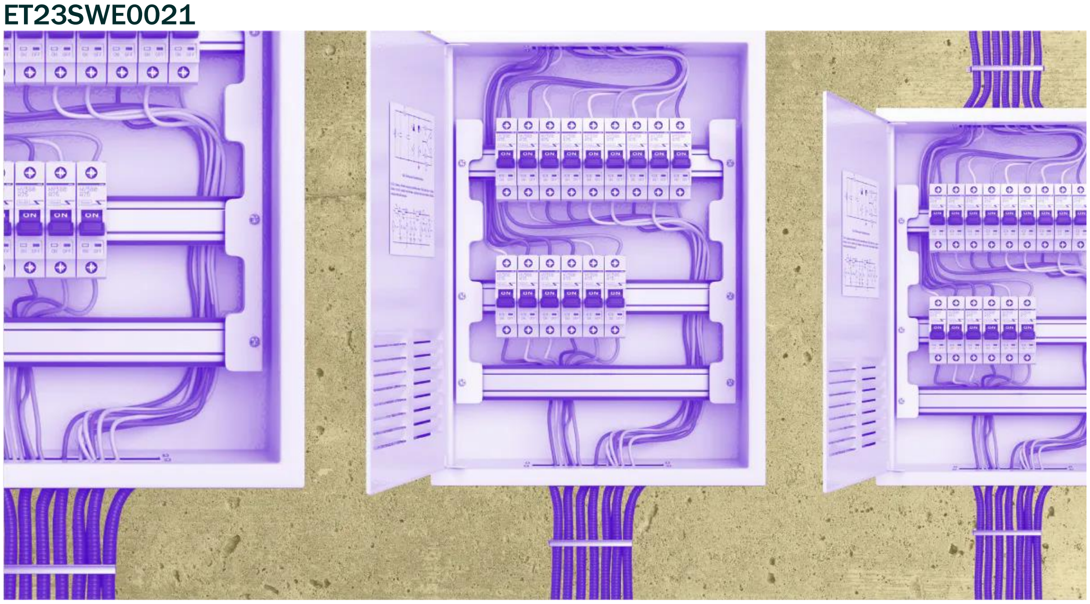
Residential Electrical Service Upgrade Decision Tool

Final Report

ET23SWE0021



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Acknowledgements

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2050 Partners

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A special shoutout to Josie Gaillard, Tom Kabat, and Sean Armstrong at Redwood Energy for their innovation, leadership, and early work developing strategies and tools to remain on existing electrical panels during home electrification.

Disclaimer

Executive Summary

BACKGROUND: Meeting California's climate and clean air goals requires the electrification of the existing residential housing stock. Residential electrification is often erroneously assumed to require electrical panel and service upgrades for all dwellings that currently have less than 200 amps of capacity. Under this assumption, a substantial minority (30 to 40 percent) of all dwellings in the state of California would require costly and time-consuming panel and service upsizing, representing $25 to 40 billion dollars of investment, as well as significant upstream investments to the utility electrical grid to support the additional service (Less, et al, 2024).

OBJECTIVES: The actual requirements for electrification may be much less and, in any case, depend on much more granular information collection and decision-making. To address this, the project team's goal is to leverage current research and practices to provide a "Residential Service Upgrade Decision Tool" focused on electrical panels at existing residential single-family and multifamily homes. The Tool has two versions, built on common underlying calculations: one aimed at contractors and homeowners and which provides guidance on when to upsize an individual electrical panel or service, versus alternatives to manage available panel and service capacity to electrify the home. The second version is intended for utilities and policy makers to inform investment decisions on strategies for electrifying homes across a service territory or building portfolio.

APPROACH: The project team started with initial background research, including:

- Literature review
- Initial stakeholder outreach
- Existing tool review

Following the background research and stakeholder engagement, the project team developed the decision-making guide, customer journey, individual home tool, and building stock tool.

As a first step of the tool development, the project team developed decision-making guides, which are a step-by-step process by which a homeowner, in consultation with their contractor(s), can determine whether the existing panel and service can accommodate all of their electrification needs.

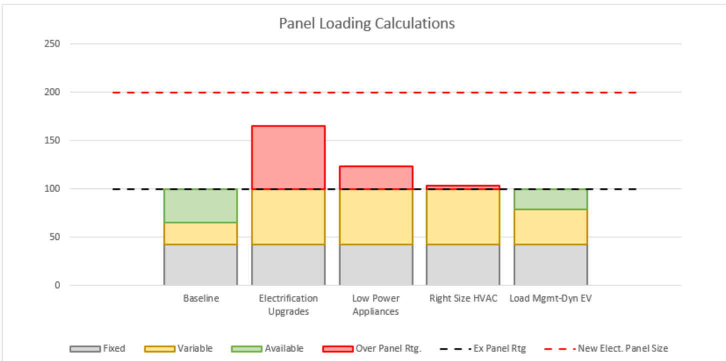
RESULTS and DECISION TOOLS: For the tools themselves, the project team developed a Microsoft Excel-based interface that walks users through various scenarios and strategies to support decision-making on electrification choices.

The individual home tool is designed for contractors to use in collaboration with homeowners. Although homeowners should be guiding the electrification priorities, some of the technical information or equipment details may require the expertise of a contractor to accurately input.

The individual home tool walks users through a series of screens, allowing for inputs of current conditions and electrification priorities. It then gives the users a variety of electrification options and optimization strategies, showing the user the effect those choices have on panel and service capacity, based on electrical code load calculations. The ideal result will be a strategy to meet all the customer's electrification goals within the existing electrical and service capacity. However, depending on the goals specified and the optimization strategies selected, there may also be

scenarios that the existing panel and service capacity cannot accommodate. In this case, the tool will indicate the magnitude of the service upgrade required.

Figure 1. Example results screen from the Individual Home Tool.



	Baseline	Electrification Options	Opt #1 - Low Pwr Appliances	Opt #2 - Right-Size HVAC	Opt #3 - Load Mgmt
Baseline Amperage	65.1				
Amperage of Full Electrification		165.8			
Amps Saved by Options			42.6	62.2	87.2
% Amps Saved			25.7%	37.5%	52.6%
Total Amperage		**165.8**	**123.2**	**103.6**	**78.6**

Panel Electrification Results

The existing main electrical panel is 100 Amps.

With all the electrification measures chosen in the 'Electrification Upgrades' tab, the minimum size electrical panel and service will need to be 200 Amps.

The optimizations selected will permit electrification without increasing the panel and service size.

Panel Optimization Recommendations

The electrification upgrades selected will require a panel and service upgrade, but follow the optimization options recommendations below to mitigate this impact.

The currently selected optimizations will meet the existing panel capacity and no panel upgrade is required.

Low Power Appliances - The LPA options selected will reduce the panel size, but not enough to eliminate a panel size increase. Continue to the next optimization tabs for further options.

Right-Size HVAC - The HVAC options selected will reduce the panel size, but not enough to eliminate a panel size increase. Continue to the next optimization tab for further options.

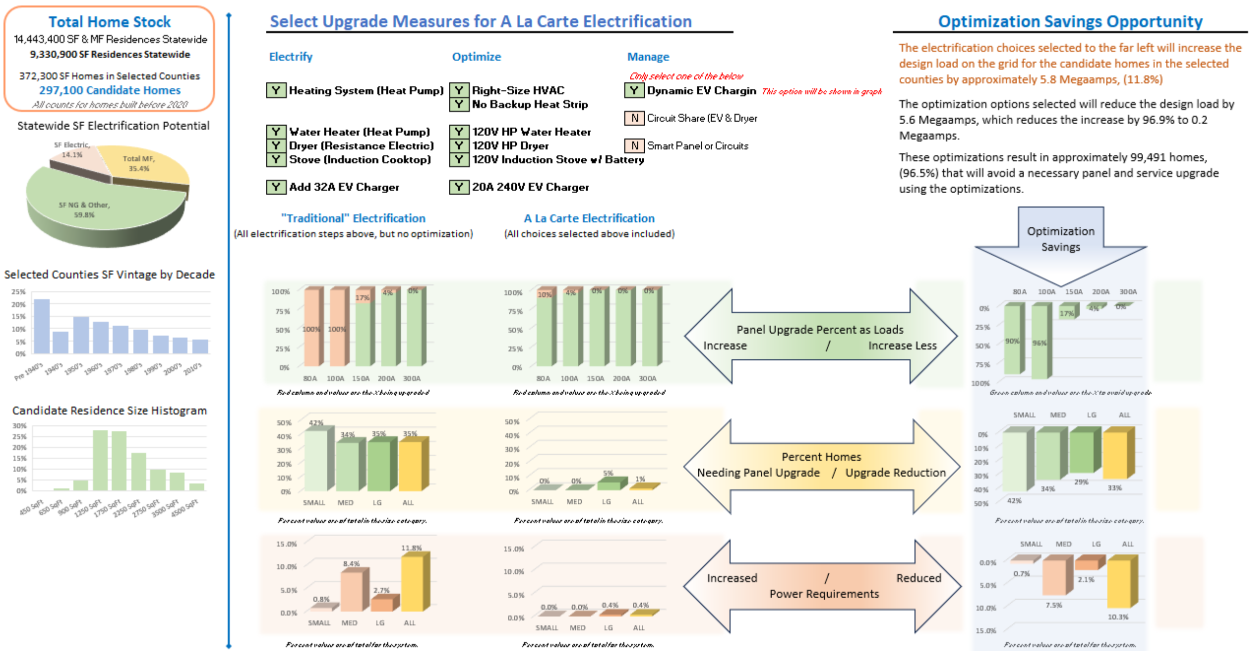
Load Management - The LM selections now fit within your existing panel capacity. You DO NOT need a panel upgrade. However, using more efficient equipment choices may reduce energy consumption and peak load to save on electric bills.

The optimized main electrical panel is 100 Amps.

Note: All tool results and calculations must be confirmed by a qualified contractor, verifying conditions on site. Contractor to verify that selected strategies and calculation approach are allowable by the local permitting agency.

In addition to the Individual Home Tool described above, the project team developed a Building Stock Assessment tool to provide a portfolio-level outlook. The primary target user of the Building Stock Assessment Tool is an electrification program administrator who needs to evaluate the frequency of panel upgrades likely to be triggered by building electrification measures. The tool could also be useful for local governments or other agencies with a need to assess electrification impacts over a portfolio of residential buildings. The goal of the Building Stock Assessment tool is to help guide program decisions to support residential electrification, while also minimizing the need for costly panel, service, and infrastructure upgrades. The Building Stock Assessment Tool will provide users with estimates of the proportion of their building stock that may require panel and service upgrades, based on electrification options and panel optimization strategies selected.

Figure 2. Example results screen from the Building Stock Assessment Tool.



The research and tools the project team developed demonstrate a proof of concept of screening tools for residential building electrification and panel or service capacity optimization strategies for both individual home panels and utility-scale building portfolios.

RECOMMENDATIONS: Tools, such as those the project team developed, are a critical component for supporting electrification, but there are other needs and opportunities that utilities should support:

- Wrap-around support services for electrification programs – The Tool is just one part of the broader electrification program process. In addition to panel and service optimization calculator tools, programs need to support a broader framework of education, training, and other wrap-around support services to support electrification,
- Program support and measure development to encourage tool use – To encourage the load reduction and panel optimization strategies that calculator tools recommend, utility programs need to adapt to actively support those strategies, such as power-efficient appliances, circuit sharing, or smart panels. Utilities can also play a role in developing the market for those strategies, encouraging the development of additional product offerings, and thereby encouraging further cost-competitiveness for these innovative strategies. In addition, utility programs should develop program measures to encourage the use of calculator tools, such as those developed through this project, to further support panel optimization strategies alongside building electrification efforts.
- Support further tool development – This project and other similar tools represent the potential for using calculator tools to support residential electrification, but further development and updates will be needed to refine these tools and keep them current. Opportunities for further support include additional user testing, development of more streamlined user experience, future updates to the tools as optimization strategies and

products develop, and further research to inform the development and updates of calculator tools and electrification programs generally.

- Support and encourage updates to electrical codes and enforcement practices – Current interpretations of electrical code language and inconsistent enforcement at the local jurisdiction result in uncertainty for some panel and electrical load optimization strategies. Utilities can support updates to national model codes and enforcement practices in local building departments to consistently encourage panel optimization and technologies that allow for electrification without requiring panel or service upgrades.

NEXT STEPS: Following on the outputs of this project, the project team identified the following opportunities for future projects or with additional funding:

- Continued tool development – Opportunities to further the development of the tools the project team focused on include additional user testing and refinements based on user feedback, additional user experience development, and expanding the tool functionality to additional user groups, among others.
- Keeping the Tool up-to-date – Future work should identify and implement strategies for keeping these tools current and plan for regular updates to accommodate any future changes in code requirements or load reduction and panel optimization strategies.
- Making the tool publicly available – In addition to further refinement and tool updates, future efforts should strategize how these tools should be hosted and maintained for public access, and how any future updates will be communicated, in collaboration with utilities or other agencies.

Abbreviations and Acronyms

Acronym	Meaning
CCA	Community Choice Aggregator
CEC	California Energy Commission
ESA MF	Energy Savings Assistance for Multifamily Homes Program
ET	Emerging Technology
EV	Electric Vehicle
HVAC	Heating, Ventilation, and Air Conditioning
IOU	Investor-Owned Utility
kWh	Kilowatt-hour
LADWP	Los Angeles Department of Water and Power
LBNL	Lawrence Berkeley National Laboratory
NEC	National Electrical Code
PCE	Peninsula Clean Energy
PG&E	Pacific Gas & Electric
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SMUD	Sacramento Municipal Utilities District
TECH	TECH Clean California program

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Introduction

Meeting California's climate and clean air goals requires the electrification of the existing residential housing stock. Residential electrification is often arbitrarily assumed to require electrical panel and service upgrades in all dwellings that currently have less than 200 amps of capacity, regardless of any additional factors. Under this assumption, a substantial minority (30 to 40 percent) of all dwellings in the state of California would require costly and time-consuming panel and service upsizing, representing $25 to 40 billion dollars of investment (Less, et al, 2024). These upgrades will also impose additional stress on the electrical grid, requiring substantial upstream investments by utilities and ratepayers. This represents a major bottleneck to rapid and equitable building electrification. This path poses an especially large burden on the state's disadvantaged communities and tenants in older single-family and multifamily housing, who are more likely to have inadequate electrical infrastructure.

To address these challenges, this project developed a "Residential Service Upgrade Decision Tool," hereafter referred to as the "Tool", focused on electrical panels at existing residential single-family and multifamily homes. The Tool has two versions, built on common underlying calculations: the first version is aimed at contractors and homeowners to provide guidance on when to upsize an individual electrical panel or service versus alternatives to manage available panel and service capacity to electrify the home. The second version is intended for utilities and policy makers to inform investment decisions on strategies for electrifying homes across a service territory or building portfolio.

Background

The Tool builds on a growing body of knowledge and partial tools developed by various entities in the state that have tried to address the same issue but with limited scopes and a limited ability to run scenario analyses. The project leveraged the collaborative work of the California Panel Optimization Work & Electrical Reassessments (POWER) Group, facilitated by Build It Green. The POWER Group includes utilities, researchers, consumer advocates, electrification experts, policy makers and advocates for disadvantaged and marginalized communities.

The project team conducted an extensive assessment of the current market landscape, leveraging the previous experience with utility residential energy efficiency programs (e.g., the Energy Savings Assistance for Multifamily Homes Program (ESA MF) and the California residential new construction program). They also looked at a recent project, funded by Southern California Edison (SCE), related to costs for upgrading residential electrical panels and service. They additionally had discussions with CalNEXT project partners on two recently funded projects that address residential electrical capacity. Several partners in the project also gathered relevant data, as well as additional data collection tools. VEIC led a project conducting a market study of options available to homeowners. Ortiz Group led a project evaluating the prevalence of panel capacity and constraints in existing single-family homes. AESC also conducted a project (separately funded by SCE) on a market study and recommendations for panel upgrades. Peninsula Clean Energy (PCE) recently developed an electrification options slide deck aimed at homeowners, including example products. Redwood Energy developed a 'Watt Diet' calculator on their website to evaluate panel capacity management while adding electrification loads.

This project builds on these existing studies. The major barrier that this project aims to address is the lack of knowledge of alternatives to traditional panel upgrades and infrastructure work on the part of utilities, homeowners, and contractors. This barrier is perhaps most clear in the NV5 report to PG&E/SDG&E related to electrical panel and service upgrades, where one of the key findings is that "electricians, who work primarily with customers, are unaware of the efficiency or load sharing options available to mitigate service upgrades during retrofits, and instead resort to upgrading a panel capacity, and thus a resulting service." The same study also concluded "while whole home electrification contractors may be aware, most other contractors and customers are unaware of options to mitigate the need for a service upgrade entirely."

Objectives

This project is part of a larger initiative of a stakeholder group, beyond the CalNEXT program, consisting of California utilities, researchers, practitioners, and developers to address electrical service capacity constraints and solutions. The project team's goal is to leverage current research and practices to provide a "Residential Service Upgrade Decision Tool" focused on electrical panels at existing residential single-family and multifamily homes. The Tool is aimed at contractors and homeowners, utilities, regulators, and policy makers, and provides guidance on when to upsize electrical panels and service, versus alternatives to manage available panel and service capacity to electrify homes. As noted above, the Tool is in two versions: one for individual homes aimed at contractors and homeowners, and one for a wider building stock aimed at utilities and policymakers. The Tool is one of the outcomes of the initiative. It will also support the overall objective of promoting cost-effective decarbonization of existing homes.

The project also builds on work currently being done by CalNEXT on this topic. It is specifically designed to complement and not supplant any of their current efforts. As these CalNEXT projects develop better understanding of the propensity of existing homes to have certain panel sizes and electric service capacity and develop insights into the types of equipment needing electrification, the Tool will be able to incorporate that data into its decision-making trees.

Methods & Approach

This project addressed the barriers and challenges outlined above through a thoughtful engagement of key stakeholders – utilities, researchers, subject matter experts, developers, and policy makers, including local jurisdictions and state agencies – that are part of a POWER network facilitated by Build It Green. The team also engaged CalNEXT partners on leveraging data generated from concurrent CalNEXT and other efforts to guide this project.

Literature Review

As noted above, this project builds on extensive existing research to support the development of the Tool. The project team compiled and reviewed relevant information from current and past studies. A full list of the sources reviewed is outlined in Appendix A. Key findings from the literature review are outlined in the Research Findings section, below.

Stakeholder Outreach

The project team leveraged Build It Green's POWER network to gather input and feedback from leading decarbonization experts and experts on electrical service upgrades, since many of these experts are part of the network. The network currently includes the California Energy Commission (CEC), Lawrence Berkeley National Laboratory (LBNL), Sacramento Municipal Utilities District (SMUD), Southern California Edison (SCE), Los Angeles Department of Water and Power (LADWP), Redwood Energy, Tom Kabat, Josie Gaillard, and community choice aggregators, including PCE and others, to name a few. These individuals and organizations are currently engaged in various initiatives focused on residential electrification and actively share information on strategies to avoid unnecessary panel and service upsizing.

Through the POWER network, the project team engaged the Building Decarbonization Coalition, utility program managers, third party program implementers, local government, policy advocates, electrical contractors, community-based organizations, and other panel tool software developers that are active in the residential electrification space. The goal of this engagement was to understand the users and use cases for the Tool. This includes specific inputs on individual strategies, approaches currently being used, and a user wish list for incorporation into the Tool.

The project team communicated with relevant stakeholders in standing POWER meetings, direct outreach, and overlapping group efforts (for example, the TECH Panel Symposium, led by Energy Solutions, in December 2023) to coordinate parallel efforts for collaboration and avoid duplication of work.

The project team also coordinated with other entities who are working on developing other tools.

Existing Tool Review

The project team reviewed and collated information currently available in existing tools designed to support the residential electrification of multiple systems. The team compiled inputs, outputs, and the criterion used to make decisions for these existing tools. The project team noted the users, use cases and limitations of these tools, along with their capabilities, accuracy, and bias towards one solution or the other. The project team also evaluated available tools to determine how they can inform the Residential Service Upgrade Decision Tool, and to avoid duplicating any existing tools or ongoing efforts.

Tools reviewed include the following:

- Watt Diet Calculator, Redwood Energy
- Personal Electrification Planner, Rewiring America
- Your Electrification Roadmap, Elephant Energy
- HomeIntel Energy Audit, HEA
- Zero Carbon Home, Josie Gaillard

Some contractors also use manufacturer-developed system sizing tools for individual systems like HVAC, or established professional standards such as Air Conditioning Contractors of America (ACCA) Manual J standards. Because the focus of this effort is on panel and service capacity for whole home electrification, the project team did not review manufacturer-specific tools or contractors' system sizing practices.

Tool Development

Building on the research findings and existing resources, as outlined above, the project team developed decision-making guides and the decision tool, as summarized below:

- Electrification Panel and Service Upgrade Alternatives - The project team identified a range of opportunities, based on the background research, for utilizing existing panel and service capacity, while doing electrification retrofits in existing residential buildings. These opportunities include a range of strategies such as power efficient appliance options, active load management (circuit sharing, smart panels, smart devices, etc.), and energy efficiency and building envelope improvement opportunities.
- Decision-Making Guides - The project team developed a series of "what to do, when" decision-making guides that provide guidance on:
    - The potential for electrification within the existing panel and service capacity
    - The panel and service capacity impacts of specific electrification technologies
    - Technology options that can work within the constraints of existing capacity
    - Options for service and capacity upgrades when needed
    - Correlation between house size and historical energy use, versus the potential to electrify based on available panel capacity
- Residential Service Upgrade Decision Tool - The project team developed a tool that leverages the decision-making guides described above, providing options and alternatives to a specific scenario that the user specifies. The Tool was developed in an easy-to-use Microsoft Excel format that can be used both online and offline to allow for rapid prototyping, ease of updates, and ease of use by various users.
- Stakeholder Engagement and User Testing - The project team conducted regular outreach to key stakeholders – utilities, policy makers, industry experts – to gain input and feedback on the proposed decision-making guides through the POWER network.

Research Findings

The following sections provide initial findings from literature review, stakeholder outreach, and a review of existing tools. The goal of the analysis for these initial findings was to inform inputs and development of the decision-making guides and tool development, as part of the next steps of this project.

Market Characterization of Existing Electrical Panel and Service Capacity

The following list shows the literature examined for the market characterization of existing panels (see Table 1). The service capacity is expected to be at least as high as the panel capacity and could be higher.

Table 1. Literature on the market characterization of electrical panels

Source	Panel Sample Size	Building Characteristics	Sample type
Lindsey (2023)	2,950	All US, residential, mostly SFH	Sample of convenience - voluntary survey
Merski (2021)	263	Mostly Austin, TX, residential, mostly SFH	Sample of convenience - participants in a program
NV5 (2022)	Not an empirical study	California SFH	No direct sampling of panel sizes, but home vintage is from a representative sample
SPUR (2023) A compilation of data from Home Energy Analytics, TECH Clean California, and BayREN	10,433	California; mostly SFH	Sample of convenience - participants in programs
Home Energy Analytics (2023)	1,480	PG&E territory (Northern & Central California); mostly SFH	Sample of convenience - participants in a program
SPUR (2023)b analysis of Home Energy Analytics panel utilization data	359	PG&E territory (Northern & Central California); mostly SFH	Sample of convenience - participants in a program

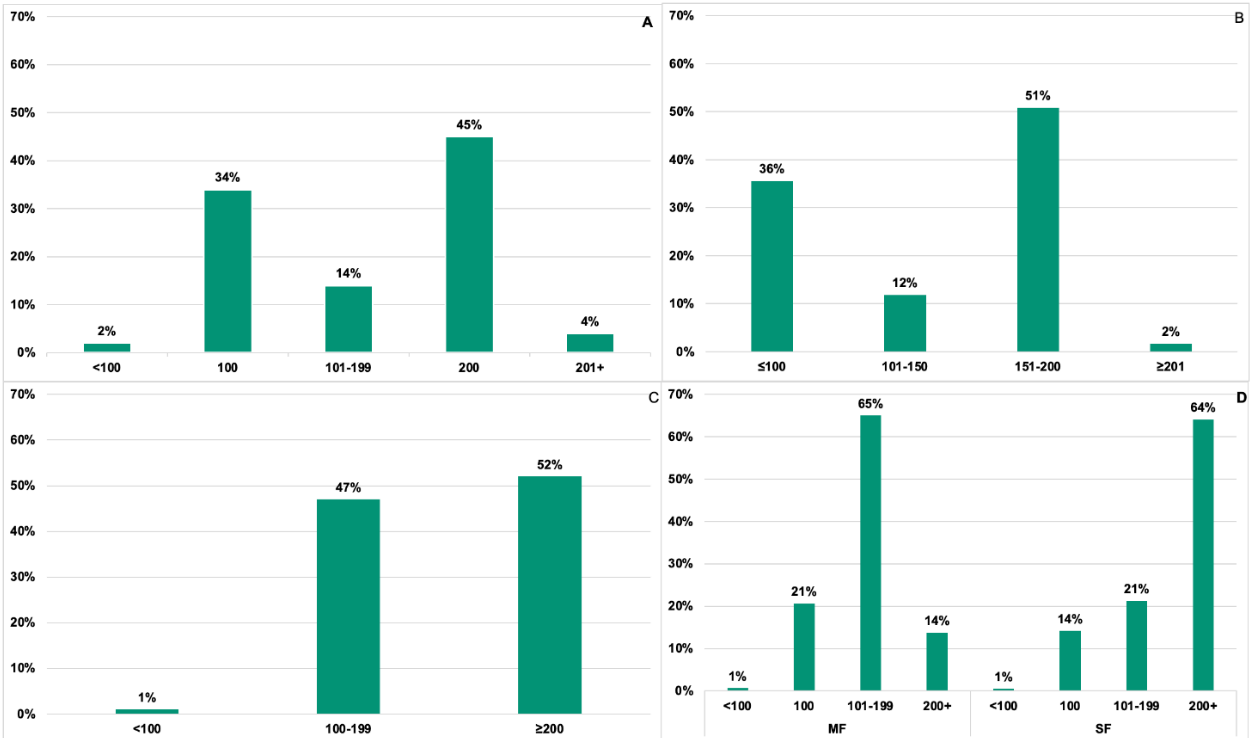
Source	Panel Sample Size	Building Characteristics	Sample type
Opinion Dynamics and Guidehouse (2024)	555 (160 MF, 395 SF)	California SFH and MFH. Sampled panels for individual dwelling units in MFH.	Survey. Sample design not described.
Less et al. (2024)	Over 500	California SFH	Representative sample

SFH = single-family home

Panel Capacity in Existing Homes

Less et al. (2024) shared a pre-publication dataset from a representative dataset on panel capacity in California single-family homes. Their results indicate that 45 percent of homes have 200-amp panels, and 34 percent have 100-amp panels (Figure 3, panel A). The results from Less et al. agree with the other datasets despite the fact that they were not representative samples (Figure 3, panels B, C and D). The broad agreement indicates that there is not a systemic bias on panel capacity for the datasets reviewed. The results for multifamily units in Opinion Dynamics and Guidehouse are different from single-family results: 100 to 199 amp panels were most common in multifamily homes, compared with 200-amp panels in single-family homes.

Figure 3. Histogram of six datasets of panel capacity. (A) Less, et al. 2024, representative sample of single-family homes in California. (B) Lindsey 2023. (C) SPUR 2023 compilation of three datasets: TECH, BayREN, HEA. (D) Opinion Dynamics and Guidehouse 2024.



The NV5 analysis (NV5 2022) assessed historic code requirements for panel capacity in California homes and estimated the percentage of homes with a given panel capacity, assuming the panel still met the code minimum at the time the home was built. This represents a reasonable bottom-end estimate of panel capacity for California homes. From 1965 to 1967, local codes on new single-family homes began to require 100-amp electrical service. Based on this, they assumed that single-family homes built after 1968 have 100-amp panels. They further assumed that any home built in 1968 and prior that has since installed a central air conditioning system would likewise have 100-amp panels. Based on these assumptions, combined with 2020 American Community Survey Data on home vintage, they estimated that 71 percent of California single-family homes had at least 100-amp panels. There did not appear to be an assessment of historical code requirements for multi-family dwellings in the NV5 study or other literature that was reviewed. This is a data gap that should be rectified.

Lindsey conducted a voluntary online survey of 2,950 housing units across the United States (Lindsey 2023). The sample included both single- and multifamily units but was heavily weighted towards single-family dwellings. The results were grouped by multi-state regions. The study found that 36 percent of homes had panels less than or equal to 100 amps, and 64 percent had panel capacities over 100 amps. This aligns well with the NV5 assessment. The NV5 assessment would be expected to provide a result more highly biased toward smaller panel capacity than a survey of installed panel capacities. Using NV5 as a bottom-end estimate, and Lindsey as a more accurate estimate, the result indicates that the majority of single-family California homes have panels over 100 amps (see Table 2).

Table 2. Panel Capacities From National Voluntary Survey Of Housing Units By Lindsey (2023)

Panel Capacity	US (%)	West (%)
201+ Amps	3%	2%
151-200 Amps	50%	51%
101-150 Amps	14%	12%
100 Amps or less	33%	36%

Note: Percentages for Lindsey 2023 were recalculated to exclude results for which the respondent reported that they didn't know their panel capacity. The study grouped its results by multi-state regions. West includes WA, OR, CA, NV, ID, AZ, UT, CO, NM, WY, MT. Margin of error US +/- 2.0, West =/- 4.5.

Building Characteristics that Correlate with Panel Capacity

Both Lindsey and Merski found that building square footage correlated with panel capacity, with older homes more likely to have lower-capacity panels (Lindsey 2023) (Merski 2021). The studies found contradictory results as to whether building age correlates with panel capacity. Lindsey found support for a correlation, while Merski did not.

Electrical Service and Panel Utilization

Available datasets indicate some spare capacity in the existing electrical service and panels in most homes, even those with low-capacity panels. Peak power demand (the highest value in a year of smart meter data for a connection) for a large sample of homes in PG&E territory was below 88 amps for the vast majority of homes (Khanolkar, Armstrong, and Kabat,). Mean percent utilization of service capacity in PG&E territory was 34 percent (Home Energy Analytics 2023). A sample of homes in PG&E territory showed that most homes, even those with just 100-amp panels, had at least 50 percent unused panel capacity (SPUR 2023). In Sacramento Municipal Utility District territory, average peak demand for all-electric homes (no gas end-uses) was just 32 amps, compared with 20 amps for mixed-fuel homes (Khanolkar, Armstrong, and Kabat 2023). These results suggest that many homes in California could electrify some or all end-uses within existing service capacity, depending on the individual conditions at each home.

Open Breaker Slots

About half of the homes surveyed in Western states had two or less breaker slots available and would need to either employ a subpanel or use tandem breakers (devices that can fit two circuits in one breaker slot or replace the panel (Lindsey 2023)).

Technology Options

The following sections outline a variety of equipment and technology options available on the market to upgrade service capacity or manage load within existing service and panel capacity. When installed properly, all the interventions outlined comply with building codes, though anecdotal reports from contractors indicate that some permitting agencies are unfamiliar with newer technologies such as dynamic load management devices and smart panels.

Load Management

1. **Devices exist that control two or more high load appliances on a single circuit with cost ranges from $200 to $1750.** (Herrschaft 2023; Gaillard and Kabat 2021; Redwood Energy 2022)

    - Circuit-sharing devices allow two appliances with loads up to 50A to be used on the same circuit. A dryer buddy is an example of a circuit-sharing device.
    - Circuit pausers will automatically shed the load of one appliance when the peak load is reached for the home.
    - Smart splitters are programmed to “triage” load between two or more appliances (StopWaste and Association for Energy Affordability 2021).
    - Smart circuit breakers and relays add energy management capabilities on individual circuit breaker levels within panels (VEIC and Ortiz Group 2023).

2. **In multifamily properties, lighting controls and electric vehicle (EV) dynamic load management are helpful to lower overall load and avoid times of peak load, respectively** (StopWaste and Association for Energy Affordability 2021).

    - The EV dynamic load management utilizes demand response for EV charging. It does so by connecting to an existing electrical infrastructure, such as serving a multifamily building’s central laundry room. To manage the load, EV chargers will then draw power when demand is low on the infrastructure.

Panel Upgrade Technology Options

1. **Standard panel upgrades increase overall panel capacity, but typically require upgraded electrical service from the utility.**

    - Panel and service capacity needs should consider all electric loads planned, including potential future needs.
    - Project costs and complexity are highly dependent on specific conditions and needs at each home (E Source 2022).
    - Coordination between contractors, utilities, and local building departments can delay panel upgrade projects.
    - Utility service upgrades can add significant costs for panel upgrades. Factors include, but are not limited to, overall service needs, existing utility transformer capacity, and needs for trenching for underground service.

2. **Smart Panels may provide an alternative to electrical service upgrades. (E Source 2022; Kabat and Gaillard 2021)**

    - Smart panels use communication and controls to manage active loads in the home and prevent overloading the panel.
    - Depending on the added loads, smart panels may be able to accommodate new electric loads within the existing panel and service capacity.

- Higher costs of smart panels may be offset by the avoided cost of electrical service upgrades.
- Lack of familiarity at utilities and building departments may be a barrier for smart panel products.

Power-efficient Electrification Options

1. **Power-efficient appliances and equipment can support home electrification while limiting additional load on the panel or electrical service.**

- Examples include 120v heat pump water heaters, heat pump electric clothes dryers, combined washer-dryers, induction cooktops, induction ranges with battery supply (120v), low amperage EV chargers, etc. (E Source 2022; Kabat and Gaillard 2021).
- Power-efficient options may come with some performance trade-offs, compared with incumbent gas or electric options (e.g., first hour rating for water heating, heat delivery for heat pump heating, load size for heat pump dryers, charging speed for EV charging). Power-efficient appliances may also have more limited product choices and may include higher costs than more traditional appliance options.
- However, an industry survey suggests that customers may also prioritize factors such as project delivery models and indoor air quality, rather than focusing solely on the system performance (Casquero-Modrego, et al. 2022).

National Electric Code Review and Recommendations

1. **Part IV of NEC Article 220 - i.e. 220.80 sections - details the optional service and feeder load calculation methods that may allow single-family and multifamily buildings to avoid electrical panel and service upgrades.**

- NEC Section 220.80 identifies the home's square footage, the number of electrical appliances/devices, the nameplate ratings of these appliances/devices, and the number of dedicated branch circuits as factors that influence calculations (Pecan Street 2021; Commonwealth Edison Company 2022).
- NEC Section 220.83 employs a formula that conservatively calculates the building load by assuming 100 percent coincidence for the first 8kVA of load and 40 percent coincidence of remaining loads (Murphy 2022). When electrifying two or more devices in a home, using the calculation methods offered by 220.83 is more helpful for staying on the existing panel (NV5 2022).
- NEC Section 220.84 employs a formula for multifamily buildings with three or more units that could be helpful for avoiding panel and service upgrades when electrifying cooking appliances (StopWaste and Association for Energy Affordability 2021).
- NEC Section 220.87 uses metered demand data to determine panel capacity. This section applies a factor of 1.25 to the maximum metered demand data over a year (or a minimum of a 30-day period), then adds the new load to calculate capacity (Murphy 2022; NV5 2022). When electrifying one device in a home, Section 220.87 is more helpful than Section 220.83 for staying on the existing panel. Presently, Section 220.87 can lead to a double count of loads because it assumes "historical peak demand and new load are

coincident" (e.g. replacing a gas heater with an electric heat pump in a home with air conditioning) (Murphy 2022).

2. **Load management devices are not explicitly referenced in 220.80 sections, so the allowance of these devices to reduce load calculations varies, depending on the jurisdiction and building inspector.** (Murphy 2022).
3. **NEC 220.12 is a lighting section for multifamily buildings and clarifies that LED lighting retrofits should be done before employing load monitoring strategies to count the load reduction** (StopWaste and Association for Energy Affordability 2021).
4. **NEC 625.42 applies to the use of an automatic load management system for electric vehicle charging. Because the maximum load of the automatic load management system is used in determining panel and service capacity, lower loads will be calculated for charging two or more electric vehicles simultaneously in this section** (Pecan Street 2021).
5. **NEC 705.12 specifies that the total load of all breakers supplying power to a panel cannot be more than 120 percent of the panel's current capacity. This 120 percent rule likely drives the panel upgrades 20 to 30 percent of the time for rooftop solar photovoltaic installations, according to the Building Decarbonization Coalition** (2020).

Cost, Timeline, and Social Impacts

1. **Southern California Edison estimated the cost of a panel replacement within their territory in 2019 at $4,530,** which only included the new panel, new conduit, wiring, and new breakers (E Source 2022). This estimate did not include any trenching costs where required, or other associated upgrades or costs related to the panel replacement.
2. **Timelines for panel replacement projects are typically two to six weeks, depending on project location and conditions** (E Source 2022). This timeline estimate was independent of any other electrification projects associated with the panel upgrade. A range of factors can influence the overall project timeline, including:
    - Project complexity, especially when working with underground electrical services
    - Age of the home and condition of existing electrical wiring
    - Types of end-use equipment
    - Weather and seasonal delays
    - Staffing constraints
3. **Additional factors can pose challenges or barriers for electrical service upgrades, including** (E Source 2022):
    - Property ownership and configuration: Customers living in multifamily properties or neighborhoods with homeowners' associations may need to coordinate their activities with building owners or other third-party entities.
    - Language barriers or other communication challenges between the various parties involved (customers, contractors and other work crews, utilities, local building inspectors, etc.).

4. **Service upgrade costs have a bimodal distribution** (Pacific Gas and Electric 2024). PG&E reported costs only include the utility costs, some of which are covered by a utility allowance, and the remainder of which are paid by the customer. Project costs exclude costs paid directly from the customer to an independent contractor or to a local government.

- When modifying electric overhead service less than 400 amps:
    - 20 percent of projects cost less than $3,000
    - 75 percent of projects cost less than $13,000
    - Five percent of projects cost more than $40,000
    - The five percent of projects costing more than $40,000 required a right of way or easement, or upgrades to utility-owned infrastructure apart from just the service drop line, or both.
- When modifying electric underground service less than 400 amps:
    - 20 percent of projects cost less than $2,500
    - 75 percent of projects cost less than $10,000
    - Five percent of projects cost more than $31,000
    - The five percent of projects that costing more than $31,000 required a right of way or easement, or upgrades to utility-owned infrastructure apart from just the service drop line, trenching by the utility, a long trench, working in difficult conditions, or some combination of these factors.

Policy Development for Electrical Panels and Service

Recommendations to Decision-Makers on Improving the Panel and Service Upgrade Process

The literature we reviewed made many recommendations to decision-makers. We summarize the major types of recommendations below.

- Avoid panel and service upgrades when possible. To avoid panel and service upgrades:
    - Encourage homeowners to develop electrification plans so they can understand the decisions they should make if they want to optimize their existing panel.
    - Encourage the use of Watt Diet strategies, such as 120-volt heat pump water heaters, smart panels, smart breakers, and circuit splitters (ComEd 2023) to optimize existing panels. Utilities can do this when a customer applies for a service upgrade. Incentive providers can subsidize the use of load management technology, and partner with weatherization programs to bring down the required heating and cooling load for homes.
    - Incentive programs need to do more than they have in the past to address in-unit energy upgrades in multifamily housing. Addressing common area and in-unit load is necessary to avoid costly electrical upgrades.
    - California's Department of Housing and Community Development should update the California Electrical Code to discourage unnecessary panel and service upgrades.

    - Increase workforce training for contractors and building inspectors on the benefits of avoiding panel and service upgrades and strategies for doing so. The Department of Industrial Relations and Contractors State License Boards can strengthen education on panel optimization for electricians by including it in the licensing exam and in continuing education requirements.
    - Conduct further research into how best to avoid panel and service upgrades. One paper was more skeptical of some of the approaches endorsed by the Watt Diet (ComEd 2023). They recommend additional research into their value before deciding whether to encourage their uptake.
- Improve the customer experience when working with utilities on panel and service upgrades.
    - Regulators should require utilities to plan for building decarbonization ahead of customer demand.
    - Improve utilities' internal management of service upgrade processes to make the process more automated and provide metrics on timelines.
- Socialize the cost-of-service upgrades among utility ratepayers. A variety of approaches are possible, including:
    - Increase the Rule 16 allowances to relieve the cost burden on an individual customer.
    - Spread costs for distribution infrastructure upsizing to all customers who are served by that infrastructure. Diangle and Jungers state that the first customer to trigger an upgrade pays for work that benefits other customers (Diangle and Jungers 2022). This author notes that there is some ambiguity as to when this is the case. Per Electric Tariff Rule 15, when two or more existing services are being served by a piece of equipment (considered existing distribution), any upgrade costs should be borne by the utility.
    - Conducting distribution system upsizing in advance of a customer applying for a service upgrade would also have the effect of socializing the costs (a recommendation is listed below on better utility planning).
- Use better utility planning to leverage economies of scale and to relieve customers of the time delays and costs of doing service upgrades on a case-by-case basis.
    - Utilities should plan ahead for the distribution system infrastructure upgrades required for building electrification, so they can work on projects in bulk and do capacity upgrades at the same time as other distribution system work. This also has the effect of socializing the cost of distribution system upgrades for electrification, rather than charging them to individual customers.
- Reduce the cost of panel upgrades and service upgrades by leveraging economies of scale.
    - A zonal approach to electrification, in which an entire neighborhood converts to all-electric at once, would allow better economies of scale in doing panel and distribution system upgrades.
- Offer funding and financing for panel and service upsizing.

    - The federal IRA provides some funding for panel and writing upgrades. Incentive providers should monitor those offerings and be prepared to supplement those offerings as necessary.
    - One paper recommends making funding and financing for panel and service upgrades contingent on the contractor demonstrating a good-faith effort to avoid the panel upgrade. One way to implement this would be to require an electrician to sign a document stating that the panel upgrade was unavoidable (Murphy 2022).
- Offer funding and financing for approaches that mitigate the need for panel upsizing.
    - Watt diet approaches such as circuit-sharing and low-voltage equipment should be eligible for subsidies.
- Some authors recommend that all single-family homes upsize to at least 200-amp panels and service lines. Some specific recommendations along those lines are to stop allowing service line replacement of under 200 amps, for utilities to identify homes with sub-200 amp service, and to use education and incentive to encourage customers to upsize their panels and service as soon as possible.
- Make it possible for building owners to electrify when old equipment burns out without having to wait for electrical infrastructure work to be performed. This can be done by encouraging building owners to plan for electrification in advance, and by developing loaner programs that allow customers to borrow temporary gas-fired equipment or 120-volt water heaters while waiting for their permanent equipment.

Utility Rules Governing Electrical Service and Panel Work

Rule 15 is a tariff that defines the funding for investor-owned electric utilities distribution line extensions. These are extensions of the existing distribution lines from the nearest permanent and available distribution facilities to commercial areas and residential neighborhoods. Rule 16 is an electric utility tariff that outlines the rules and requirements for service line extensions. Service line extensions connect the distribution lines to the customers' electric meters. Electric utilities also set the design and construction standards for panels and service that property owners must follow. These go under a variety of names, such as PG&E's Greenbook, Southern California Edison's Manual on Electric Service Requirements, and San Diego Gas and Electric's Service Standards and Guide.

Market Characterization of Existing Homes

Table 3 below summarizes data available from the market characterization sources TRC has reviewed. All sources listed in the table include data on home vintages. Key data points that are of particular interest to the decision-making guide and tool development are highlighted in bold in the table below.

Table 3. Summary of sources for market characterization of existing homes

Source	Mechanical Equipment and/or Energy Data	Demographic Data
American Housing Survey, US Census Bureau - national survey of housing and household characteristics	**Fuel types** **Heating equipment** **Cooling equipment** **Kitchen appliances** **Laundry appliances** Solar PV	Race and ethnicity Age of householder Education Citizenship Household characteristics Household income
California Residential Appliance Saturation Study (RASS), CEC 2019 - statewide study of residential energy use and equipment and physical attributes (DNV GL 2021)	**Heating equipment** **Cooling equipment** **Water heating** **Kitchen appliances** **Laundry appliances** **Electric vehicles** Other equipment and electric end-uses	
Multifamily Market Analysis, TRC 2018 - assessment of energy savings opportunities for codes and standards in the California multifamily market (TRC 2018)	**Heating systems** **Cooling systems** **Water heating**	
San Joaquin Valley Disadvantaged Community (DAC) Data Gathering Plan Findings Report, Opinion Dynamics 2021 - results of a data gathering plan to increase access to affordable energy in DAC in the San Joaquin Valley (Opinion Dynamics 2021)	Solar and energy storage **Heating systems** **Cooling systems** Thermostats **Cooking appliances** **Electrical wiring** **Laundry appliances** Other appliances	Homeownership Household income Languages spoken at home Children in the home Race and ethnicity Education

Source	Mechanical Equipment and/or Energy Data	Demographic Data
Silicon Valley Clean Energy (SVCE) Buildings Baseline Study, SVCE 2020 - aggregated energy end uses for residential and commercial buildings in SVCE territory (SVCE 2022)	Aggregate energy end-use data by equipment or appliance type	

Ultimately, the project team chose to use data from the American Housing Survey as part of the Building Stock Assessment tool (described below), because it was the most complete single set of data, and it allowed for disaggregation by county.

Review of Existing Tools

The project team reviewed five available tools. Each of the tools is designed to support residential electrification in varying ways, from a general assessment of energy and carbon reductions, to a detailed assessments of existing panel conditions and the ability to select specific equipment and appliances, depending on the tool. All of these existing tools are available online for free and are relatively well-known among electrification advocates. The project team was unable to determine the awareness or use of these tools beyond the community of electrification experts and advocates. Where possible, the decision guides and tools in this project incorporated findings and knowledge from existing work to avoid duplicating efforts.

Stakeholder Engagement and Feedback

The project team has engaged and communicated with relevant stakeholders to inform, learn, and collaborate with them in the project's tool development. The following are the activities to date on our engagement and findings:

1. POWER group

- In the full group monthly meetings that occurred in September, October and December 2023, the project team introduced our project and invited POWER members to collaborate in the project tool development, including coordinating with those undertaking similar efforts. In April 2024, we previewed our draft tool and accompanying visuals with the group to gather feedback and areas for improvement.
- The multifamily buildings subgroup kicked off in October to hold a focused space to understand the considerations, strategies, and barriers on the electrical panel(s) when electrifying multifamily buildings. These discussions have covered the following:

- The NEC 220.84's definition of multifamily (i.e. buildings with three units and above) would be the main scope for discussions.
- Within a multifamily building, electrical panels exist at three levels: (1) the unit level for a household, (2) the property owner level for shared services and amenities, and (3) the whole building level (i.e. the master meter).
- The electrical panel capacity, on both the unit and whole building levels, determines the extent of electrification retrofits with water heating easier to electrify due to cost.
- In determining the unit's panel available capacity for electrification, running relevant NEC calculations is the first step before metering, which could cost $1,500 to $2,000 for the installation of metering equipment. For larger buildings, discussions will occur with authorities having jurisdiction to negotiate a reasonable sample of units to meter - e.g. 25 percent of a 100-unit building.
- Presently, various electrification programs are implemented by different organizations. As a result, holistic and power-efficient approaches to electrification are uncommon. Big property management companies are more likely to understand longer-term electrification planning.
- To avoid panel upsizing, usage of lower power appliances has been the top strategy employed. Smart splitters are not often used for load management strategies because of tenants' unfamiliarity with them.
- Older buildings, such as 1960s and earlier, will be more costly to electrify because of lower panel capacities, the prevalence of original electrical gear, the code implications of relocating and updating equipment, and meter banks closely located near one another.
- Past practices included undersizing transformers for multifamily buildings as historically no major electrification end-use existed.
- Utilities transmission distribution staff tested load management devices and found they did not perform as reliably as they would like.

2. Lawrence Berkeley National Laboratory (LBNL)

- The project team learned of a similar effort by LBNL contracting with Redwood Energy to develop a decision-making guide for contractors on residential electrical panel upgrades.
- LBNL researchers provided our project team a tabular summary of panel ratings in California households. Panel ratings were derived from LBNL's database containing electrical panel and household information in over 35,000 dwellings. Tabulated ratings were disaggregated based on household characteristics (e.g., building type, vintage, floor area and appliance fuels). Details of this database will be published in a forthcoming paper (Murphy et al., 2024). We utilized these tabulations in our building stock panel tool.

3. Specific stakeholder groups

- During the development of the tool, the project team has engaged specific stakeholder groups, especially electrification contractors and program implementers, to collect feedback on the tool and make improvements.

- Contractors reviewed the technical feasibility and usefulness of the tool. They see value in the tool supporting their homeowner engagement with electrification projects and initial panel assessments calculations.
- The project team held two meetings with California program implementers in May of 2024 to demonstrate the functionality of the Building Stock Tool and collect feedback. Attendees of these meetings included staff at community choice aggregators, regional energy networks, utilities, city environment departments, and state agencies. The team presented to potential users the tool's proposed functionalities and received useful input on the design and application of the tool. Input from these meetings informed the design of the tool itself, as well as accompanying informational materials for the tool, including the Building Stock Tool infographic and one-pager.

4. Test Run Draft Individual Home Tool

- The project team shared an initial test draft version of the Individual Home Tool with all POWER Network members on May 20, 2024, and requested any feedback they had from using the tool. The project team received written feedback from five test tool reviewers (in addition to the verbal feedback described above). Reviewers identified minor calculation errors, and made suggestions for improvements of the tool, including opportunities for clarification and simplification and opportunities to improve and expand the options and capabilities of tool. The project team reviewed all the feedback in refining and finalizing the tool. Some suggestions for expanded capabilities or increased options will need to be addressed in future iterations of the tool.

Tool Development

Following the background research and stakeholder engagement outlined above, the project team developed the decision-making guide, customer journey, individual home tool, and building stock tool, as described in the following sections.

Decision-Making Guide and Customer Journey

As a first step of the tool development, the project team developed decision-making diagrams, which illustrate the process by which a homeowner, in consultation with their contractor(s), can determine whether the existing panel and service can accommodate all their electrification needs.

These decision-making diagrams are illustrated in the graphics below.

Figure 4. Proposed decision-making process for homeowners using the Tool.

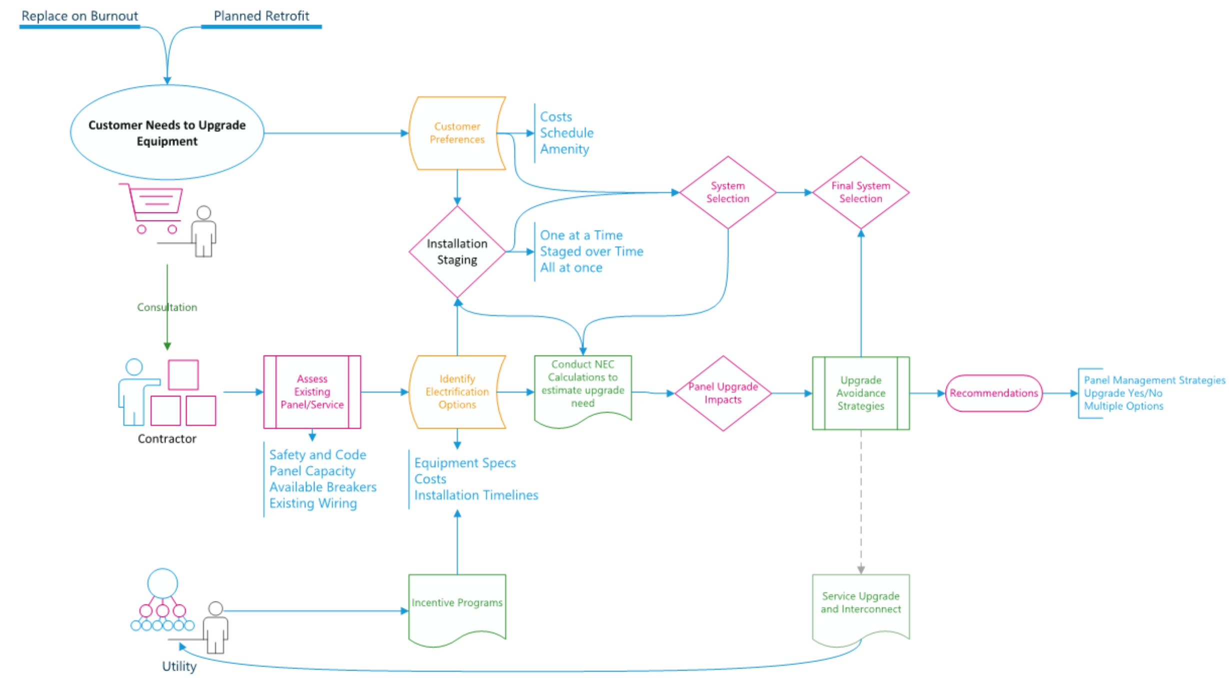
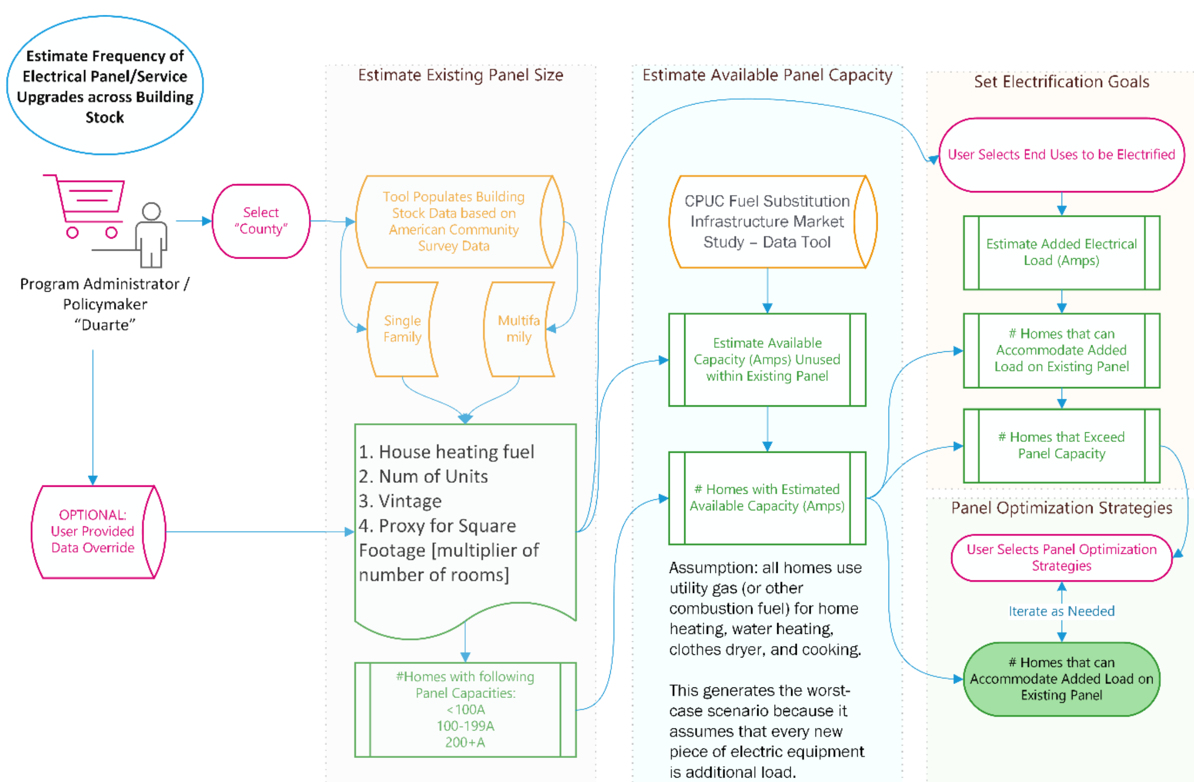


Figure 5. Proposed decision-making process for building stock.

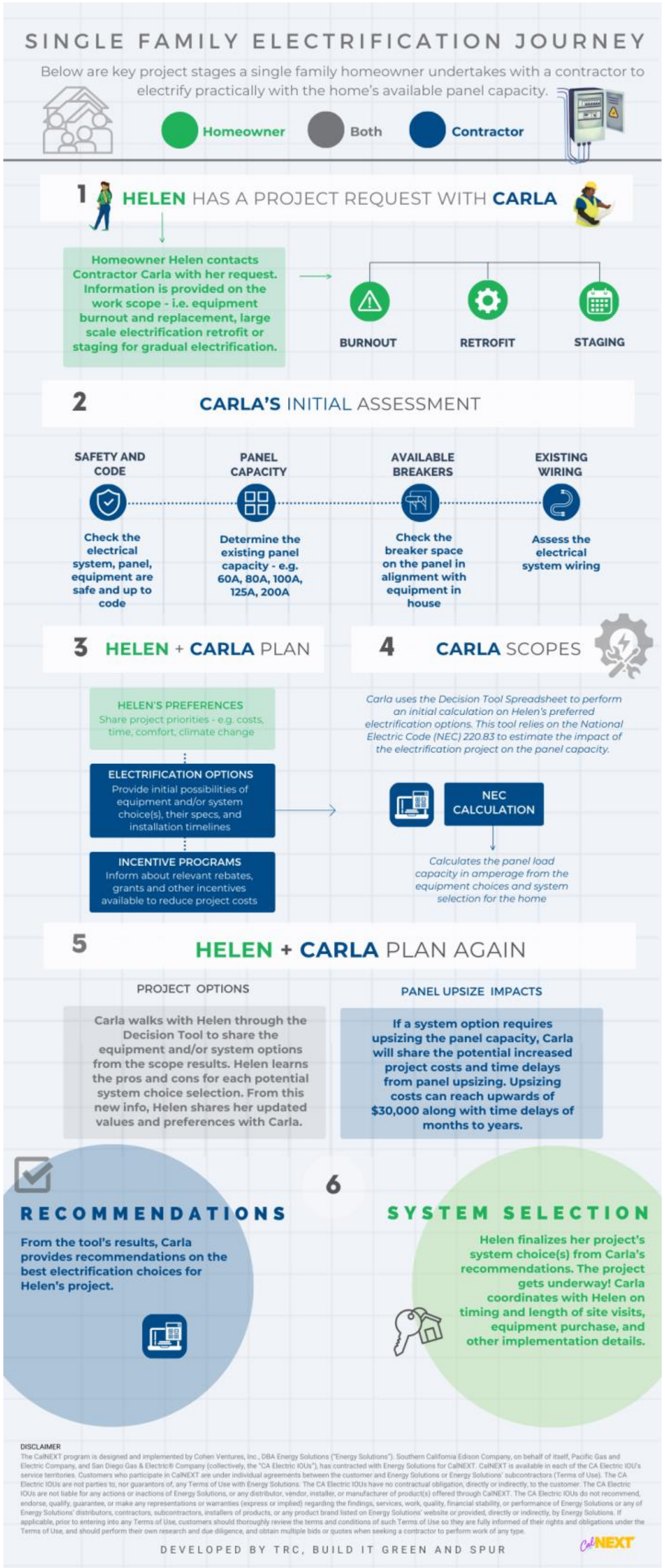


Building on these diagrams, the project team developed a decision-making guidebook to document typical processes for users to reference as they use the Tool. The guidebook establishes typical personas and how the Tool will support decision-making for those personas, as examples. The guidebook provides additional details and context to inform customer decision-making, including where the customer and contractor will need to assess conditions outside of the Tool, and how customer priorities and needs inform the use of the Tool. For each persona, the guidebook walks through an example home electrification project. Each example persona and project described in the guidebook includes:

1. Persona – A description of the example homeowner to contextualize the decision-making process.
2. Homeowner priorities – An initial description of homeowner electrification priorities (e.g., whole-home electrification, or specific systems only) and timeline (all projects completed at once or phased over time).
3. Contractor verification – The contractor assesses existing conditions and makes documentation of building systems and existing panel and service capacity.
4. Tool inputs and results – The contractor uses homeowner priorities and existing conditions as inputs to the calculator tool, and any optimization strategies that may be needed; the contractor verifies the viability of potential optimization strategies based on the on-site conditions.
5. Contractor shares results with homeowner – The contractor and customer review and adjust the outputs of the tool, including any optimization strategies and options.
6. Homeowner and contractor finalize plan – Based on the results of the tool and any additional feedback from the homeowner, the homeowner and contractor agree on a final plan for electrification, including the system choices and a schedule.

In addition, as a visual complement to the Decision-Making Guidebook, the project team developed customer journey diagrams, showing an example journey of a residential single-family homeowner. This journey starts with the identification of need, followed by the engagement of a contractor, scheduling considerations, the baseline conditions assessment, the identification of electrification options, the selection of the most power efficient option, and, finally, the assessment as to whether that option eliminates the need for a panel and/or service upgrade. For each option selected, the customer journey provides considerations, such as the implications on project costs, timelines, utility reviews and approvals, and any reductions or increases in amenities, as well as any impact of appliance usage patterns or operational behaviors. The diagram below in Figure 6 shows an example of this customer journey diagram.

Figure 6. Infographic for homeowner electrification journey.



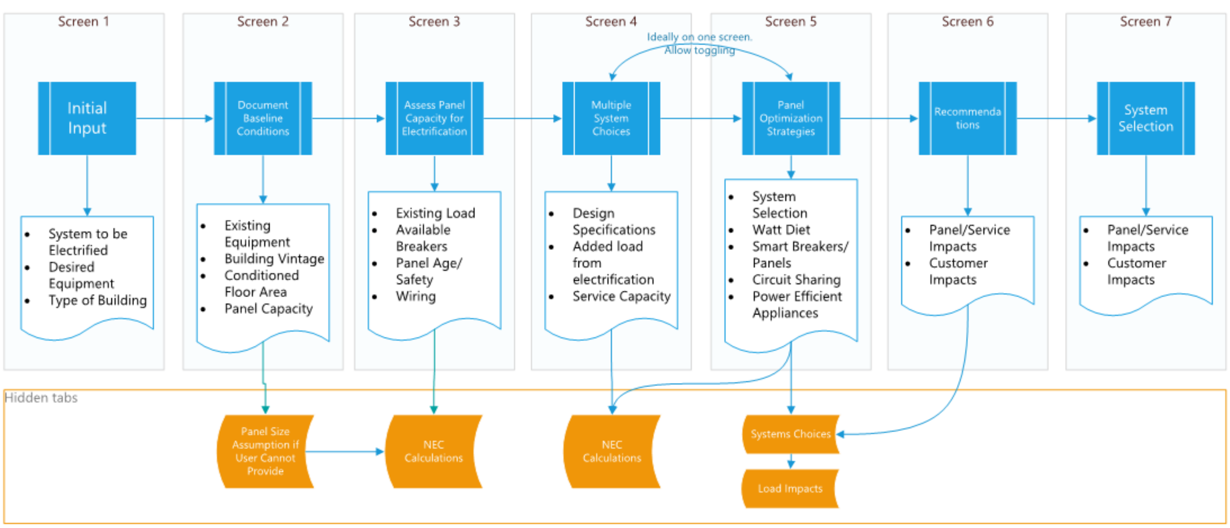
Individual Home Tool

Building on the research findings and the decision-making guides outlined above, the project team developed a Microsoft Excel-based interface that walks the user through various scenarios and strategies to support decision-making on electrification choices and service and panel choices.

The Tool is designed for contractors to use in collaboration with homeowners. While homeowners should be guiding the electrification priorities, some of the technical information or equipment details may require the expertise of a contractor to accurately input. In addition, the Tool uses standard electrical code load calculations to determine potential electrification strategy options, but qualified contractors will need to verify conditions at the site and determine how to implement the selected strategy.

The Tool walks users through a series of screens, as illustrated in the early concept diagram below (see Figure 7), allowing for inputs of current conditions and electrification priorities. Users can choose to pursue a variety of electrification options and optimization strategies and see the resulting effect those choices have on panel and service capacity.

Figure 7. Initial conceptual diagram of the individual home tool.



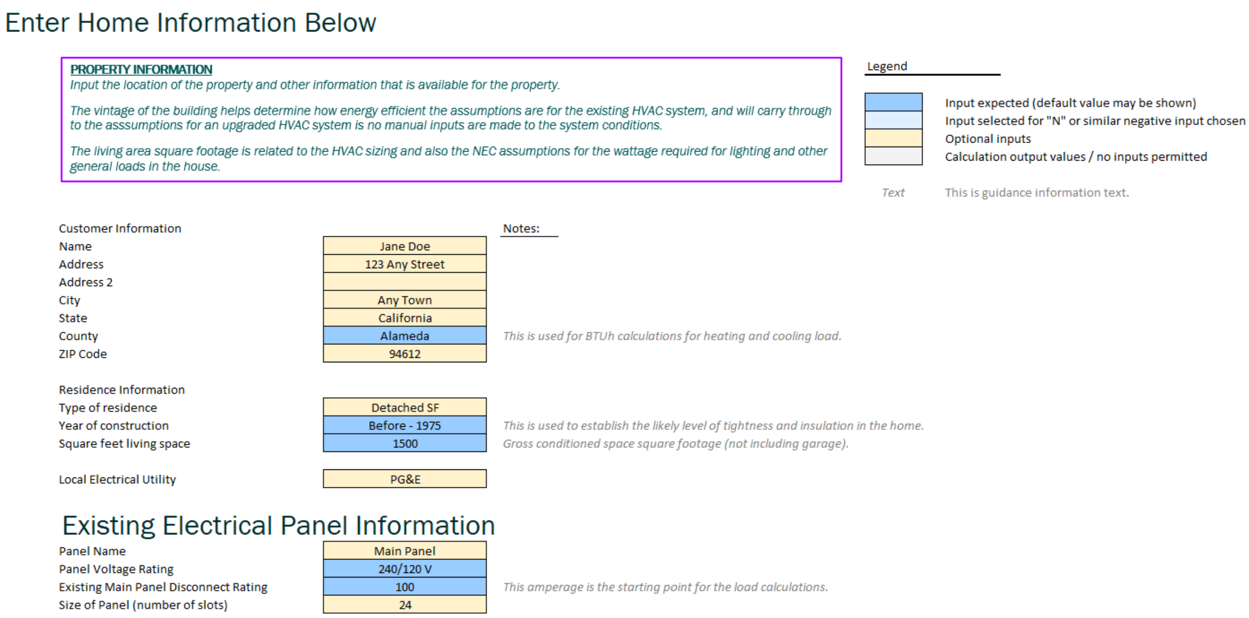
Tool Walkthrough

Tool inputs and outputs are organized as described in the following sections. The Tool also includes information and instructions tabs for user reference. The "About" tab provides information on the contract that produced this tool and information on the tool development team. The next tab is "Instructions and Info" and is where information on the procedures and calculations assumptions are stored. The next tab, "Notes" is intended for the user to make notes about the calculations and results that may be important to retain for future decision making after the main calculation scenarios are established.

PROPERTY INFORMATION

The first input screen of the Tool asks the user to provide basic information about the home and the electrical panel, including the location, home size, electrical service capacity, and electrical panel configuration, as Figure 8, below, illustrates. County, year of construction, square feet of living area, panel voltage rating, and existing main panel disconnect rating must be entered to accurately calculate default loads and panel results. Other inputs on this tab are optional.

Figure 8. Example of a Property Information screen.



EXISTING SYSTEMS AND LOADS

The next screen asks the user to provide details on all existing systems in the home, including space heating, air conditioning, ventilation, water heating, kitchen appliances, and laundry appliances. The Tool also allows users to specify additional loads that may not be listed in the specific equipment types. This screen includes a standard list of fixed appliances that must be included in load calculations if they are present in the home, including the refrigerator, garbage disposal, microwave, dishwasher, kitchen range hood, and bathroom fans (see Figure 9). For each appliance and electrical load, the Tool provides default power or size details based on standard appliances and the size of the home if details are not available. These defaults can be overridden, and users should provide actual nameplate values for system sizing wherever available for increased accuracy.

Figure 9. An example of an Existing Systems and Loads screen.

Enter Existing Building System Information Below

Select "Y" if System Exists in Home	Description	Type	Main Energy Source	Assumed Size	Electrical Characteristics of System: Default Voltage	Assumed Nameplate Power (VA)	Use Default?	Manual Voltage	Manual Amperage	Existing Loads: Volt-Amps (VA)
Y	Space Heating	Central forced air	NG, Propane, Fuel oi	2.5 ton	120	100	Y			100
Y	Space Cooling	Central forced air	Electric	2.0 ton	240	4080	Y			4080
Y	Ventilation	Air Handler	Electric	600 watts	240	600	Y			600
N	Reserved for HP Backup	Strip Heat	Electric				Y			
Y	Clothes Washer	Side by Side Full size	Electric	480 watts	120	480	Y			480
Y	Clothes Dryer	Side by Side Full size	NG, Propane	480 watts	120	480	Y			480
Y	Range (cooktop and oven)	30" CT/Oven	NG, Propane	480 watts	120	480	Y			480
N	Oven (seperates) - Single						Y			
N	Oven (seperates) - Double						Y			
N	Cooktop (seperates)						Y			
Y	Water Heater	Tank < 50gal	NG, Propane	305 watts	120	305	Y			305
N	Water heater 2						Y			
N	EV Charger						Y			
N	Other Large Loads 1									
N	Other Large Loads 2									
N	Other Large Loads 3									

Other Existing Electric Loads (not impacted by electrification retrofit)

General Loads

	Description	Notes	Quantity	Default Voltage	Default Power	Use Default?	Manual Volt-Amps	Volt-Amps (VA)
Req'd	Lighting Circuits			120	3	Y		4500
Req'd	Small Appliance Circuits (2 circuits minimum)		2	120	1500	Y		3000
Req'd	Laundry Circuit (1500 VA minimum)		1	120	1500	Y		1500

Fixed Appliances

Exists in Home?	Description	Notes	Quantity	Default Voltage	Default Power	Use Default?	Manual Volt-Amps	Volt-Amps (VA)
Y	Refrigerator			120	750	Y		750
Y	Garbage Disposal			120	600	Y		600
Y	Dishwasher			120	1200	Y		1200
Y	Microwave			120	1500	Y		1500
Y	Kitchen Hood			120	250	Y		250
Y	Bathroom Fan		2	120	150	Y		300
N	Other Appliance 1			120				
N	Other Appliance 2			120				
N	Other Appliance 3			120				

ELECTRIFICATION UPGRADES

This screen asks the user to specify their electrification goals for their home. For each natural gas-powered system or appliance in the home, there will be an option for electrifying the system (see Figure 10). Ideally, users will pursue electrification for all systems. As with the previous screen, each system will have default system sizing, based on a one-to-one conversion from the natural gas system. Users will be able to override these defaults as needed if they have specific system specifications or goals. Similarly, there are additional unspecified systems that users can add if there are electrification goals not captured in the pre-specified system types (for example, if a user wanted to add a second EV charger, they could include it on one of the "Other Large Loads" lines). The selections made on this screen will inform the load calculation outputs shown on the Panel Impacts and Rec's. screen (see below), to determine whether optimization strategies are needed.

Figure 10. An example of an Electrification Upgrades screen.

Select Building System Electrification Goals

Default electrification systems reflect Standard Practice 1:1 replacements for the existing gas systems. If system details are known, enter in the Manual Input cells. System details on this page may imply a need for panel and service upgrades. Use the optimization tabs to identify potential strategies to avoid panel upgrades.

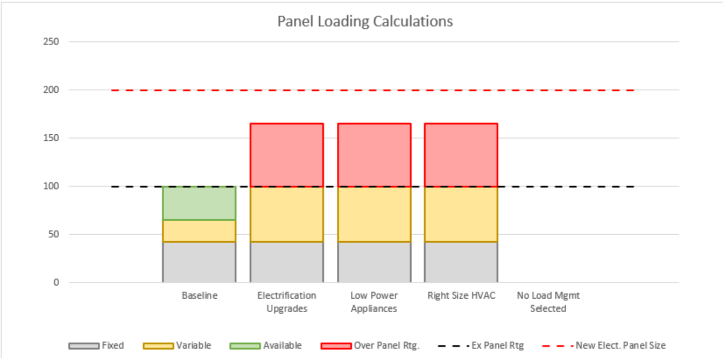
						Electrical Characteristics of New System					
Exists in Home?	Upgrade/Electrify System?	Description	Type	Main Energy Source	Assumed Size	Default Voltage	Assumed Nameplate Power (VA)	Use Default?	Manual Input Voltage	Manual Input Amperage	Volt-Amps (VA)
Y	Y	Space Heating	Central forced air	Electric - Heat Pump	2.5 ton	240	4800	Y			4800
Y	Y	Upgraded with Heating	Central forced air	Electric				Y			
Y	Y	Ventilation	Air Handler	Electric	500 watts	240	500	Y			500
N	Y	Backup Strip Heat	Strip Heat	Electric	5760 watts	240	5760	Y			5760
Y	N	Clothes Washer	Side by Side Full size	Electric				Y			
Y	Y	Clothes Dryer	Side by Side Full size	Electric - Heat Pump	4000 watts	240	4000	Y			4000
Y	Y	Range (cooktop and oven)	30" CT/Oven	Electric - Induction	4800 watts	240	4800	Y			4800
N	N	Oven (seperates) - Single						Y			
N	N	Oven (seperates) - Double						Y			
N	N	Cooktop (seperates)						Y			
Y	Y	Water Heater	Tank < 50gal	Electric - Heat Pump	4500 watts	240	4500	Y			4500
N	N	Water Heater 2	Tankless 3gpm					Y			
N	Y	EV Charger	50 Amp	Electric	12000 watts	240	12000	Y			12000
N	N	Other Large Loads 1		Electric							
N	N	Other Large Loads 2		Electric							
N	N	Other Large Loads 3		Electric							

PANEL IMPACTS AND REC'S

This screen shows a summary of the results of the electrification goals and any load reduction decision making, in relation to the existing electrical panel and service. Tool users should check this tab immediately after entering electrification goals for initial results. The graph on this tab illustrates the impact of the choices on the "Electrification Upgrades" tab on the electrical panel (see Figure 11). Segments of the bar chart shown in red indicate that the selected loads exceed the existing panel capacity. If the electrification upgrades exceed existing panel capacity, users can explore optimization options as outlined below to reduce the overall load and achieve the upgrades within existing capacity. This screen also provides recommendation text to summarize the results of the tool inputs.

The example below in Figure 11 shows the screen after the initial electrification upgrades are selected, but before any optimizations. As the example shows, the selected system upgrades exceed panel capacity. The recommendations text in this example encourages the user to select optimization options to reduce the total load.

Figure 11. An example of a Panel Impacts and Rec's screen before optimizations.



	Baseline	Electrification Options	Opt #1 - Low Pwr Appliances	Opt #2 - Right-Size HVAC	Opt #3 - Load Mgmt
Baseline Amperage	65.1				
Amperage of Full Electrification		165.8			
Amps Saved by Options			0.0	0.0	
% Amps Saved			0.0%	0.0%	
Total Amperage		165.8	165.8	165.8	

No Load Management selected

Panel Electrification Results

The existing main electrical panel is 100 Amps.

With all the electrification measures chosen in the 'Electrification Upgrades' tab, the minimum size electrical panel and service will need to be 200 Amps.

The current optimization measures are insufficient to lower the panel size below the 200 Amp size.

Panel Optimization Recommendations

The electrification upgrades selected will require a panel and service upgrade, but follow the optimization options recommendations below to mitigate this impact.

Your current optimization selections exceed your existing panel capacity, and require an upgrade to a 200 Amp service. Consider making additional optimization selections, or proceed with a service upgrade.

Low Power Appliances - No LPA options are chosen. Go to the LPA tab and select options that are viable for the client.

Right Size HVAC - No HVAC options are chosen. Go to the HVAC tab and select options that are viable for the client if applicable through HVAC or envelope upgrades.

Load Management - No LM options are chosen. Go to the LM tab and select options that are viable for the client .

The optimized main electrical panel is 200 Amps.

Note: All tool results and calculations must be confirmed by a qualified contractor, verifying conditions on site. Contractor to verify that selected strategies and calculation approach are allowable by the local permitting agency.

OPT.1 – LOW-POWER APPLIANCES

This screen provides the first set of potential optimization options the user can employ if their electrification goals cannot be achieved within the current panel capacity. The first item allows the user to select power-efficient appliance options as alternatives to the baseline electrification choices on the Electrification Upgrades screen. Examples of power-efficient appliances include 120v heat pump water heaters, combined washer-dryer appliances, and lower amperage electric vehicle chargers, among others. For each option, the tool includes some brief information for customers and contractors to consider when choosing power-efficient appliances to help with decision making and prioritization, as Figure 12 demonstrates.

Figure 12. An example of options on the Opt.1 – Low-Power Appliances screen.

Proposed Building Systems Changes Round #1 - Low-Power Appliances

Consider a 120-volt Heat Pump water heater

A 120-Volt Heat Pump water heater will have a much smaller demand on the electrical panel, but it will come at the expense of increased recovery time for the hot water in the tank after the hot water has been depleted. This approach is viable in situations where the water heater is not serving a large number of occupants.

Being Upgraded?	Modify to 120V Water Heater?	Description	Type	Main Energy Source	Assumed Size	Default Voltage	Default Power (VA)	Use Default?	Manual Voltage	Manual Amperage	Volt-Amps (VA)
Y	N	Water Heater	Tank < 50gal	Electric - HP 120V				Y			
N	N	Water Heater 2						Y			

Consider a Heat Pump Dryer (240/120V)

A Heat Pump dryer will have a smaller demand on the electrical panel, but it will come at the expense of increased dry times for a load and the dryers aren't as large as the largest traditional dryers. They mostly have the benefit of not requiring an external vent exhaust, but they also do require either being connected to a drain or to have a water pan emptied after every other load. They do require more maintenance.

A 120V appliance will use substantially less energy than 240V but is liminted in size and speed because of this.

A combined unit will save the space of a second appliance, which is beneficial in smaller dwellings.

Being Upgraded?	Use a Heat Pump dryer?	Description	Type	Main Energy Source	Assumed Size	Default Voltage	Default Power (VA)	Use Default?	Manual Voltage	Manual Amperage	Volt-Amps (VA)
Y		Washer		Electric	480 watts	120		Y			
Y	N	Heat Pump dryer or combo	120V Side by Side dryer	Electric - Heat Pump				Y			

OPT. 2 – RIGHT-SIZE HVAC

If the selections in the Opt.1 – Low-Power Appliances screen do not sufficiently reduce the load within the available panel capacity, this second screen provides an additional set of options focused on HVAC system sizing adjustments to adjust for any existing system oversizing or to correspond with any building envelope or efficiency improvements to the home, as well as removing any backup strip heat in the heat pump HVAC system (see Figure 13).

Figure 13. An example of the Opt. 2 – Right-Size HVAC screen.

Proposed Building Systems Changes Round #2 - HVAC Sizing Adjustments

Consider making improvements to home envelope

Envelope improvements includes replacing windows and doors, replacing the dustwork with better R-value insulation, adding more insulation to the attic space, weathersealing, and other measures that will possibly reduce the need for the existing size of heating and/or cooling systems in the home. Many homes can benefit from some improvement to these, but it is not necessary to complete a home electrification.

One benefit of making these improvements is that the 'size' of the HVAC equipment can often be reduced because the improved enveloper performance will reduce heat gain/loss. This may lower the total cost of the new HVAC equipment and may benefit the electrical panel loading requirements.

Since the HVAC equipment has a 1.0 value for conincident factor, reducing the electrical demands of this equipment can have a direct benefit on the power demands in the panel calculation.

This adjustment is especially possible if the existing AC unit were oversized for the house, which is common practice and should be avoided.

The adjustment calculated assumes envelope improvements, including increased attic insulation, better performing windows and doors, and improved weatherstripping, and represents a possible reduction that could occur. More agressive changes may be possible with careful analysis by a design professional. Ensure that proper load calculations are performed by a trained design professional to ensure appropriate Heat Pump sizing chages are selected.

The calculations still must fit into typical 1/2 Ton size increments of modern Heat Pumps, so in some cases, the changes may not result in a reduction in the sizing of the unit. However, a design professional can make more detailed Schedule J calculations and determine if there is room for better improvements. These changes can be input manually.

Being Upgraded ?	Modify by changing HVAC Sizing?	Description	Type	Main Energy Source	Adjusted Size	Default Voltage	Default Power (VA)	Use Default?	Manual Voltage	Manual Amperage	Volt-Amps (VA)
Y	N	Space Heating	Central forced air	Electric – Heat Pump				Y			
Y	N	Air Conditioning	Central forced air	Electric				Y			
Y	N	Ventilation	Air Handler	Electric				Y			

Consider removing the Strip Heat Backup

Electric Strip Heat is commonly included in a Heat Pump system when purchased, but this is not often needed in almost all climate zones in California. This strip heat is included in the air handling unit and is commonly specified as part of that device, which in a split system is specified seperately from the condensing unit.

Strip heat has two purposes; as a backup for very cold temperatures where the HP doesn't function as well (except in high alpine areas, this does not occur in CA), and to provide heat for condensing coil defrost cycles. Defrost cycles are not needed as well in most areas unless there is high humidity and low temperatures that would cause condensation on the coils.

The strip heater backup is a very large load and in most places in California, completely unnecessary. To reduce demand for a larger panel, this will be more beneficial than added insulation and other envelope measures, but it has only a small benefit on energy consumption.

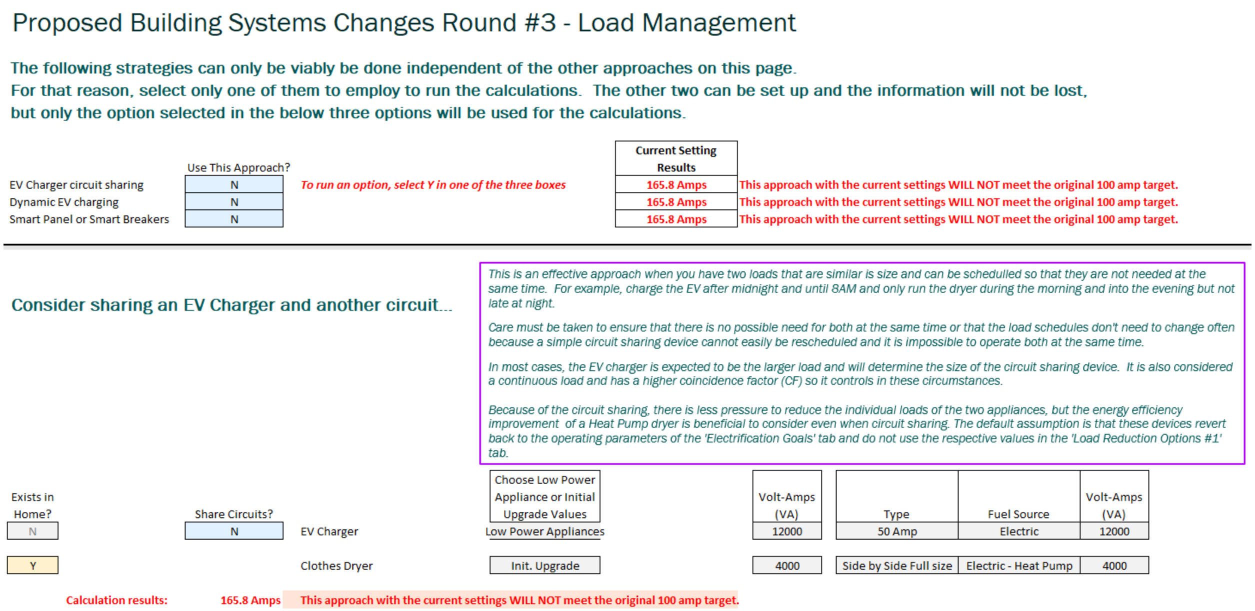
In situations where backup strip heat is required, it is possible to reduce the amount to support defrost but not function as a complete backup to the heat pump.

Being Upgraded or added?	Reduce or eliminate Strip Heat?	Description	Type	Main Energy Source	Adjusted Size	Default Voltage	Default Power (VA)	Use Default?	Manual Voltage	Manual Amperage	Volt-Amps (VA)
Y	N	Backup Strip Heat	None	Electric				Y			

OPT. 3 – LOAD MGMT.

If the previous selections do not sufficiently reduce the load within the available panel capacity, this third screen provides an additional set of options focused on load sharing or active load management strategies, such as circuit sharing, smart vehicle chargers (that automatically adjust the charging load based on available capacity), and smart electrical panels. For each option, the tool provides context and guidance to support customer decision making (see Figure 14). For example, the tool provides additional information on the implications of circuit sharing choices. It also provides some suggestions as to which systems are most effective and least disruptive for employing circuit sharing.

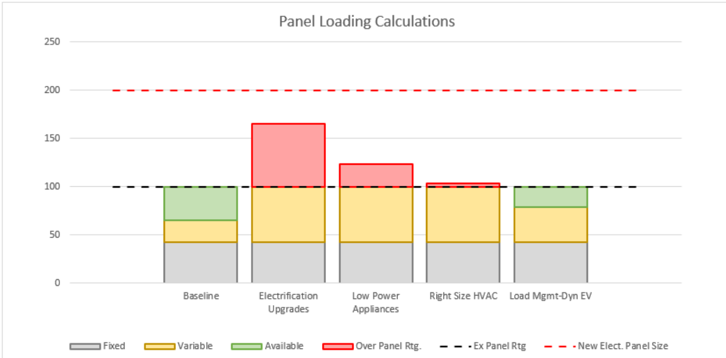
Figure 14. An example of the Opt. 3 – Load Management screen.



REVISIT PANEL IMPACTS AND REC'S.

After entering any optimization options for the project, users should revisit the Panel Impacts and Rec's. screen to determine the final electrification plan. The visual output allows users to quickly gauge the effectiveness of different strategies in the electrification goals and optimization screens. The results and recommendations text provide additional detail on outcomes of the optimization selections. The ultimate goal of the tool is to develop a strategy to meet electrification goals while employing optimization strategies to keep the total load within the existing capacity. In the example below in Figure 15, the user's selections of low-power appliances, right-size HVAC options, and load management would allow for full electrification and the addition of an EV charger within the existing 100-amp capacity of the panel. See Figure 16 and Figure 17, below, for detailed views of the graph and recommendations text in this example.

Figure 15. An example of Panel Impacts and Rec's. screen after optimization selections.



	Baseline	Electrification Options	Opt #1 - Low Pwr Appliances	Opt #2 - Right-Size HVAC	Opt #3 - Load Mgmt
Baseline Amperage	65.1				
Amperage of Full Electrification		165.8			
Amps Saved by Options			42.6	62.2	87.2
% Amps Saved			25.7%	37.5%	52.6%
Total Amperage		**165.8**	**123.2**	**103.6**	**78.6**

Panel Electrification Results

The existing main electrical panel is 100 Amps.

With all the electrification measures chosen in the 'Electrification Upgrades' tab, the minimum size electrical panel and service will need to be 200 Amps.

The optimizations selected will permit electrification without increasing the panel and service size.

Panel Optimization Recommendations

The electrification upgrades selected will require a panel and service upgrade, but follow the optimization options recommendations below to mitigate this impact.

The currently selected optimizations will meet the existing panel capacity and no panel upgrade is required.

Low Power Appliances - The LPA options selected will reduce the panel size, but not enough to eliminate a panel size increase. Continue to the next optimization tabs for further options.

Right-Size HVAC - The HVAC options selected will reduce the panel size, but not enough to eliminate a panel size increase. Continue to the next optimization tab for further options.

Load Management - The LM selections now fit within your existing panel capacity. You DO NOT need a panel upgrade. However, using more efficient equipment choices may reduce energy consumption and peak load to save on electric bills.

The optimized main electrical panel is 100 Amps.

Note: All tool results and calculations must be confirmed by a qualified contractor, verifying conditions on site. Contractor to verify that selected strategies and calculation approach are allowable by the local permitting agency.

Figure 16. A detailed example of a Panel Load Calculations graph from the Panel Impacts and Rec's. screen.

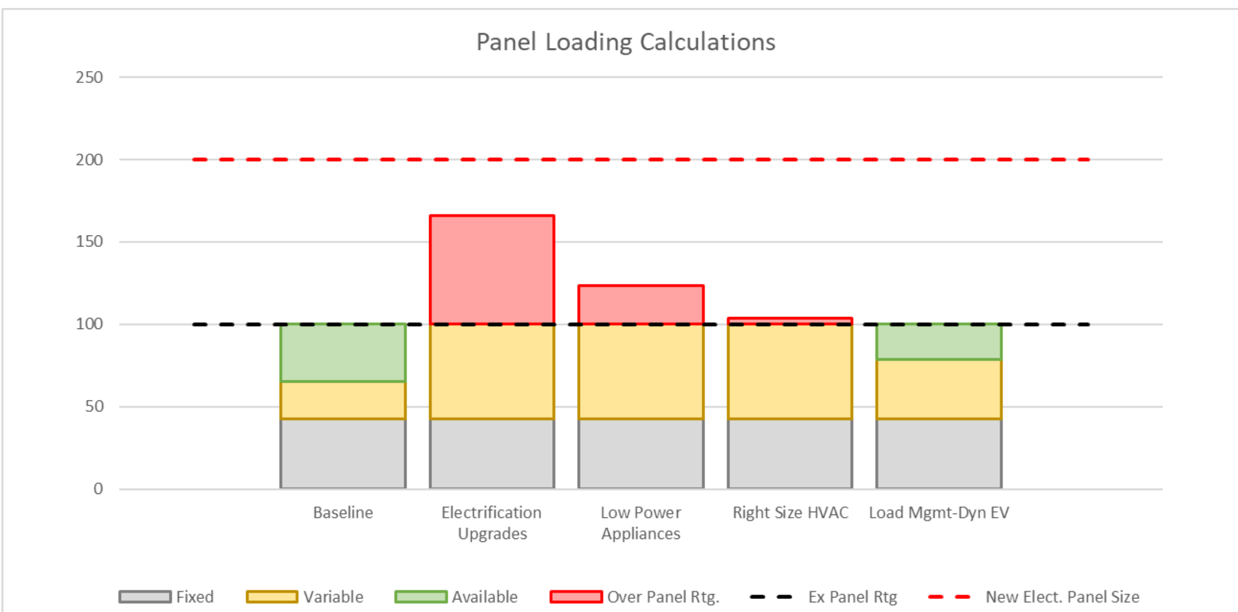


Figure 17. The recommendations text from the Panel Impacts and Rec's. screen in detail.

Panel Electrification Results

The existing main electrical panel is 100 Amps.

With all the electrification measures chosen in the 'Electrification Upgrades' tab, the minimum size electrical panel and service will need to be 200 Amps.

The optimizations selected will permit electrification without increasing the panel and service size.

Panel Optimization Recommendations

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Load Management - The LM selections now fit within your existing panel capacity. You DO NOT need a panel upgrade. However, using more efficient equipment choices may reduce energy consumption and peak load to save on electric bills.

The optimized main electrical panel is 100 Amps.

Note: All tool results and calculations must be confirmed by a qualified contractor, verifying conditions on site. Contractor to verify that selected strategies and calculation approach are allowable by the local permitting agency.

Building Stock Assessment Tool

In addition to the Individual Home Tool described above, the project team developed a Building Stock Assessment tool to provide a portfolio-level outlook.

The primary target user of the Building Stock Assessment Tool is an electrification program administrator who needs to evaluate the frequency of panel upgrades likely to be triggered by electrifying building systems across the building stock. The Tool could also be useful for local governments or other agencies with a need to assess electrification impacts over a portfolio of residential buildings. The goal of the Building Stock Assessment tool is to help guide program decisions to support residential electrification, while also minimizing the need for costly panel, service, and infrastructure upgrades. Users could include public administrators managing statewide programs, utility planners working on distribution planning and electrification efforts, or regional and local administrators at community choice aggregators, air districts, or cities and counties working to transition building stocks toward electricity and off polluting equipment.

Like the Individual Home Tool described above, the Building Stock Tool relies upon the National Electric Code (NEC) calculation procedures, primarily in Section 220.83, to determine a level of connected load that will pass the code test for a renovated/altered existing single-family home. The Tool combines residential building stock data from the US Census Bureau's American Community Survey (ACS) with additional electrical panel data supplied as part of a research project by the Lawrance Berkley National Laboratory (LBNL) for soon-to-be-published research. LBNL researchers provided our project team with a tabular summary of panel ratings in California households. Panel ratings were derived from LBNL's database containing electrical panel and household information in more than 35,000 dwellings. Tabulated ratings were disaggregated based on household characteristics (e.g., building type, vintage, floor area and appliance fuels). Details of this database will be published in a forthcoming paper (Murphy et al., 2024). We utilized these tabulations in our building stock panel tool.

Additional details on the assumptions and calculations for the Building Stock Assessment Tool are available in Appendix C, below.

Tool Walkthrough

There are multiple tabs on the spreadsheet that are visible, but almost all the cells in the workbook are locked and calculation tabs are hidden to avoid damaging the structure of the background calculations that occur in the workbook.

Starting from the left, the "About" tab provides information on the contract that produced this tool and information on the tool development team. The next tab is "Instructions and Info" and is where information on the procedures and calculations assumptions are stored. The next tab, "Notes" is intended for the user to make notes about the calculations and results that may be important to retain for future decision making after the main calculation scenarios are established.

RECOMMENDED PROCEDURE

1. Go to the "County Selection" tab and select the counties you want included in the analysis.
2. Go to the "Dashboard Full Electrification" tab and review the information about the counties selected and what the traditional full electrification impacts might be with full market adoption.
3. Move to the "Dashboard A La Carte" tab and make selections regarding the electrification options and the optimization options to see what the impacts will be.
4. (If desired), Move on to the "Results" tab and see the panel impact counts that are presented in more detail.

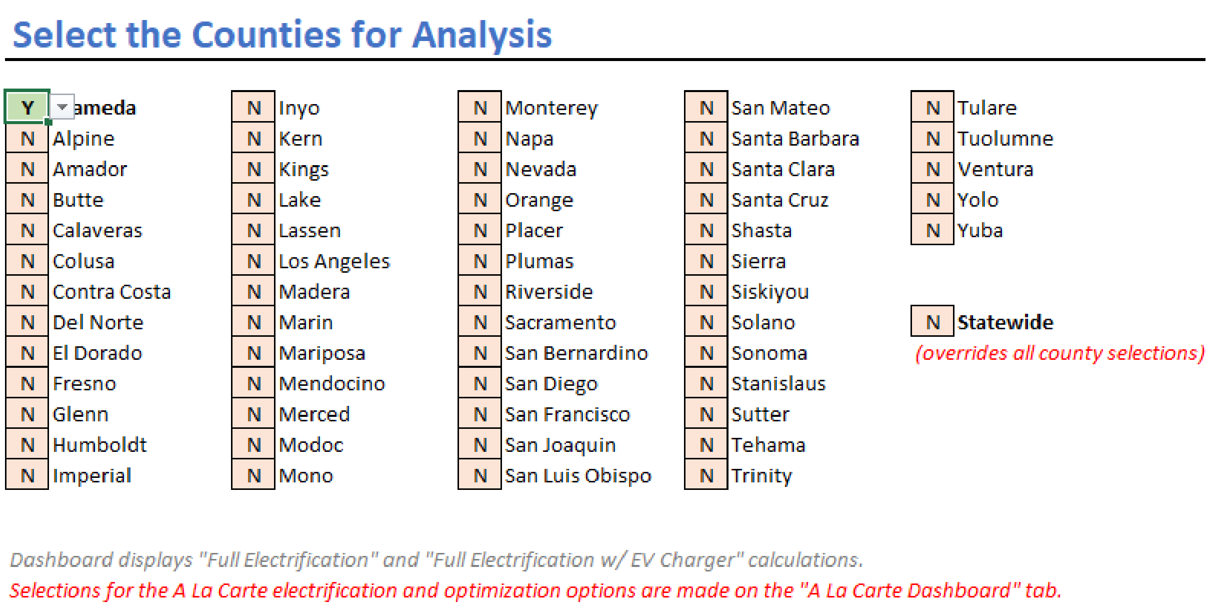
5. (If desired), Go back to the “Notes” tab and make some notes about the results of the analysis that you can save with the file.

Each of these steps, and the options in each tab are described in more detail in the sections below.

COUNTY SELECTION TAB

The “County Selection” tab provides a list of the counties in California to choose for the analysis. Toggling between the “Y” and “N” to the left of the county name will cause the tool to recalculate the results automatically. There is a “Statewide” option that will override all the counties to run values for the full state. The selections are color coded to help indicate which ones are selected for the calculations (see Figure 18).

Figure 18. An example of the County Selection screen.



DASHBOARD FULL ELECTRIFICATION TAB

After selecting the counties, the “Dashboard Full Electrification” tab provides information on the number of single-family homes in the counties and statewide, along with information on the vintage and size breakdown of the single-family homes in the selected counties, as Figure 19 illustrates.

The second column on the dashboard provides information on the estimated percentage of panels that are not up to current NEC code (typically older homes with lower capacity panels built under previous code versions), and which would likely require a panel upgrade to meet code in conjunction with any significant electrical project in the home. This column shows these percentages both by panel size and by size of home (small homes, less than 1000 square feet; medium homes, 1000 to2499 square feet; or large homes, 2500 square feet or greater).

The third column shows the impact of a “Full Electrification” (space heating, water heating, cooking, and clothes drying all converted to electric appliances) on the number of panels requiring an upgrade. Again, results are shown for both existing panel size and home size. The chart at the bottom shows a calculation of the increase in megaamperes (MA) that these electrification projects will cause to the design load on the grid supplying power. These values are based on the loading that the transformer is being designed for (the meter rating) and the voltage of the power supplied to the homes (240V is assumed for all the calculations).

Similarly, the fourth column provides the same information but for a full electrification with the addition of one 32A EV vehicle charger (see Figure 20 for a detail example of the third and fourth columns).

Figure 19. An example of the "Dashboard Full Electrification" screen.

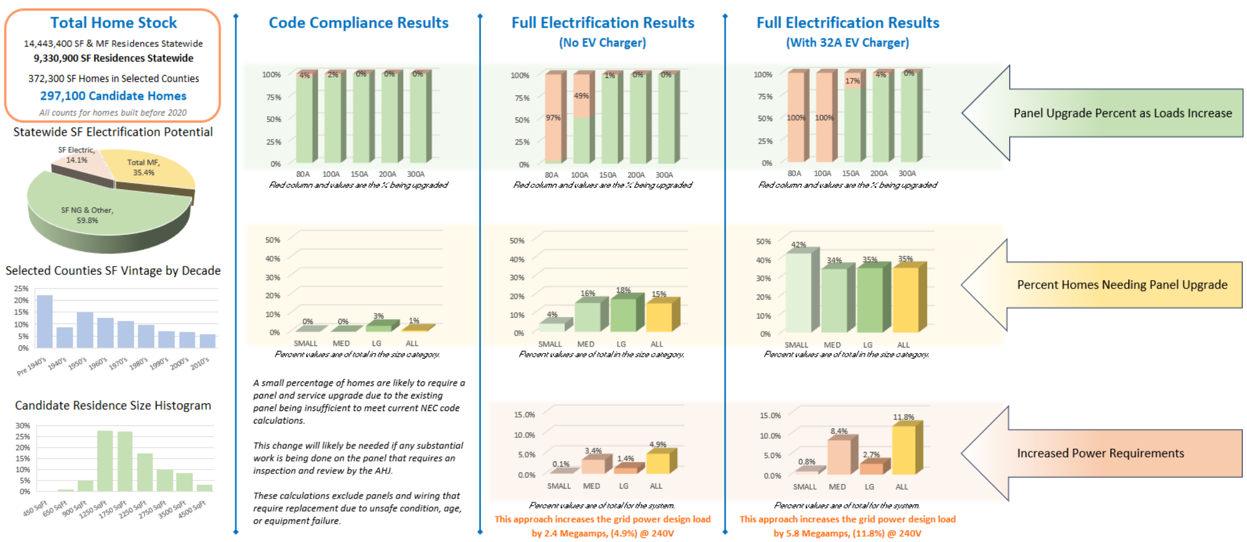
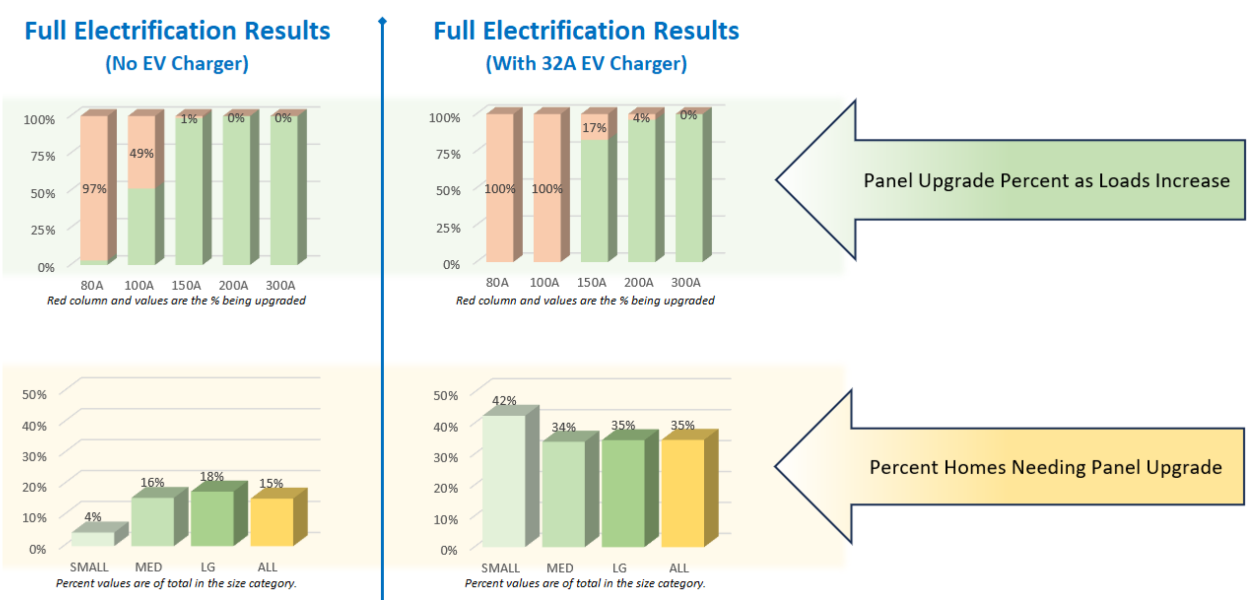


Figure 20. The "Dashboard Full Electrification" screen in detail, showing the upgrades required.



DASHBOARD A LA CARTE TAB

This tab provides similar information to the previous dashboard tab, but the electrification and the optimizations options must be selected before results will be displayed (see Figure 21 and Figure 22).

If all four electrification options are selected (but not the EV Charger option), the results in the "'Traditional' Electrification" column will match the results of the "Full Electrification (No EV Charger)" column on the previous dashboard and if the EV Charger option is included, it will match the "Full Electrification (With 32A EV Charger)" column.

The "A La Carte Electrification" column will also match if no optimization options have been selected, but once any of these are selected, the results begin to vary, and the relative impact of each optimization choice can be observed (however small or large it may be).

The far-right column displays the savings opportunity by using the various optimization options selected in the dashboard. See Figure 23 for a detailed view example of the results on this screen.

Figure 21. An example of the "Dashboard A La Carte" screen.

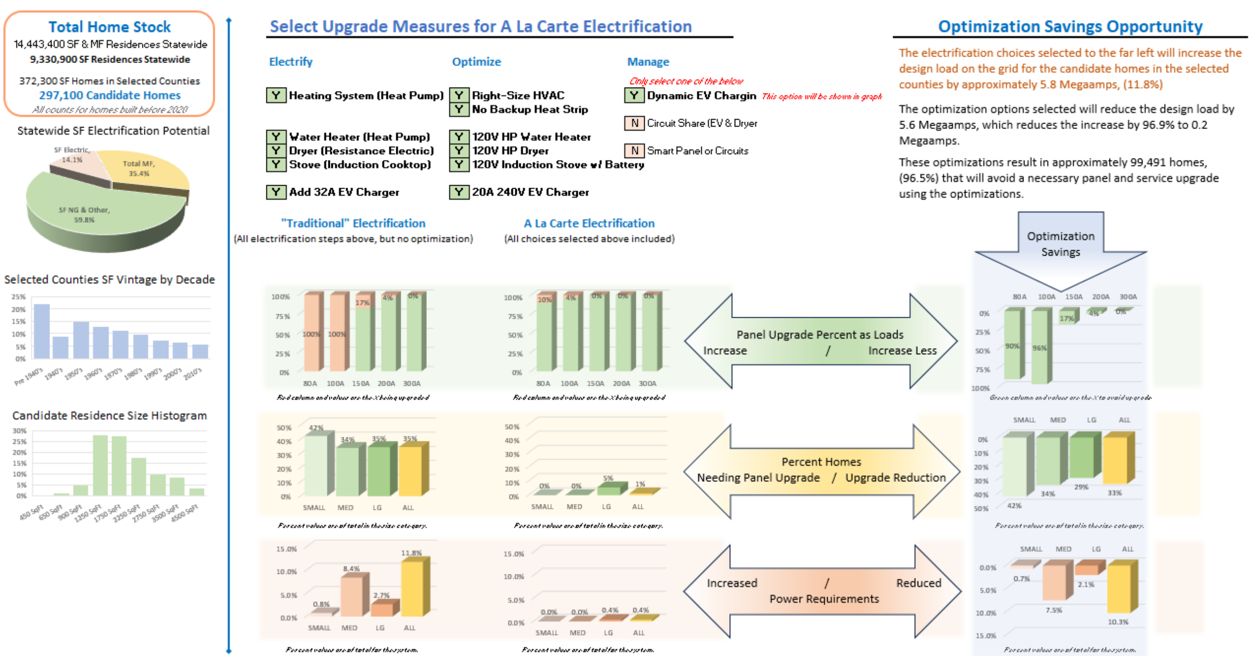


Figure 22. The “Dashboard A La Carte" screen in detail, showing the electrification and optimization options.

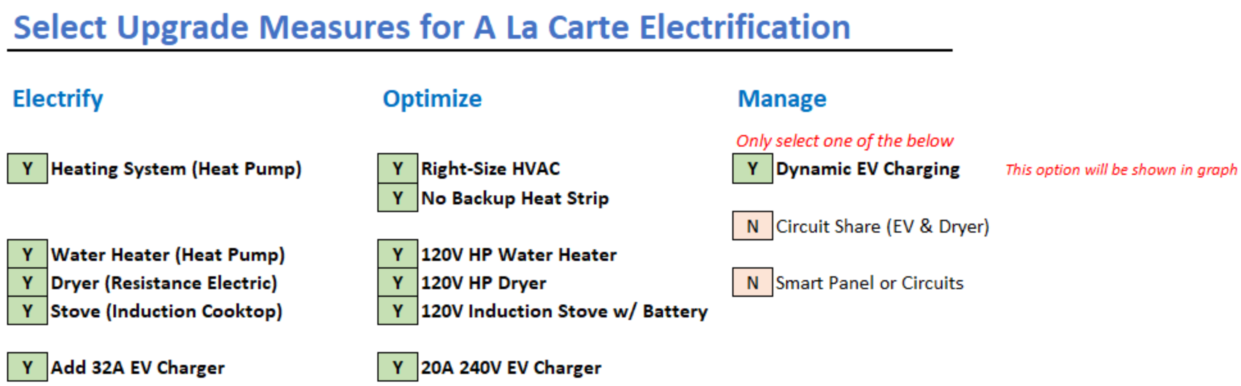
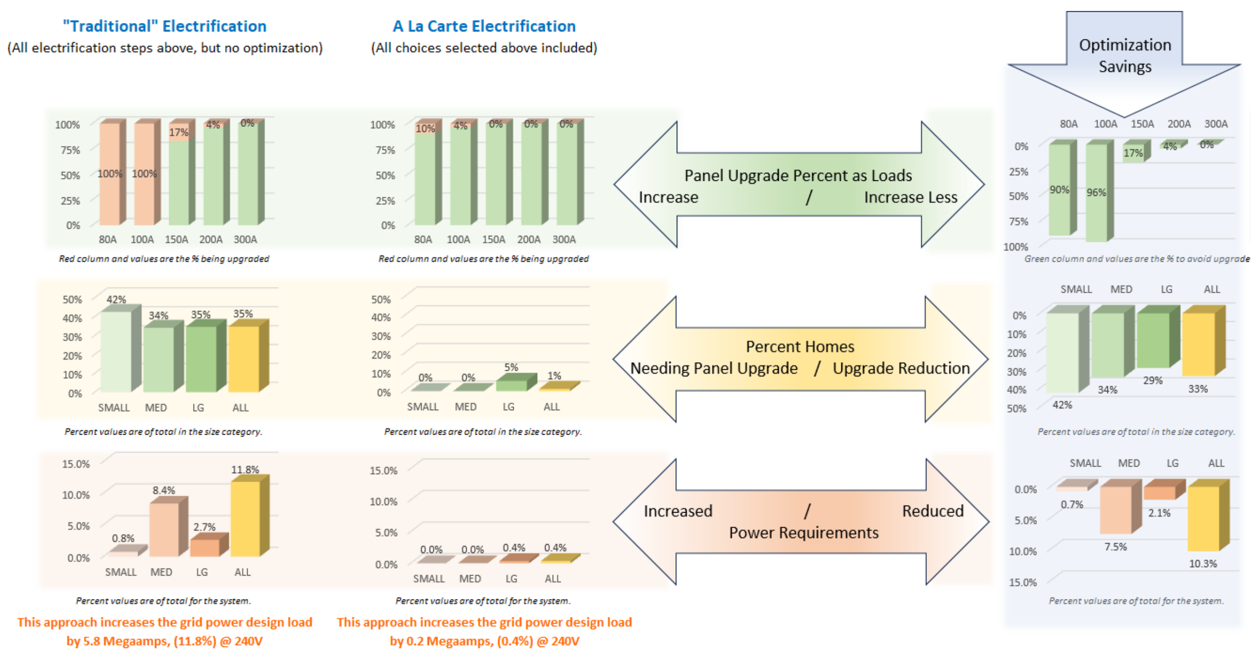


Figure 23. The “Dashboard A La Carte” screen in detail, showing the results.



RESULTS TAB

This tab displays the results of the building bin analysis and shows the breakdown of electrical panels from the original size (down the left side and totaled to the right) and the resultant panel counts after the load calculations have been performed (across the top and with totals at the bottom), as shown in Figure 24 and Figure 25.

To read this graph effectively, read from the left side across the row of a pre-electrification panel size. The yellow box displays the number of panels that will not require upgrading. If there are some that do require upgrading, those counts will be to the right in other columns that represent the size required for the homes to meet the NEC after electrification. If all of them are in a single white box just to the right, it means the next size up panel may be sufficient for them (from an 80-amp panel to a 100-amp panel, for example), but if there are values in more than one box to the right of the yellow box, some of the panels may require an increase in size by more than one step (from an 80-amp panel to at least a 150-amp panel, for example).

Figure 24. An example of the "Results" screen, showing the first two rows of results tables.

Building Stock Panel Results

All Homes — Select the house size for analysis results

Code Compliance for Electrical Additions (NO electrification included)

		NEC Code Recommended Panel Size					
		<100 (80)	100	101-199 (150)	200	>200 (300)	Total
Pre-electrification Panel Size (Baseline)	<100 (80)	3,516	108	54	0	0	3,678
	100		83,283	1,837	0	0	85,120
	101-199 (150)			48,751	0	0	48,751
	200				149,287	0	149,287
	>200 (300)					10,312	10,312
	Total	3,516	83,391	50,642	149,287	10,312	297,148

		NEC Code Recommended Panel Size				
		<100 (80)	100	101-199 (150)	200	>200 (300)
Pre-electrification Panel Size (Baseline)	<100 (80)	96%	3%	1%	0%	0%
	100		98%	2%	0%	0%
	101-199 (150)			100%	0%	0%
	200				100%	0%
	>200 (300)					100%

Full Electrification (NO EV charger)

		Post-Electrification Panel Size					
		<100 (80)	100	101-199 (150)	200	>200 (300)	Total
Pre-electrification Panel Size (Baseline)	<100 (80)	113	1,923	1,588	54	0	3,678
	100		43,665	39,618	1,837	0	85,120
	101-199 (150)			48,106	645	0	48,751
	200				149,287	0	149,287
	>200 (300)					10,312	10,312
	Total	113	45,588	89,312	151,823	10,312	297,148

		Post-Electrification Panel Size				
		<100 (80)	100	101-199 (150)	200	>200 (300)
Pre-electrification Panel Size (Baseline)	<100 (80)	3%	52%	43%	1%	0%
	100		51%	47%	2%	0%
	101-199 (150)			99%	1%	0%
	200				100%	0%
	>200 (300)					100%

Figure 25. An example of the "Results" screen in detail, showing the results tables for selections in the Dashboard A La Carte screen.

A La Carte Electrification - All Options Selected on Control Panel Included

		Post-Electrification Panel Size					
		<100 (80)	100	101-199 (150)	200	>200 (300)	Total
Pre-electrification Panel Size (Baseline)	<100 (80)	3,304	274	100	0	0	3,678
	100		81,919	3,202	0	0	85,120
	101-199 (150)			48,751	0	0	48,751
	200				149,287	0	149,287
	>200 (300)					10,312	10,312
	Total	3,304	82,193	52,052	149,287	10,312	297,148

		Post-Electrification Panel Size				
		<100 (80)	100	101-199 (150)	200	>200 (300)
Pre-electrification Panel Size (Baseline)	<100 (80)	90%	7%	3%	0%	0%
	100		96%	4%	0%	0%
	101-199 (150)			100%	0%	0%
	200				100%	0%
	>200 (300)					100%

Recommendations and Next Steps

The research and tools the project team developed demonstrate a proof of concept of screening tools for residential building electrification and panel or service capacity optimization strategies for both individual home panels and utility-scale building portfolios.

The results and findings of the research and tool development process demonstrate several key recommendations and next steps to continue supporting residential building electrification programs and strategies.

Recommendations

Tools, like those the project team developed, are a critical component for supporting electrification, but there are other needs and opportunities that utilities should support:

- Wrap-around support services for electrification programs – The Tool is just one part of the broader electrification program process. In addition to panel and service optimization calculator tools, programs need to support a broader framework of education, training, and other wrap-around support services to support electrification.
- Program support and measure development to encourage Tool use – To encourage the load reduction and panel optimization strategies that calculator tools recommend, utility programs need to adapt to actively support those strategies, such as power-efficient appliances, circuit sharing, or smart panels. Utilities can also play a role in developing the market for those strategies, encouraging the development of additional product offerings, and thereby encouraging further cost-competitiveness for these innovative strategies. In addition, utility programs should develop program measures to encourage the use of calculator tools, such as those developed through this project and others identified in this report, to further support panel optimization strategies alongside building electrification efforts.
- Support further tool development – This project and other similar tools represent the potential for using calculator tools to support residential electrification, but further development and updates will be needed to refine these tools and keep them current. Opportunities for further support include additional user testing, development of more streamlined user experience, future updates to the tools as optimization strategies and products develop, and further research to inform the development and updates of calculator tools and electrification programs generally.
- Support and encourage updates to electrical codes and enforcement practices – Current interpretations of electrical code language and inconsistent enforcement at the local jurisdiction result in uncertainty for some panel and electrical load optimization strategies. Utilities can support updates to national model codes and enforcement practices in local building departments to consistently support panel optimization and technologies that allow for electrification without requiring panel or service upgrades.

Next Steps

Following on the outputs of this project, the project team identified the following opportunities for future projects or with additional funding:

- Continued tool development – Opportunities to further the development of the tools the project team developed include additional user testing and refinements based on user feedback, additional user experience development, and expanding the tool functionality to additional user groups, among others.
- Keeping the Tool up-to-date – Future work should identify and implement strategies for keeping these tools current and plan for regular updates to accommodate any future changes in code requirements or load reduction and panel optimization strategies.
- Making the Tool publicly available – In addition to further refinement and tool updates, future efforts should strategize how these tools should be hosted and maintained for public access, and how any future updates will be communicated, in collaboration with utilities or other agencies.

Appendix A: Literature Sources and Resources

Armstrong, Sean, Emily Higbee, and Dylan Anderson, Redwood Energy. 2021. "A Pocket Guide to All-Electric Retrofits of Single-Family Homes." Building Decarbonization Coalition. https://buildingdecarb.org/resource/a-pocket-guide-to-all-electric-retrofits-of-single-family-homes

Boyd, Lucas. 2023. "Emerging Technologies Review 2023: Beyond Efficiency to Electrification in California." The 2035 Initiative, UC Santa Barbara. https://www.2035initiative.com/etr-2023-memo?mc_cid=612af005af&mc_eid=795796eb0f

Building Decarbonization Coalition. 2020. "Decoding Grid Integrated Buildings Report." https://gridworks.org/wp-content/uploads/2020/02/Decoding-Grid-Integrated-Buildings_WEB.pdf

Casquero-Modrego, N, et al. 2022. "Getting to Scale for Decarbonizing Homes in the US: An Industry Survey." IOP Conference Series: Earth and Environmental Science. https://iopscience.iop.org/article/10.1088/1755-1315/1085/1/012036/pdf

DNV GL. 2021. "2019 California Residential Appliance Saturation Study (RASS)." California Energy Commission. https://www.energy.ca.gov/publications/2021/2019-california-residential-appliance-saturation-study-rass

E Source. 2022. "Enhancing the Customer Experience of Upgrading an Electric Service Panel." Building Decarbonization Coalition. https://buildingdecarb.org/wp-content/uploads/BDC-Panel-Upgrade-Report.pdf

Gaillard, Josie and Tom Kabat. 2023. "Decarbonizing Single Family Homes." Presentation for BayREN and San Mateo County Office of Sustainability.

Herrschaft, Blake. 2023. "Design Guidelines for Home Electrification." Peninsula Clean Energy.

Kabat, Tom and Josie Gaillard. 2021. "Accelerating the Electrification of Everything." Presentation to Lawrence Berkeley National Lab. https://homes.lbl.gov/sites/default/files/2022-01/JOSIE%20-%20LBNL%20Lunch%20Presentation%20122221.pdf

Khanolkar, Amruta, Sean Armstrong and Tom Kabat. 2023. "We Can Power Homes of the Future With Electric Panels of the Past." https://newbuildings.org/we-can-power-the-homes-of-the-future-with-electric-panels-of-the-past/

Less, Brennan, Iain Walker, Sean Murphy, and Eric Fournier. 2024. "Electrical Service Panel Capacity in California Households with Insights for Equitable Building Electrification." In ACEEE Summer Study on Energy Efficiency in Buildings.

Lindsey, Doug, EPRI. 2023. "Residential Electrical Panels: How Many Need to be Upgraded?" Presentation to ACEEE Hot Air/Hot Water Forum.

Merki, Cavan. 2021. "Addressing an Electrification Roadblock: Residential Electric Panel Capacity." Pecan Street. https://www.pecanstreet.org/2021/08/panel-size/

Murphy, Sean. 2022. "Getting Past the Electrical Panel: Towards Affordable Residential Building Electrification in California." A Study Conducted for the Office of Senator Henry Stern, Sacramento, California.

Murphy, Sean; Lixi Liu, Brennan Less, Yingli Lou, Jeff Deason, Iain Walker, Xin Jin. 2024. Characterizing electrical panel capacity and replacement needs in the U.S. residential building stock. Forthcoming.

NV5. 2022. "Service Upgrades for Electrification Retrofits Study Final Report." Pacific Gas & Electric Company and San Diego Gas and Electric Company. https://www.redwoodenergy.net/research/service-upgrades-for-electrification-retrofits-study-final-report-2

Opinion Dynamics. 2021. "SJV DAC Data Gathering Plan: Findings Report." Pacific Gas & Electric Company. https://opiniondynamics.com/wp-content/uploads/2023/06/SJV_DAC_Data_Gathering_Findings_Report_Vol1_FINAL_2021-08-27.pdf

Silicon Valley Clean Energy (SVCE). 2022. "Silicon Valley Clean Energy Buildings Baseline Study." https://www.svcleanenergy.org/wp-content/uploads/2020/02/SVCE-Buildings-Baseline-Study_FINAL_share.pdf

Slipstream. 2023. "Home Infrastructure Upgrades to Enable Residential Electrification."

SPUR. 2023. "Memo on the Number of Energy Customers Potentially Impacted by Proposed Amendment to SB 410, Targeted Common Facility Cost Treatment for Utility Grid Improvements for Existing Residential Customers"

Stopwaste and Association for Energy Affordability (AEA). 2021. "Accelerating Electrification of California's Multifamily Buildings: Policy Considerations and Technical Guidelines." https://www.stopwaste.org/accelerating-electrification-of-california%E2%80%99s-multifamily-buildings

Sustainable San Mateo County. 2022. "Building Electrification in San Mateo County, 2022 Indicators Report."

TRC. 2018. "Multifamily Market Analysis." Pacific Gas & Electric Company. http://title24stakeholders.com/wp-content/uploads/2018/09/PGE_MultifamilyMarketAnalysis_TRC_FinalReport_2018-05-18.pdf

VEIC and Ortiz Group. 2023. "Market Study of Household Electric Infrastructure Upgrade Alternatives for Electrification." CalNEXT, California statewide electric emerging technologies program. ET22SWE0057_Market-Study-of-Electric-Infrastructure-Upgrade-Alternatives-for-Electrification_Final-Report.pdf (calnext.com)

United States Census Bureau. "American Housing Survey (AHS)." Department of Housing and Urban Development. https://www.census.gov/programs-surveys/ahs.html

Appendix B: POWER Group Members

Participants in Build It Green's California Panel Optimization Work and Electrical Reassessments (POWER) Group, including the following:

2050 Partners

All-Electric California

Association for Energy Affordability, Inc.

BC Hydro

Beyond Efficiency

BlocPower

Blue Rock Home

Building Decarbonization Coalition

Caliber Strategies

California Air Resources Board

Canary Media

Carbon Free Palo Alto

California Energy Commission

Central California Asthma Collaborative

City of Oakland

City of Pasadena

City of Palo Alto

City of San Francisco

City of San Luis Obispo

CivicWell

ConnectDER

Connected Technology

Consortium for Energy Efficiency

Contra Costa County

California Public Utilities Commission

Dow and Associates

Dunsky

E Source

Eco Performance Builders

Electric Power Research Institute

Energy Conservation Options

Energy Solutions

Environmental & Energy Consulting

EV Load

Franklin Energy

Harris & Sloan

Heat Pump Summit

Home Energy Academy

HomeIntel by HEA

IBEW Local 595

IDeAs Consulting

Los Angeles Department of Water and Power

Lawrence Berkeley National Laboratory

Lumin

Lumina

NeoCharge

New Buildings Institute

New York City Housing Authority

npc Solar

NREL

Onsemble

Opinion Dynamics

Pacific Gas and Electric

Palo Alto Utilities

Peninsula Clean Energy

Plumas-Sierra Rural Electric Cooperative

Portland General Electric

QuitCarbon

Redwood Energy

Rewiring America

San Diego Green Rating

Sattler Electrical Service

Shovels

Southern California Edison

Sierra Business Council

Silicon Valley Clean Energy

Slipstream

Sacramento Municipal Utility District

simpleSwitch

Sonoma County Transportation Authority

SPUR

Stanford University

Stepwise

StopWaste

SunWork Renewable Energy Projects

The Climate Salon

The Energy Coalition

thirdACT

TRC

UC Berkeley

UCLA

UL

USGBC

VEIC

XeroHome

Zero Homes

Individuals:

- Aimee Bailey
- Bryce Nesbitt
- Dave Clark
- Gypsy Achong
- Josie Gaillard
- Julia Yrani
- Marti Roach
- Tom Kabat

Appendix C: Building Stock Tool Calculation Procedure and Assumptions

The sections below detail the calculation procedures and assumptions underlying the Building Stock Tool. The text below is also included in the Tool workbook itself as a reference to users.

Building Stock and Panel Characteristics

This tool compiles building stock characteristic information from the county-level ACS data for the selected counties. This information includes the number of single-family homes in the county, segmented by whether the home uses electric, natural gas (NG) or "Other" fuel sources as the primary energy resource for heating. The information is also binned into the vintage of the original construction of the home.

However, more information on the size of the home or the size of the existing main electrical panel is not included in the ACS. For this information, the team relied on the LBNL energy efficiency program participation data that was compiled from a variety of sources, including TECH California and other EE programs data for a collection of approximately 25,000 home statistics. Within this dataset is information on home size, panel size, vintage, climate zone, and other aspects. LBNL provided statistical breakdowns of the data, particularly panel size by vintage, panel size by climate zone, and panel size by home size.

Combining these sources, the team developed a model to calculate the size distribution of homes in the selected counties with bins accounting for home size, home panel size, and vintage. The location of the homes is factored in through the selection process for the counties. This provided the team with a breakdown of the number of homes in the selected region for each bin (by size and vintage).

NEC Calculations

NEC 220.83 stipulates that the first 8,000 Volt Amps (VA) are counted at full rating and additional load beyond that applies coincidence factors (CF), multipliers that adjust the scale of a given load in the calculations. The minimum required NEC loads that are not being upgraded as part of the electrification will all combine to exceed the 8,000 VA in even the smallest of homes, so all the calculations allow the electrification activities to be computed by adding the load difference of the old equipment and the new equipment multiplied by the CF. This makes it possible to calculate large populations of homes without having made an explicitly direct NEC calculation for every circumstance in the house and panel size bins.

The NEC requires a 125 percent coincidence factor (CF) for EV chargers because they are considered a continuous load, whereas most other loads in a home only require a 40 percent CF. The HVAC equipment has a 10 percent CF. As a result, EV chargers have an outsized impact on forcing a panel upgrade because they are large loads and the load calculation procedure increases the actual load by 125 percent.

HVAC Calculations

To estimate default HVAC system sizes (for both baseline and electrification scenarios), the team ran Manual J calculations for a set of prototype homes of three sizes, three vintages, in four representative climate zones. The vintage bins include assumptions about how the home was built (amounts of insulation, types of windows, level of airtightness, etc.) and the prevailing energy efficiency code levels at the time of construction. From this set of simulations, the team developed a formula for estimating HVAC system sizing for any home size bin in the dataset.

Appliance Calculations

The appliance characteristics in the calculations are based in part on vendor data available for standard appliances, but the NEC also dictates a certain amount of load for some typical appliances, so the impacts of electrifying the appliances depends on both of these factors. The team assumed that typical appliances were being employed and the sizes of the appliances are also typical. Specialty or commercial-grade appliances are not included in these calculations, nor are there viable power and energy efficient alternatives for most of these specialty appliances.

EV Charger

The team assumed that a 32A EV charger (one that will work on a 40A-240 volt feed) is the speed of charger that is typical for single-family residential applications. Higher speed chargers become extraordinarily difficult to accommodate on an existing electrical panel because of the very large amperage that they may require as part of the NEC calculations.

Upgrade Assumptions

Upgrade Trigger Point

With the NEC load calculations for the prototypical homes that have been binned into house and panel size bins, the prediction whether the panel must be upgraded is a simple comparison of the VA calculated to the panel rating. However, this is not a reasonable approach for a population of homes and the differing conditions in each home.

The team applied a prediction model to the results to make a more appropriate distribution of upgrades as they may occur in individual homes when strictly following the NEC calculations.

- 10A or more below the panel rating – 0% of homes upgrade
- Between 10A and greater than 5A below the panel rating – 10 percent upgrade
- Between 5A under and 5A over the panel rating – 50 percent upgrade
- Between 5A and 10A over the panel rating – 90 percent upgrade
- Over 10A greater than the panel rating – 100 percent upgrade

Home Calculation Assumptions

The model assumes that all the homes, regardless of size, have the same basic functions included in them, but that the larger homes will get more of some devices. All existing homes are assumed to include:

- Microwave circuit
- Full size kitchen appliances
- Laundry circuits for washer and dryer
- One bathroom fan
- All minimum NEC circuit requirements for general appliances and other loads

As homes get larger, there are some items that increase to be reflective of what is likely to occur in larger homes:

- More bathroom fans
- More appliance circuits in the kitchen
- An additional appliance circuit in the laundry

The general electrical loads (including lighting loads) are a code-mandated 3W/sf formula, so as the home increases in size, this automatically increases in load through the NEC formula, so this load does increase as home size increases.

The home size spectrum was grouped into size bins per the following:

- Small homes:
  - Under 500 SF (modeled at 450SF)
  - Between 500 and 749SF (modeled at 650SF)
  - Between 750 and 999SF (modeled at 900SF)
- Medium homes:
  - Between 1000 and 1499SF (modeled at 1250SF)
  - Between 1500 and 1999SF (modeled at 1750SF)
  - Between 2000 and 2499SF (modeled at 2250SF)
- Large homes:
  - Between 2500 and 2999SF (modeled at 2750SF)
  - Between 3000 and 3999SF (modeled at 3500SF)
  - Over 4000SF (modeled at 4500SF)

Whether an existing home has air conditioning is not a factor in determining whether a home needs a panel upgrade because the heating load is larger than the cooling load for all climate zones in the state. Additionally, whether the homeowner wishes to install AC capability in a home that doesn't currently have it is not relevant for the same reason. Because of this, the only way that existing AC may impact the home is that it may have caused a panel upgrade in the past (so existing homes with AC may have larger panels than homes without AC) and that will reduce the need for a panel upgrade as part of the electrification process. However, this is already factored into the existing panel size distribution, so no adjustments are made for this.

"Fixed" or "Floating" Load Assumptions

Most of the loads being added in the electrification process are fixed loads; they are almost universally uniform across the state and do not vary much. An example of this is the load that is added for a stove/oven combination. While there is a range of possible Volt-Amp (VA) loads for the variety of stoves available on the market, they fall within a narrow range and the NEC specifies some minimum parameters for this appliance, so the value is not going to vary much, and certainly will not vary by climate zone.

Conversely, the HVAC loads are variable by house size, house vintage, and climate zone, so these values can't be universally applied. The tool assumes that the existing heating and cooling system is reasonably sized (which is not necessarily the case as oversizing has been a common design approach in the market for a long time). The tool applies a comparably correctly sized heat pump system to the electrified home, but the new system will employ higher performance equipment than an older existing system. This performance increase has a small impact on the panel sizing because the nameplate power rating for the HVAC equipment does not necessarily directly relate to the heating or cooling performance metrics.

This aspect of the HVAC equipment sizing has been included in the modeling for HVAC impacts on the panel.

The Two Largest Load Impacts: Heat Pump "Strip" Heat Backup and EV Chargers

Heat pumps may commonly include an electric "strip" heat backup. This is a resistance heater and has relatively low heating efficiency compared to the heat pump. Most climate zones in California can significantly reduce or eliminate the strip heat without sacrificing heating performance because the outside temperatures do not drop low enough that the heat pump cannot function. Although the heat pump efficacy decreases as the outside temperature decreases, it is still better than strip heat directly. The model assumes that the strip heat is sized to meet approximately 75 percent of the heating load in the home, so it is acting as a supplement to the heat pump, not a complete replacement. The HVAC equipment includes a 100 percent CF for the panel sizing, so the load seen by the panel is amplified compared to most other loads in the home.

Unfortunately, the strip heat backup can more than double the apparent load of a heat pump on the panel because they cannot be considered non-coincident loads with the heat pump, so eliminating the strip heat will have a considerable impact on the home panel sizing.

EV chargers (EVSE) will possibly have the largest impact on the home panel calculation because they are already very large electrical loads and they have an added penalty of being considered a continuous load in the NEC which places a 125 percent CF on the calculation. This amplifies the impact of the EV charger on the panel size calculation.

One possible avenue to reduce or eliminate the impact of EV charging on the panel size calculations is to ensure that the EV charger is being load-managed by an external system (as at this point, load management isn't a typical functional internal capability of most EV chargers). This makes the EV charger "dynamic" and the load management device can monitor the total load on the main panel and automatically reduce power to the EV charger to ensure the panel does not become overloaded. This approach is included in the load management optimization options in two locations; the "Dynamic EV Charging" and the "Smart Panel or Circuits" options. Selecting either of these two will effectively eliminate the EV charger load when the panel is experiencing heavy power demands.

Appendix D: Building Stock Assessment Tool Infographic

Figure 26. An example of the Building Stock Assessment Tool infographic.