, connect oven and fryer to panel	33	$9,457	$8,441	$989	$18,887
Add 200A panel, add circuit and disconnect, connect oven and fryer to panel	28	N/A	N/A	N/A	$8,506
Install 600A panel, upgrade wiring, add circuit and disconnect, connect oven and fryer to panel	33	$9,840	$9,251	$1,002	$20,092

Table 67 presents the average costs associated with an electrician connecting an air source heat pump and 80-gallon HPWH at a nonresidential building with a preexisting forced air gas-fired furnace and a 60-gallon domestic hot water heater.

Table 67. Forced Air Gas Fired Furnace and 60 Gallon Domestic Hot Water Heater to Air Source Heat Pump and 80 Gallon Heat Pump Water Heater

Electrical Work Scenario	Sample Size	Labor	Materials	Miscellaneous	Total
Add circuit and disconnect, connect HPWH and ASHP to panel	33	$3,445	$2,002	$238	$5,685
Install 400A panel, add circuit and disconnect, connect HPWH and ASHP to panel	33	$8,094	$6,710	$876	$15,680
Add 200A panel, add circuit and disconnect, connect HPWH and ASHP to panel	26	N/A	N/A	N/A	$8,837
Install 400A panel, upgrade wiring, add circuit and disconnect, connect HPWH and ASHP to panel	33	$9,148	$7,199	$842	$17,190

FS Infra MS Data Tool Adjustments

Similar to the residential sector, the team used the results presented below to develop adjustment factors used in the FS Infra MS Data Tool.

Use and Cost of Panel Optimization Strategies

Nonresidential electricians reported how often it is possible to optimize space in an electrical panel rather than upgrade the panel to a high amperage at the different types of nonresidential buildings where they work. Table 68 depicts the distribution of responses. Like with the residential electrician results, the team used these responses to calculate an adjustment factor that estimated the proportion of sites requiring panel optimization that were likely to receive panel optimization services given current electrician practices. As detailed in Section 2.6, we calculated that nonresidential electricians use optimization when technically feasible about 53% of the time and applied this adjustment factor to the Technical Engineering Needs Assessment results to calculate adjusted Workforce Implementation Likelihood results. Although this report focuses on the Technical Engineering Needs Assessment results, the FS Infra MS Data Tool includes both outcomes.

Table 68. Nonresidential Residential Feasibility of Panel Optimization

Business Type	n	Always	Often	Sometimes	Rarely	Never	Don't know
Small Office	21	10%	29%	43%	19%	0%	0%
Large Office	18	22%	39%	33%	6%	0%	0%
Retail	13	8%	38%	23%	23%	8%	0%
Healthcare	12	0%	42%	25%	25%	8%	0%
Restaurant	8	0%	0%	63%	38%	0%	0%
Education	8	0%	13%	75%	13%	0%	0%
Lodging	5	0%	20%	20%	60%	0%	0%
Religious	4	25%	25%	25%	25%	0%	0%
Supermarket	1	0%	0%	100%	0%	0%	0%

The team asked the nonresidential electricians how often they used different panel optimization options when they had a space-constrained panel. Table 69 depicts the distribution of responses. Subpanels were by far the strategy electricians used most frequently.

Table 69. Nonresidential Panel Optimization Options

Optimization Option	n	Always	Often	Sometimes	Rarely	Never	Don't know
Sub-Panel	33	21%	45%	33%	0%	0%	0%
Smart Circuit Breakers	33	3%	12%	9%	27%	48%	0%
Smart Panel	33	3%	0%	6%	24%	67%	0%
Meter Collars	33	3%	0%	3%	12%	73%	9%
Circuit Pausers	33	0%	0%	12%	21%	67%	0%
Load-Sharing	33	0%	9%	27%	18%	45%	0%
Other	33	0%	0%	24%	3%	33%	39%

The team asked nonresidential electricians about the typical costs associated with the panel optimization strategies they had experience with. Table 70 depicts the average costs.

Table 70. Nonresidential Panel Optimization Option Costs

Optimization Option	n	Average Cost
Smart Panel	11	$3,720
Load-Sharing	18	$3,688
Sub-Panel	33	$2,594
Meter Collars	6	$1,792
Other	9	$1,647
Circuit Pausers	11	$1,300
Smart Circuit Breakers	17	$971

Multiple Measure Adjustment

The team asked residential electricians how much the electrical project cost to connect a packaged heat pump at a nonresidential property would increase if they were to connect two packaged heat pumps. On average, electricians reported it would cost an additional $2,697 (n=33).

Appendix A. Scenario Development and Literature Review Memos

2022 Literature Review Memo

CPUC PG
Study_Panel Upgrad

Residential Memo

CPUC FS Infra
MS_Task 2 Res Sumr

Nonresidential Memo

CPUC FS Infra
MS_Task 2 Commerc

Appendix B. Scenario Development References

Below is a comprehensive list of references that were used to support the scenario development references provided in Appendix A. Scenario Development and Literature Review Memos.

Adler, David. 2022. “Decarbonizing Existing Nonresidential Buildings.” San Diego, CA: San Diego Green Building Council.

Aitchison, Jack, Nick Dirr, Aubrey Dority, and Ben Cooper. 2021. “Accelerating Electrification of California’s Multifamily Buildings.” Edited by Jennifer Roberts. California Energy Commission.

Armstrong, Sean, Emily Higbee, Dylan Anderson, Diane Bailey, and Tom Kabat. 2022. “A Zero Emissions All-Electric Retrofit Single-Family Construction Guide.” Redwood Energy.

Bastian, Hannah, and Charlotte Cohn. 2022. “Ready to Upgrade: Barriers and Strategies for Residential Electrification.” Washington, DC: American Council for an Energy-Efficient Economy (ACEEE). http://www.aceee.org/research-report/b2206.

California Technical Forum. 2024. “ETRM - Fuel Substitution Measures.” California Electronic Technical Reference Manual. 2024. https://www.caetrm.com/measures/?search=Fuel+Substitution&use_category=&status=#.

Davis, Rhys. 2021. “Barriers and Opportunities for Multifamily Building Electrification Retrofits in Sacramento.” M.Sc. Thesis, University of California, Davis.

Frontier Energy, Inc., and Misti Bruceri & Associates, LLC. 2022. “Cost-Effectiveness Analysis: Existing Multifamily Residential Building Upgrades.” Pacific Gas and Electric Company.

Hooper, Barry. 2022. “Existing Nonresidential Buildings.” San Francisco, CA: SF Environment.

Hopkins, Asa, Kenji Takahashi, Devi Glick, and Melissa Whited. 2018. “Decarbonization of Heating Energy Use in California Buildings.” Synapse Energy Economics, Inc.

Itron, Inc., KEMA, ADM Associates, Volt VIEWTech, Inc., J.J. Hirsch and Associates, and SDV/ACCI. 2006. “California Nonresidential End-Use Survey.” California Energy Commission.

Kenney, Michael, Nicholas Janusch, Ingrid Neumann, and Mike Jaske. 2021. “California Building Decarbonization Assessment.” California Energy Commission.

Kisch, Teddi, Alison Seel, Rory Cox, Dylan Sarkisian, Evan Kamei, and Peter Florin. 2022. “TECH Clean California’s Heat Pump Market Transformation Approach: Lessons Learned in Year 1.” In Proceedings of the 2022 Summer Study on Energy Efficiency in Buildings. Pacific Grove, CA: American Council for an Energy Efficient Economy (ACEEE).

Mahone, Amber, Charles Li, Zack Subin, Michael Sontag, Gabe Mantegna, Alexis Karolides, Alea German, and Peter Morris. 2019. "Residential Building Electrification." E3 - Energy and Environmental Economics, Inc.

Miller, Alexi, and Cathy Higgins. 2021. "The Building Electrification Technology Roadmap (BETR)." Portland, OR: Building Decarbonization Coalition.

National Electrical Code Committee. 2022. NFPA 70, National Electrical Code. National Fire Protection Agency.

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

Neal, John. 2022. "Navigating Multifamily Electrical Constraints." Association for Energy Affordability.

Solarte-Caicedo, Sebastian, Stephanie Pincetl, Felicia Federico, and Eric Fournier. 2023. "Literature Review – Identified Barriers and Potential Research Gaps." Los Angeles, CA: California Center for Sustainable Communities at UCLA.

"The 2022 American Home Size Index." 2022. American Home Shield: Best Rated Home Warranty Company. November 6, 2022. http://www.ahs.com/home-matters/real-estate/the-2022-american-home-size-index/.

The City of Berkeley, Rincon, Rocky Mountain Institute, and Ecology Center. 2021. "Existing Building Electrification Strategy." Berkeley, CA: The City of Berkeley.

U.S. Census Bureau. 2012. "Table 1006. Nonresidential Buildings—Summary: 2003." Statistical Abstract of the United States. https://www2.census.gov/library/publications/2011/compendia/statab/131ed/tables/12s1006.pdf

Walker, Iain, Brennan Less, and Nuria Casqueo-Modrego. 2022. "Pathways to Home Decarbonization in the US." In Proceedings of the 2022 Summer Study on Energy Efficiency in Buildings. Pacific Grove, CA: American Council for an Energy Efficient Economy (ACEEE).

Walker, Iain, Brennan Less, Nuria Casqueo-Modrego, and Leo Rainer. 2021. "The Cost of Decarbonization and Energy Upgrade Retrofits for US Homes." Lawrence Berkeley National Laboratory.

Zank, Benjamin, Tim Minezaki, and Eliot Stein. 2022. "Electric Panels for the 21st Century." Energy Solutions.

Appendix C. Survey Instruments

Residential Occupant Survey

CPUC Fuel Sub
Study_Residential O

Nonresidential Customer Survey

Commercial
Customer Survey_Fir

Electrician Survey

CPUC Fuel
Substitution Study_I

Appendix D. Sampling Plans

Residential Sampling Plan

Fuel Substitution
Study_Residential Sa

Nonresidential Sampling Plan

Fuel Substitution
Study_Commercial S

Appendix E. Detailed Data Cleaning and Analysis Methods

Data cleaning

The process of cleaning data for both residential and nonresidential surveys was comprised of two steps. The first step involved the identification of relevant questions and responses in the survey, cleaning up those responses, and storing them in new variables for later use. In the second step, missing panel size information was filled using respondent-submitted images of the electrical panel. If the information was unclear from the image, cross-segmented average panel sizes by building type and square footage were used. The focus of the residential part of this study was on market rate customers only, so equity customers were dropped from the residential dataset as an additional step.

The variables that we created as part of the first step of the data cleaning process included the following:

1. Climate Region: Buildings in climate zones 1-6 are assigned to the “Marine” climate region, buildings in climate zones 7-15 are assigned to the “Hot-Dry” climate region, and buildings in climate zone 16 are assigned to the “Cold” climate region.
2. Utility: The primary utility serving the building, which included smaller utilities such as Ferrellgas and Kamps.
3. Building Type: Residential building types were either single-family or multifamily, while nonresidential building types are defined according to the business operating in the building: Agricultural, Automotive, Education, Healthcare, Industrial, Lodging, Miscellaneous, Offices, Religious, Restaurants, Retail, Storage and Supermarket/Grocery.
4. Panel Size: Respondents chose from 100, 125, 150, and 200 amps in the residential survey and 200, 400, and 600 amps in the nonresidential survey. They were also able to input another panel size if theirs did not match the options provided in the survey. In cases where the respondent answered ‘Don’t know/Unsure,’ we used images of their electrical panel, if they submitted one, to identify and fill in the panel size. There were still many remaining electrical panel size records with missing values (215 out of 642) after doing the above steps, and the approach taken to deal with them is discussed below.
5. Open Slots: Respondents inputted the number of open slots their electrical panels have, but we found that many of them were inaccurate, probably due to a lack of familiarity with the electrical panel technology. We, therefore, used respondent-submitted panel images, where available, to verify or fix the open slot responses.
6. Building Square Footage: In the residential survey, respondents reported their building square footage according to whether it falls within a range, and we converted those ranges to a numeric square foot value by assuming that a building’s square footage is the midpoint value of the range it falls under. Unknown values were assigned a value of 1860 sq.ft., which is the average home size in California[24]. In the nonresidential survey, most respondents gave their exact building size in sq.ft., but 82 out of 476 did not know their building size. The approach taken to address these unknown nonresidential building types is discussed below.

[24] American Home Shield, *“The 2022 American Home Size Index.”*

7. Equipment Purchase Order and Cost and Equipment Purchase Preference: These are important for the factional attribution portion of the analysis.

Nonresidential Building Sizes Approach: With 82 out of 476 nonresidential buildings having unknown building sizes, our approach to assigning them a square foot building size value rested on a cross-tabulation by building type and building size bins. We created the bins, following U.S. Census bin sizes[25], from survey responses to the building square footage question, and we cross-tabulated them with the building type to understand the frequency distribution of existing building size bins by building type. We then assigned a bin to the unknown building size records according to this frequency distribution. To get a numerical square footage value for these unknown records that now have an assigned building size bin, we averaged the square footage within each bin and assigned those average values to the unknown building sizes according to the bins they have been assigned. As an example, nine buildings with a “Religious” building type have unknown building sizes. There are also nine “Religious” buildings with known square footages: four buildings are in the 1,001 – 5,000 sq. ft. bin, two buildings are in the 5,001 – 10,000 sq. ft. bin, and three buildings are in the 10,001 – 25,000 sq. ft. bin. The average known building sizes are 2,380 sq. ft. for the 1,001 – 5,000 sq. ft. bin, 7,340 sq. ft. for the 5,001 – 10,000 sq. ft. bin, and 17,680 sq. ft. for the 10,001 – 25,000 sq. ft. bin. Therefore, four out of the nine unknown building sizes are assigned a 2,380 sq. ft. building size, two out of the nine are assigned a 7,340 sq. ft. building size, and the remaining three are assigned a 17,680 sq. ft. building size. Figure 2 offers a clarifying visualization of this example.

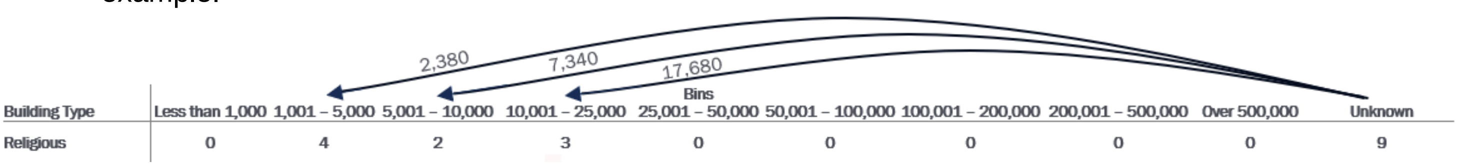

Figure 2. Visualizing Square Footage Assignments to Unknown Building Size Records

Panel Size Approach for Residential and Nonresidential Buildings: The approach to assigning missing panel sizes in both surveys is the same as the approach taken to fill in missing building size values in the nonresidential survey minus the need to distribute unknown records. Just as in the building size approach, we performed a cross-tabulation by building type and building size bins and found the average panel size for each combination. The averages we found were then rounded to the nearest commercially available panel size: 100, 125, 150, 200 amps for residential, and 100, 125, 200, 225, 250, 300, 400, 600, 800, 1000, 2000, 3000 and 4000 amps. The rounded values were then assigned to the missing panel size records according to their building type/building size bin combination. For example, nonresidential buildings with an “Education” building type that also fall under the 1,001 – 5,000 sq. ft. bin have an average panel size of 285.7 amps, so unknown panel size records with a corresponding building type and bin are assigned 300 amps.

Data Analysis

The data analysis process for both nonresidential and residential surveys involved four steps. Firstly, we gathered the number of installed equipment and their associated fuel types. Next, we researched and assigned typical wattages for electrical equipment. Then, we calculated the

[25] U.S. Census Bureau; *Statistical Abstract of the United States, Table 1006*

remaining panel capacity by determining the maximum electrical load of all installed electrical equipment against the full panel capacity. Finally, we flagged all cases that required gas-to-electric equipment replacement and added flags to indicate whether a panel upgrade was necessary based on capacity constraints, space constraints, or both.

Mapping Building Equipment: The first step of the analysis is essentially a mapping of the electrical and gas systems in each residential home or nonresidential building. Table 71 displays information on the system type, the corresponding equipment respondents can report owning for this system, and the fuel types they can specify for the equipment's operation. Alongside reporting the equipment they have and the associated fuel type, respondents also report the quantity of each equipment they have, and this allowed us to map the equipment in each site.

Table 71. Survey Options for Equipment Respondents Can Report Having

System	Equipment	Fuel Types
Residential Homes		
Space Heating	Electric resistance - Central Heat Pump - Mini-split/Through-the-Wall Heat Pump	Electric
	Forced Air Furnace - Wall Heater - Boiler	Electric, Gas or Unknown
Cooling	Central AC - Central Evaporative Cooler - Central Heat Pump - Mini-split/Through-the-Wall Heat Pump - Packaged Terminal Air Conditioner (PTAC)	Electric
Water Heaters	Heat Pump Water Heater	Electric
	Storage Tank Water Heater - Tankless Water Heater - Other Water Heater	Electric, Gas or Unknown
Clothes Dryers	Heat Pump Clothes Dryer	Electric
	Standard Clothes Dryer	Electric, Gas or Unknown
Cooking	Range - Stove Top - Wall Oven - Range Hood/Vent - Electric Grill	Electric, Gas or Unknown
Other Equipment	Freezer - Garbage Disposal - Microwave - Dishwasher - Clothes Washer - Garage Door Opener - Well Pump - Solar Panel - EV Charger	Electric
	Heated Pool	Electric or Gas
Nonresidential Buildings		
Space Heating	Packaged Heat Pump - Ductless/Mini-Split Heat Pump - Packaged Terminal Heat Pump (PTHP)	Electric
	Packaged Central Unit - Boiler - Furnace - Other Space Heating Equipment	Electric, Gas or Unknown
Cooling	Packaged Central Unit - Central Chiller - Ductless/Mini-Split Heat Pump - Central AC - Packaged Terminal Air Conditioner (PTAC) - Evaporative Coolers - Packaged Heat Pump - Packaged Terminal Heat Pump (PTHP) - Other Cooling Equipment	Electric
Water Heaters	Large Storage Nonresidential Heat Pump Water Heater - Small Residential-Style Heat Pump Water Heater	Electric

System	Equipment	Fuel Types
	Large Storage Nonresidential Water Heater - Small Residential-Style Storage Water Heater	Electric, Gas or Unknown
Cooking	Convection Oven - Fryer	Electric, Gas or Unknown
Other Equipment	Solar Panel - EV Charger	Electric

Typical Wattages for Existing Electrical Equipment: We tried to rely on information from industry research products, academic articles, DOE studies, and averages of online product listings as much as possible to find reasonable wattage assumptions for existing electrical equipment, but when none is available from such sources, we performed general online research and used a minimum of two reliable online sources to produce a reasonable wattage assumption. A summary of our research is provided in Table 72 including our notes for each confirmed wattage value and the source.

Table 72. Typical Wattages for Equipment Connected to the Electrical Panel

Equipment	Typical Wattage (W)	Notes	Source
Residential Homes			
Any Electric Heater	sqft×12,000/500×1.7×0.293	An industry rule of thumb is that the maximum space heating capacity is 1.7× the cooling capacity	https://rc.cfmdistributors.com/helpful-tips/hvac-rules-of-thumb/
Heat Pump Heater	sqft×12,000/500×0.293	Heat Pump Heaters are sized the same way as cooling systems.	See Cooling sources
Cooling	sqft×12,000/500×0.293	An industry rule of thumb is that an AC requires one ton of cooling power to cool 500 sq. ft. One ton of cooling power is equivalent to 12,000 BTU/hr.	https://www.warmup.ca/blog/btu-per-square-foot-heating-rule-of-thumb https://www.wolcott.pro/what-is-the-thumb-rule-for-air-conditioning-load-calculation/
Heat Pump Water Heater	3,800	The average of the Input kW column of the table for 50-gallon HPWH in the source gives 3800W.	https://www.ahridirectory.org/NewSearch?programId=24&searchTypeId=3 Filter for Heat Pumo with Tank for the Energy Source, Storage for the Heater Type, and 50 gal for Nominal Capacity
Storage Tank Water Heaters	4,500	The average of the Input kW column of the table for 50-gallon storage tank water heaters in the source gives 4500W.	https://www.ahridirectory.org/NewSearch?programId=24&searchTypeId=3 Filter for Electric Resistance for the Energy Source, Storage for the Heater Type, and

Equipment	Typical Wattage (W)	Notes	Source
			50 gal for Nominal Capacity
Tankless Water Heater	20,000	The average wattage of water heaters listed in the source is 20kW.	https://www.ahridirectory.org/NewSearch?programId=24&searchTypeId=3
Heat Pump Clothes Dryer	840	New technology with limited publicly available information. The source recommends using 3.5A and 240V, which becomes 840W.	https://www.electricalsafetyfirst.org.uk/guidance/safety-around-the-home/home-appliances-ratings/
Regular Clothes Dryer	3,500	Used data provided by SGIP	SGIP Load Calculator Template
Electric Range	9,600	Used data provided by SGIP	SGIP Load Calculator Template
Oven	3,050	Academic article from IEEE published in 2008. Table 1 shows that an oven's wattage is 3050W.	https://ieeexplore.ieee.org/document/4596224
Stove Top	4,800	Used data provided by SGIP	SGIP Load Calculator Template
Range Hood	150	Sources give the following ranges of wattages for a range hood: 70-150, 65-300, 65-300, and 125-250. We chose 150 as it is the highest wattage covered by all those ranges.	https://kowalske.com/kitchen-appliances-that-use-the-most-power https://www.thehomehacksdiy.com/how-much-power-watts-does-a-kitchen-range-hood-use/ https://homeefficiencyguide.com/range-hood-wire-sizes/ https://joteo.net/electricity-usage-calculator/electricity-usage-of-a-cooker-hood

Equipment	Typical Wattage (W)	Notes	Source
Electric Grill	2,000	Academic article from the Journal of Low-Carbon Technologies. The study was done in the UK, and Figure 10 gives the wattage of an electric grill as 2000W.	https://academic.oup.com/ijlct/article/11/1/66/2363520
Refrigerator	700	The typical wattage of refrigerators is 500W, but older models go up to 1000W. Choosing 700W, which gives a slight bias to older models.	https://naturesgenerator.com/blogs/news/how-many-watts-does-a-refrigerator-use https://www.solarreviews.com/blog/refrigerator-how-many-watts https://www.coastappliances.ca/blogs/learn/how-many-watts-does-a-refrigerator-use
Freezer	600	Used data provided by SGIP	SGIP Load Calculator Template
Garbage Disposal	700	0.75-1 hp is the typical operating power, which equates to ~700 watts, as sources agree on.	https://www.galvinpower.org/how-many-amps-does-a-garbage-disposal-use/ https://sepurahome.com/blogs/guides/garbage-disposal-power-how-many-watts-do-you-need https://yardandgardenguru.com/how-many-amps-does-a-garbage-disposal-use/
Microwave	800	Typical ranges are 600-800W for a small microwave and 800-1000W for a standard microwave. Chose 800W.	https://www.jackery.com/blogs/knowledge/how-many-watts-does-a-microwave-use
Dishwasher	1,800	Multiple sources cite 1800W as a typical dishwasher load	https://energyusecalculator.com/electricity_dishwasher.htm https://www.perchenergy.com/energy-calculators/dishwasher-electricity-use-cost https://www.finishdishwashing.com/dishwasher-benefits/energy/ https://www.inspirecleanenergy.com/blog/sustainab

Equipment	Typical Wattage (W)	Notes	Source
			le-living/cost-to-run-dishwasher
Clothes Washer	900	Sources give a range of 400-1400W with an average of approximately 850W. Rounding to the nearest 100 gives 900W.	https://energyusecalculator.com/electricity_clotheswasher.htm https://www.energybot.com/energy-usage/washing-machine.html https://news.energysage.com/how-many-watts-does-a-washing-machine-use/ https://www.batteryequivalents.com/washing-machine-wattage-how-many-watts-does-a-washing-machine-use.html
Garage Door Opener	1,400	Idle, starting, and running watts differ: idle wattage range is 350-600W, the starting wattage range is 1000-1400W, and the running wattage range once the door is in motion is 550-725W. Using a maximum of 1400W.	https://www.conserve-energy-future.com/amps-garage-door-opener-use.php
Heat Pump Pool Heater	25,000	5 BTUs/gal for spring and fall, 6 BTUs/gal for winter, 4 BTUs for summer. Using 5 BTUs. The average pool size is 16ftx32ft, which fills 17,280 gals. So 5BTU/gal × 17,280gal × 0.293W/BTU = 86,400×0.293 = ~25,000W	https://blog.thepoolfactory.com/sizing-your-heat-pump-pool-heater https://calimingo.com/blog/what-is-the-average-pool-size-for-homes-in-california/
Nonresidential Buildings			
Any Electric Space Heating	sqft×12,000/300×1.7×0.293	An industry rule of thumb is that the maximum space heating capacity is 1.7× the cooling capacity	https://rc.cfmdistributors.com/helpful-tips/hvac-rules-of-thumb/
Heat Pump Heater	sqft*12,000/300*0.293	An industry rule of thumb is that 1 ton of cooling or heat pump space heating is needed per 300 sq. ft. in nonresidential buildings. This is lower than the residential 1 ton per 500 sq. ft. to account for the increased windows, people, and other sources of air leakage that nonresidential buildings have.	https://rc.cfmdistributors.com/helpful-tips/hvac-rules-of-thumb/ https://www.themcdermottgroup.com/Newsworthy/HVAC%20Issues/Rule%20of%20Thumb%20Sizing.htm

Equipment	Typical Wattage (W)	Notes	Source
Cooling	sqft*12,000/300*0.293	See Heat Pump Heater notes.	See Heat Pump Heater sources.
Nonresidential Heat Pump Water Heaters	12,000	Most HPWHs on the list in the source are 12kW rated, and only one is 15kW.	https://www.energystar.gov/productfinder/product/certified-nonresidential-water-heaters/results?formId=a67eec9a-bb4c-4d81-be85-145357da572a, filter for Electric Heat Pump
Nonresidential Storage Tank Water Heater	18,000	The range of wattages goes from 9 to 54kW. A lot are 12kW, but some are 18kW. Going for 18kW to account for the upper bound of 9-54kW.	https://www.energystar.gov/productfinder/product/certified-nonresidential-water-heaters/results?formId=a67eec9a-bb4c-4d81-be85-145357da572a, filter for Gas Storage.
Electric Fryers	18,000	Small nonresidential fryers range of wattages is 13.5kW-14kW, and large nonresidential fryers range is 21-22kW.	https://www.fermag.com/articles/9823-how-to-spec-an-electric-fryer/ https://www.webstaurantstore.com/14389/electric-fryers.html
Convection Ovens	15,000	15kW is within the range of the most commonly offered electric nonresidential convection ovens.	https://www.webstaurantstore.com/14181/nonresidential-convection-ovens.html

Calculating the Remaining Panel Capacity: These wattage values were used alongside the latest edition of the National Electrical Code (NEC)[26] to calculate the load that all the installed equipment has on the panel. We needed to do this only for the residential survey data because, for the nonresidential survey data, we were provided with a peak demand value by California IOUs, which allowed us to size the maximum existing load on the panel without needing to know all the installed equipment.

For calculating the existing load on electrical panels for residential survey respondents, we followed NEC guidance to address HVAC and non-HVAC equipment loads. The NEC recommended adding the loads of all non-HVAC equipment up to 10,000 W and then adding only 40% of the remaining load above 10,000 W. An additional demand factor of 75% is applied if the total number of non-HVAC equipment is greater than three. This is considered the total general load.

[26] *NFPA 70, National Electrical Code* 2022, Article 220

For cooling HVAC equipment, the load is based on the square footage of the home according to the formula in Table 72. If there are multiple cooling equipment, each one's contribution to the total load is divided between them, but the total load remains the same as it is based on the square footage of the home. This total load is the **total cooling load**. For space heating HVAC equipment, if a heat pump heater exists, we take the full load of the heat pump heaters, which should be equal to the cooling load. This is the **total heat pump space heating load**. If there are no central space heating systems, then the total load is the sum of each individual space heating load multiplied by a factor that depends on the quantity of equipment. If there are three space heating equipment units or less, then a factor of 65% is applied to the total load of the equipment, and if there are four or more space heating equipment units, then the factor becomes 40%. This is the **other space heating load**. The maximum of the total cooling load, heat pump space heating load, and other space heating load is considered the total HVAC load.

The total general and HVAC loads are then added and divided by 240V to get the existing load of residential electrical equipment in amps. For nonresidential sites, the IOU-provided peak demand value is divided by 240V to get the existing load of all electrical equipment in amps. Subtracting these existing loads from the panel size gives the remaining panel capacity, which is important for the scenario analysis component of the analysis.

Scenario Analysis: The scenario analysis involved creating multiple flags for sites that 1) are eligible for a fuel substitution measure, i.e., the sites that have gas-fueled equipment, and 2) require a panel upgrade based on the remaining panel capacity calculated above, number of open slots, or both, and the introduced load of the substituted measure. If the introduced load of the substituted measure for a certain building is greater than the remaining panel capacity of that building, then the building is flagged as a site that requires a panel upgrade based on capacity only. If the building has enough capacity but the number of open slots in its panel is less than the number of open slots required to add all the introduced electrical equipment, then the building is flagged as a site that requires a panel upgrade based on space only. Another flag is added for sites that need either a capacity-based upgrade, a panel space-based upgrade, or both. This should amount to the sum of the other two flags. These flags are then used to create the Panel Upgrade Outcomes tables for the residential and nonresidential data according to our segmentation framework.

Appendix F. FS Infra MS Data Tool

FS Infra MS Data
Tool_Final_2024.03.19.

Appendix G. FS Infra MS Data Tool Memo

FS Infra
MS_DataToolAnalysis