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NRDC CHPC Earthjustice Sierra Club comments on AB 3232 May 22 workshop

Additional submitted attachment is included below.

Comments of the Natural Resources Defense Council (NRDC), California Housing Partnership, Earthjustice, Sierra Club, on the Commissioner Workshop on the Opportunities and Challenges for Building Decarbonization in the Residential and Commercial Sectors

Docket Number 19-DECARB-01, June 8, 2020

Submitted by:

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The Natural Resources Defense Council (NRDC), California Housing Partnership, Earthjustice, Sierra Club (the Co-signers) appreciate the opportunity to comment on the Building Decarbonization Assessment Project Scope. NRDC is a non-profit membership organization with more than 95,000 California members who have an interest in receiving affordable energy services while reducing the environmental impact of California's energy consumption and transitioning to a thriving climate-safe society. California Housing Partnership creates and preserves affordable and sustainable homes for Californians with low incomes by providing expert financial and policy solutions to nonprofit and public partners. Earthjustice is the nation's largest nonprofit public interest environmental law organization with approximately 250,000 supporters in California dedicated to creating a sustainable, clean energy future. Sierra Club is a non-profit, member-based California corporation with more than 500,000 members and supporters in California and a mission of promoting the responsible use of the earth's ecosystems and resources, including working to speed California's transition to a clean energy future.

Summary

Much of the policy leadership on building decarbonization in California to date has focused on new construction because it is one of the most cost-effective decarbonization opportunities, an important strategy to avoid long-term emissions lock-in, and a way to develop the market for heat pump and other electrification technology since every new building needs new equipment whereas existing buildings only replace heating and other major appliances every 15 to 20 years. While new construction remains a critical part of advancing building decarbonization, large-scale decarbonization of existing buildings must be a central strategy for achieving AB 3232's target.

Two complementary and self-reinforcing strategies need to be implemented in tandem to decarbonize existing buildings:

1. **Transform the market for high-efficiency electric equipment**, to bring their costs down and make them more accessible when an existing appliance burns out or a building is retrofitted;

2. **Retrofit existing buildings**, including electrical upgrades, energy efficiency, and potentially onsite solar and storage measures, that are necessary to convert to efficient electric heating, water heating, and other thermal end uses in a cost-effective and equitable manner.

Pursuing both strategies in tandem is critical to achieve AB 3232's target in an affordable manner.

NRDC comments focus on the following topics:

1. **The critical need for investment in large-scale market transformation policies for clean heating technology in buildings**: Building decarbonization technology is currently available in the California market and is already cost-effective in many situations even without incentives, but its market share is very low because the lack of market volume and contractor familiarity result in high costs and low availability. This is a market failure that can be resolved through policy intervention. Developing the market and bringing this technology down the cost curve will unleash a lower-cost, lower-pollution, zero-carbon, grid-flexible technology, and well-paying local jobs to install it.

2. **Aligning state policies toward building decarbonization**: While California has made significant progress over the last few years in realigning its policies toward building decarbonization, many misalignments remain among state policies, hindering the rapid market development needed for equitable and affordable building decarbonization, and resulting in higher-energy consumption, more pollution, and greater cost for construction and appliance choices today in the state.

3. **Ensuring equitable access to clean energy buildings**: Market transformation policies are particularly critical to ensure decarbonization technology will be accessible to low-income communities. Incentive policies should be tightly integrated with tenant protection and housing affordability policies such as anti-displacement provisions in incentive programs.

I. Transforming the Market for Clean Heating Technology in Buildings

Achieving 40 percent reduction in greenhouse gas (GHG) emissions by 2030 below 1990 while ensuring net economic benefits for Californians will require that we truly transform the market for decarbonization technologies, bring costs down, and ensure an equitable and just transition away from gas appliances.

The report titled "Policy Pathways to Zero-Emissions Buildings" attached in Appendix A, developed by Olivia Ashmoore as part of her internship at NRDC and her Master of Public Policy at the Goldman School of Public Policy, UC Berkeley, includes a profile of opportunities to reduce gas use in the residential and commercial sector and overview of existing building characteristics, equity concerns and opportunities associated with pursuing building electrification, potential costs and barriers to electrification, and the expected effectiveness of incentive-based policies.

To achieve AB 3232's proposed 2030 emissions reduction goal, California needs to dramatically accelerate efficient and grid-flexible electrification of fossil fuel end uses in residential and commercial buildings. To do this effectively, equitably, and efficiently, California energy agencies and utilities need to strategically plan which technologies, building sectors, and end uses they will prioritize for fuel switching in the next ten years.

The report includes a proposed policy framework for fuel switching that lays out a strategy for market transformation. Market transformation in the building sector requires setting ambitious goals, providing financial incentives, implementing supportive policies, and ultimately setting energy and emissions standards for equipment and buildings. Policies to establish goals and incentives for heat pump adoption will signal to manufactures that there is demand for heat pump technology, demonstrate to contractors that there is value in learning how to install heat pumps, incentivize developers and designers to build innovative, all-electric new buildings, and show home and building owners that heat pumps can be cheaper than gas appliances. Ultimately, this will grow the market for efficient, electric appliances until technology costs are driven down and heat pumps are as accessible as gas appliances. NRDC recommends the AB 3232 report provides a clear framework for how to transform the market in an affordable and equitable manner for priority end uses over the next ten years.

II. Align state policies toward building decarbonization

There are many state policies that affect how buildings are built, operated, and maintained, and what equipment is installed in them. Some of these policies have started to shift toward encouraging lower-carbon solutions, including the building energy code (Title 24) and the fuel substitution test for investor-owned utility customer-funded energy efficiency programs. However, many other policy changes are needed, including:

1. **Align affordable housing incentive programs with decarbonization**, such as the Tax Credit Allocation Committee (TCAC), the California Debt Limit Allocation Committee (CDLAC), and the Affordable Housing and Sustainable Communities (AHSC), as discussed in section IV.

2. **Redesign utility rates** to not penalize the use of electricity for heat and hot water in buildings, and encourages these equipment to operate when renewable energy is abundant and low-cost, recognizing the value of electric end uses to balance the grid and help integrate renewable energy at a lower cost.

3. **Stop gas infrastructure subsidies**, such as line extension allowances, which socialize the cost of connecting new buildings to the gas grid, making other customers bear the cost of these investments that we now know will lead to unaffordable future gas costs ,[1] worsening the future costs of "stranded" investments that will no longer be needed before the end of their expected life, and making mitigating the climate crisis even more challenging and costly.

4. **Continue to evolve the state building energy code toward decarbonization:** while it made significant progress in the 2019 update, the state building code still facilitates and, in some cases, encourages construction with gas. Efforts to update it in alignment with the state's 2030 and 2045 decarbonization targets need to continue and accelerate to allow us to meet these targets in an affordable manner. The code should move to require all-electric new construction as soon as possible for each building type as new construction is one of the lowest-hanging fruit among building decarbonization policies, and promote electric-readiness until such requirements are in effect.

5. **Include the social cost of pollution in all policies**: state agencies should consistently use the social cost of both climate pollution and local air pollution when assessing the cost-effectiveness of regulations and programs that reduce pollution, including building codes, appliance standards, and rebate programs that require or incentivize energy efficiency,

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[1] E3, "The Challenges of Retail Gas in California's Low-Carbon Future,", April 2020, https://www.ethree.com/at-cec-e3-highlights-need-for-gas-transition-strategy-in-california/

electrification, distributed renewable generation and/or storage, low-carbon building materials, and refrigerant management. When CEC and Public Utilities Commission (CPUC) are designing policies and programs, they should incorporate the true cost-effectiveness of what they are considering, including the benefits of reducing climate change and health damages;

6. **Leverage government procurement**: directing state agencies to build, retrofit, and install only high-efficiency, heating, water heating and other electric equipment instead of fossil-fuel-powered buildings and equipment; The Department of General Services (DGS), CEC, and Air Resource Board (CARB) should develop an action plan and a process to ensure state procurement is accelerating the deployment of technologies that are critical for building decarbonization.

7. **Set pollution limits for fossil-fuel appliances**: gas furnaces and water heaters are now one of the primary contributors to smog, as well as indoor air pollution, resulting in asthma and other respiratory diseases. State agencies, in collaboration with regional air districts, should align their policies to set pollution standards on appliances and buildings in line with the best available science on the impacts of fossil fuel combustion on public health and the climate.

8. **Include out-of-state methane emissions associated with gas use in California in building energy policies**: 90 percent of the gas used in California is imported from other states, and the majority of methane leakage occurs at the production stage, but California's policies currently ignore these emissions when accounting for methane emissions reduction policies. This is contrary to the electricity sector where out-of-state emissions are included in CARB's greenhouse gas inventory, in building energy policies, and in AB 3232 itself as incremental electricity emissions. State agencies should account for the fact that transitioning California's buildings off gas will necessarily reduce the number of gas well drilled and fracked, and therefore out-of-state methane emissions, in the same manner that they propose to account for out-of-state power plant emissions from electrification in AB 3232's fuel switching scenario analysis.

The AB 3232 report should list all state policies that currently influence what gets built, renovated and installed, and recommend that the agencies that set these policies review them and align them toward a common goal of equitable and affordable building decarbonization.

III. Ensure Equitable Access to Clean Energy Buildings

Building decarbonization policies cannot succeed, let alone be equitable, if they do not include special considerations for the situation and needs of low-income communities which constitute a significant share of California's population. Low-income households are more likely to be renters who cannot control appliance choices, or to be unable to afford the capital investments needed for efficient electrification. The following policies are important to ensure equitable building decarbonization.

1. Accelerate the removal of electrification barriers for affordable housing in Title 24

Affordable multifamily housing is more often served by central hot water and sometimes space heating systems than market rate buildings, because smaller units have more space constraints for locating equipment in units, and because conventional gas boiler-based systems generally have lower construction costs.

The Energy Commission (CEC) and the Statewide Codes and Standards Program are pursuing major enhancements to the energy code compliance software to facilitate new construction and retrofits with central heat pump water heater (CHPWH) systems. These changes are essential and high priority to support developers and local government decarbonization leadership. They need to continue and expand current efforts as follows:

- Support a broader range of CHPWH systems including "multi-pass" systems, to provide more cost-effective options for developers;
- Provide compliance credit for solar photovoltaic (PV) and battery storage for all-electric mid- and high-rise buildings (currently only available for single-family and low-rise buildings, and for CHPWH systems), to facilitate electrification of space heating systems;
- Better value high-efficiency variable refrigerant flow (VRF), variable capacity heat pumps (VCHP), and inverter-driven package-terminal heat pumps (PTHP) to make it easier to build or retrofit existing buildings with high-efficiency electric equipment.

In the short-term, 2020-2022 timeframe (2019 code version), the focus should be on supporting market learning and local government leadership by supporting code-compliant all-electric development, balancing performance with flexibility so that we require good enough but not best-in-class performance to facilitate market adoption without creating undue cost barriers. The 2022 code update should include a strong preference for all-electric construction, including electric-ready requirements for new buildings that continue to use fossil fuels, paving the way for an all-electric required code in 2025.

2. **Remove silos between affordable housing and energy programs**

Some affordable housing incentive programs require a compliance margin above code for incentive eligibility. While well intended, this creates undue barriers to electrification given the situation in the current (2019) building energy code. Instead, these programs should align with decarbonization objectives by incentivizing code-compliant all-electric construction. This is urgent as the current situation is hindering implementation of local government electrification reach codes, and market adoption of all-electric new construction and retrofits in affordable multi-family housing. Better coordination between affordable housing programs and the building energy code is critical for building decarbonization in affordable housing.

The Commission should review the framework developed by Greenlining Institute along with the Energy Efficiency For All Coalition to ensure that the State's guidelines center the needs of environmental and social justice communities[2] through robust community engagement.

California Housing Partnership is organizing multifamily affordable housing convenings on building decarbonization in September 2020 to develop guidelines on how to decarbonize the new and existing building stock. The Commission should integrate relevant recommendations from the convening into the AB 3232 findings to reflect the priorities of the affordable housing sector.

3. **More reliable and scalable funding for decarbonization programs that work**

The Low-Income Weatherization Program (LIWP) has been very effective at high-efficiency electric retrofits of affordable housing in a way that reduces tenants' utility bills – on average the program has **reduced tenant bills by 30 percent** and slashed greenhouse gas emissions by at least 40 percent.[3] However, this program is extremely underfunded. It has a waitlist of 18,000 households that have applied for funding and are waiting to be served with energy efficiency, solar, and electrification improvements. It is a shovel-ready program to decarbonize existing affordable housing, improve health outcomes in low-income communities, and put Californians back to work.

As other building decarbonization programs are designed and implemented, including SB 1477 (Stern, 2018) BUILD and TECH programs, SGIP HPWH program, and investor-owned utility (IOU) customer-funded energy efficiency programs, these programs should

[2] Greenlining Institute, Equitable Building Electrification: A Framework for Powering Resilient Communities, September 2019, https://greenlining.org/wp-content/uploads/2019/10/Greenlining_EquitableElectrification_Report_2019_WEB.pdf

[3] Low-Income Weatherization Program Impact Report, California Housing Partnership Corporation, and Association for Energy Affordability, May 2019, https://www.nrdc.org/experts/merrian-borgeson/many-ca-low-income-renters-still-waiting-clean-energy

be expanded, with significant carve-outs for low-income communities, such as the 30 percent low-income allocation for SB 1477 funds.

There is also a need for increased program alignment between health and energy programs. Many low-income homes have severe health and habitability issues. Aligning and leveraging energy programs with programs that treat health issues like mold or asbestos would stretch each program's funds, helping reach more Californians.[4]

4. **Track building decarbonization costs and analyze gaps in different regions and building types**

Construction and retrofits of affordable housing to high-efficiency, all-electric buildings are still at an early stage. Cost data collection and analysis is critical to identify issues and quickly adjust policy to address them.

Cost data should be collected, compiled, and analyzed centrally for all building decarbonization programs, to inform effective policy development.

5. **Renter protection policies**

Building decarbonization retrofits to affordable housing, particularly "market rate" housing that is not deed-restricted, can lead to unintended consequences of enabling landlords to increase rents, or even evict tenants to enable retrofits, leading to displacement and a reduction in affordable housing availability. This is particularly true for the large stock of non-deed restricted, naturally occurring affordable housing in California. While these consequences are not specific to building decarbonization and can come with any housing improvements, renter protections and anti-displacement provisions must be an integral part of any building decarbonization policy to ensure they are part of the solution to housing affordability.

[4] Greenlining Institute, Equitable Building Electrification: A Framework for Powering Resilient Communities, September 2019, https://greenlining.org/wp-content/uploads/2019/10/Greenlining_EquitableElectrification_Report_2019_WEB.pdf

The Co-signers appreciate the opportunity to provide comments on the Opportunities and Challenges for Building Decarbonization in the Residential and Commercial Sectors.

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Policy Pathways to Zero-Emissions Buildings

A Study Conducted for the Natural Resources Defense Council

by

Olivia Ashmoore
May 2020

The author conducted this study as part of the program of professional education at the Goldman School of Public Policy, University of California at Berkeley. This paper is submitted in partial fulfillment of the course requirements for the Master of Public Policy degree. The judgements and conclusions are solely those of the author and are not necessarily endorsed by the Goldman School of Public Policy, by the University of California or by any other agency.

Policy Pathways to Zero-Emissions Buildings

I. Introduction

Climate Action in California

The state of California has set one of the most ambitious climate targets in the world—economy wide carbon neutrality by 2045. Over the next twenty-five years, California will transform the energy sector to provide carbon-free electricity, equip the built environment to rely on clean energy, and decommission fossil fuel infrastructure.

To get from current emissions levels to near-zero emissions by 2045, we have a long way to go. In 2017, greenhouse gas (GHG) emissions totaled 424 million metric tons carbon dioxide equivalent (MMTCO2e).[1] Meeting our climate goals requires reducing economy-wide emissions 4 percent every year, all while growing in population, adding new housing, and expanding the economy.

Buildings are a key source of greenhouse gas emissions. In total, residential and commercial buildings account for about 25 percent of GHG emissions.[2] Half of building emissions are due to electricity consumption and are attributed to the electric power sector, which has clear requirements for reducing GHG emissions over time. The other half are primarily from on-site fossil fuel combustion for heating, cooking, and other operations, as well as fugitive emission leaks from pipes and appliances. Reliance on natural gas is a key component of building GHG emissions. Natural gas consumption in residential and commercial buildings accounts for 8 percent of total emissions.[3] Figure 1. below summarizes greenhouse gas emissions by source and sector. Emissions attributed to buildings are only direct emissions, not upstream emissions associated with energy use.

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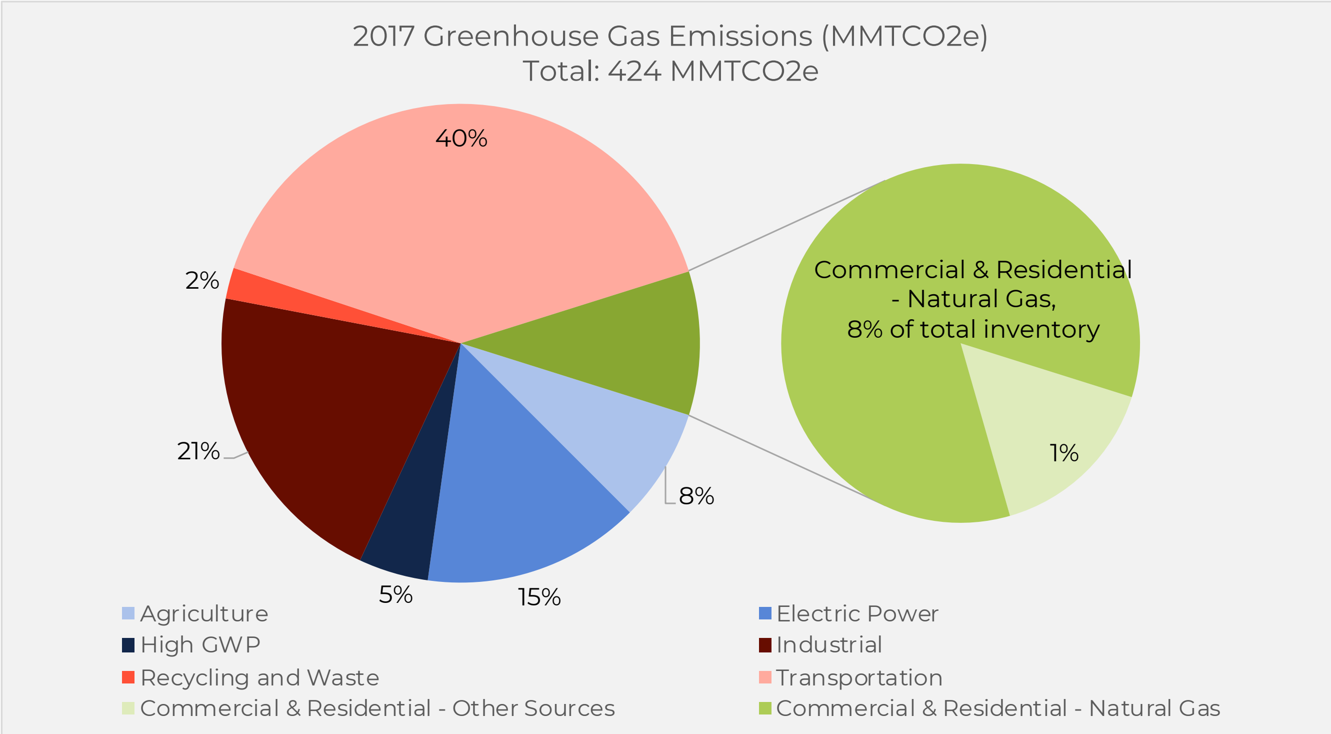
[1] "California Greenhouse Gas Emissions for 2000 to 2017." *California Air Resources Board.* 2019. https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2017/ghg_inventory_trends_00-17.pdf

[2] Vukovich, Joe. "The Real Climate Impact of California's Buildings." *NRDC.* 18 September 2018. https://www.nrdc.org/experts/joe-vukovich/real-climate-impact-californias-buildings

[3] "California Greenhouse Gas Emissions for 2000 to 2017." *California Air Resources Board.* 2019. https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2017/ghg_inventory_trends_00-17.pdf

Figure 1. 2017 Total Greenhouse Gas Emissions: 424 MMTCO2e (data from 2017 GHG Inventory)[4]



Within the commercial and residential building sector, the primary sources of emissions include fossil fuel combustion, refrigerant use, and fugitive emissions from gas distribution. Natural gas is the dominant fuel used in buildings. Other fuels, including propane, fuel oil, and wood, are also used to heat buildings, but in small amounts. Figure 2. below shows the breakdown of direct building emissions by source. The majority of emissions from buildings is due to gas combustion which primarily releases carbon dioxide, as well as methane and nitrous oxides into the atmosphere.[5]

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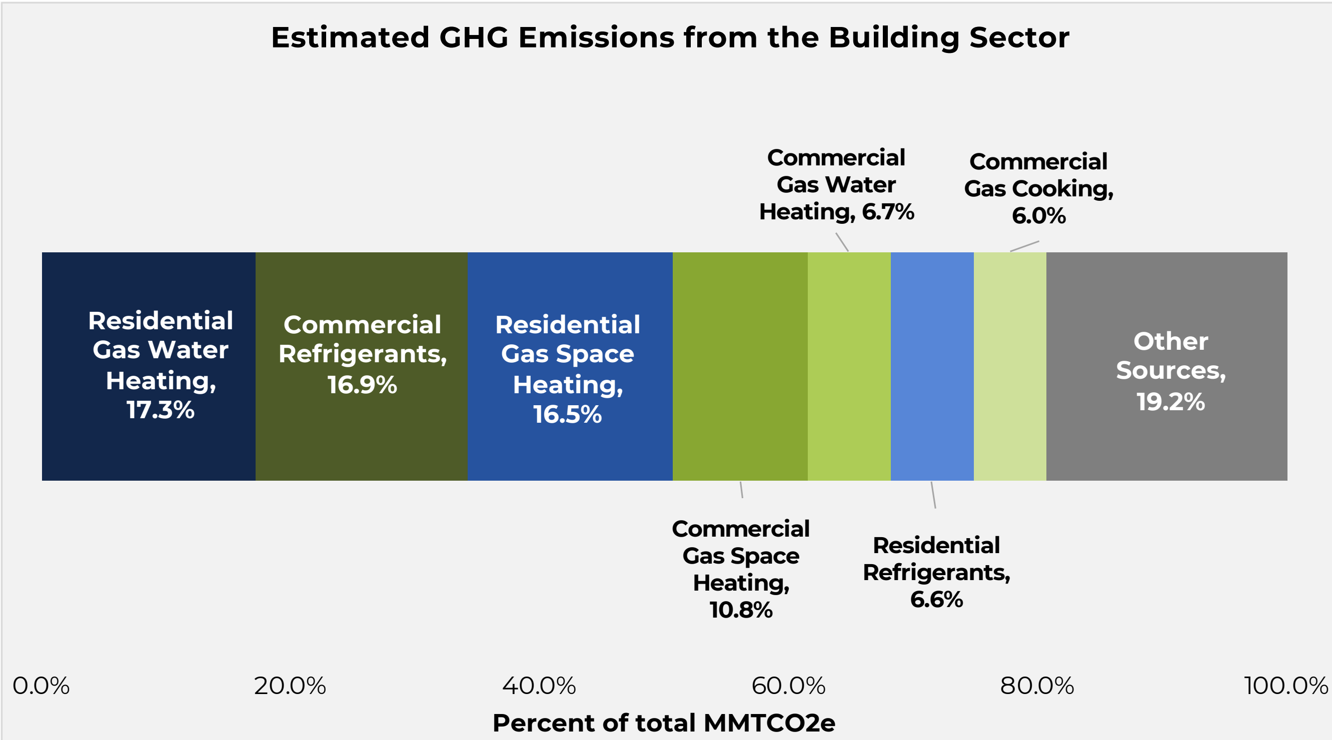
[4] "California Greenhouse Gas Emissions for 2000 to 2017." *California Air Resources Board.* 2019. https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2017/ghg_inventory_trends_00-17.pdf

[5] "2009 RECS Survey Data." *EIA*. Jan 2013. https://www.eia.gov/consumption/residential/data/2009/index.php?view=microdata & "2012 CBECS Survey Data." *EIA*. 2016. https://www.eia.gov/consumption/commercial/data/2012/index.php?view=microdata & "California Greenhouse Gas Emissions for 2000 to 2017." *California Air Resources Board.* 2019. https://ww3.arb.ca.gov/cc/inventory/pubs/reports/2000_2017/ghg_inventory_trends_00-17.pdf

Figure 2. Breakdown of building emissions by source (estimated emissions from 2017 GHG Inventory and RECS 2009 and CBECs 2012 data on gas consumption):



To be on-track to meet climate goals, California needs to reduce the climate impact of buildings 40 percent by 2030. There are numerous efforts underway to address the climate footprint of buildings. Longstanding programs have focused on energy efficiency, renewable energy, and managing refrigerants. However, only a handful of very new programs are working towards building decarbonization through fuel switching. To fully decarbonize California's building sector, most or all natural gas use will need to be replaced with efficient and flexible electricity. Switching from gas to electricity, "fuel switching," requires replacing existing gas appliances with electric ones.

PROBLEM DEFINITION: To be on track to meet 2030 climate goals, California needs to quickly accelerate fuel switching, from gas to electricity, in residential and commercial buildings. To do this effectively, equitably, and efficiently, California energy agencies and utilities need to strategically plan which technologies, building sectors, and end uses they will prioritize for fuel switching in the next ten years.

Existing Policy

California has passed laws and taken steps to address the climate impact of buildings. Existing efforts have focused primarily on increasing the energy efficiency of existing buildings, requiring new buildings meet efficiency standards, managing high-global warming potential fugitive emissions, and reducing the carbon intensity of the electricity grid. Key legislation includes:

- **SB 350**: set a goal to double energy efficiency savings in buildings by 2030[6].
- **SB 100:** requires renewable energy and zero-carbon resources supply 100% of retail sales of electricity.[7]
- **SB 1383**: requires the Air Resources Board to implement a strategy to reduce emissions of short-lived climate pollutants to achieve a 40 percent reduction in methane, 40 percent reduction in hydrofluorocarbon gases, and a 50 percent reduction in anthropogenic black carbon by 2030.[8]

Key legislation on building decarbonization includes:

- **SB 1477**: requires the California Public Utilities Commission to launch two programs to initiate market development for low-emissions heating equipment for residential buildings and provide incentives for new, near-zero GHG emissions buildings, with a focus on affordable housing.[9]
- **AB 3232**: requires the California Energy Commission to evaluate and identify strategies to reduce residential and commercial building GHG emissions 40 percent below 1990 levels by 2030.[10]

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[6] "Clean Energy and Pollution Reduction Act - SB 350." *California Energy Commission.* *https://www.energy.ca.gov/rules-and-regulations/energy-suppliers-reporting/clean-energy-and-pollution-reduction-act-sb-350*

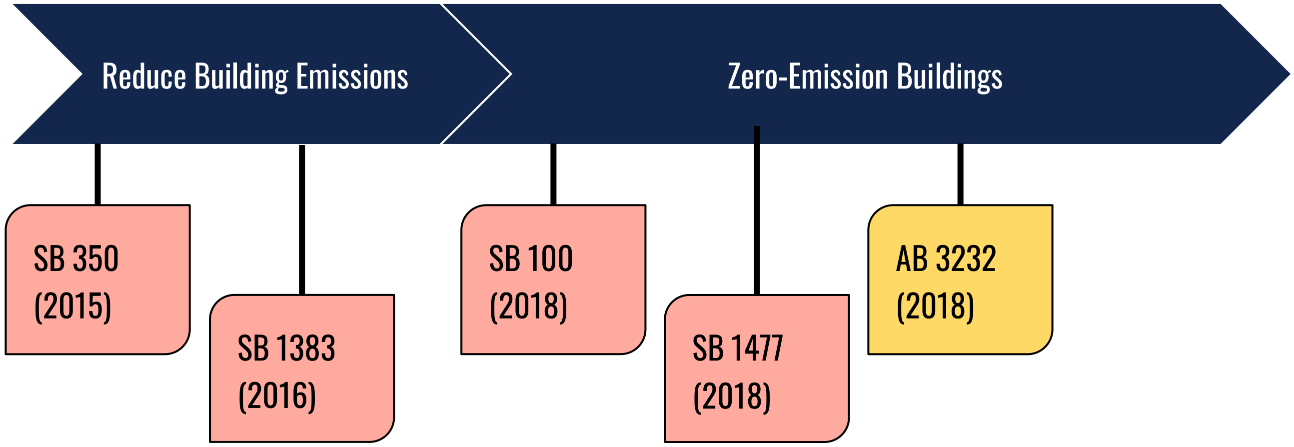
[7] "SB-100 California Renewables Portfolio Standard Program: emissions of greenhouse gases." *California Legislative Information*. 10 September 2018. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100

[8] "SB-1383 Short-lived climate pollutants: methane emissions: dairy and livestock: organic waste: landfills." *California Legislative Information*. September 2016. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB1383

[9] "SB-1477 Low-emissions buildings and sources of heat energy." *California Legislative Information.* September 2018. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1477

[10] "AB-3232 Zero-emissions buildings and sources of heat energy." *California Legislative Information.* September 2018. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB3232

Figure 3. Tracking Policies to Reduce Building Greenhouse Gas Emissions



Implementation of AB 3232

As required by AB 3232, the Commission is developing a strategy over the next several months to reduce emissions from buildings. NRDC will be involved in the workshop, proceedings, and policy development related to AB 3232. This report will inform and direct NRDC's advocacy on AB 3232. Specifically, I review the characteristics and GHG emissions of existing buildings, assess how California can achieve a 40 percent reduction in building emissions by 2030, and recommend policies to reduce emissions.

Defining the scope

As noted above, California building GHG emissions come from a variety of sources, including gas use, other fuel use, refrigerant leakage, and fugitive emissions. This paper will focus specifically on the largest end-uses of gas consumption in residential and commercial buildings. This includes gas use in residential buildings for space and water heating and gas use in commercial buildings for space heating, water heating, and cooking. I chose to focus on the largest gas end-uses because market development in these areas offers large potential emissions reductions. Similarly, I focused on gas consumption rather than other fossil fuels because propane, fuel oil, and other heating fuels contribute a small portion of building emissions in California.

Refrigerants are a significant source of direct building emissions but are not the focus of this paper. The California Air Resources Board (CARB) has policy directives, programs, and proceedings to establish regulation of refrigerants. Refrigerant management includes managing the lifecycle of appliance manufacturing, use, and disposal and refrigerants are subject to specific regulations. Proceedings for AB 3232 can play a role in shaping policies that encourage low-GWP technologies but are not the primary policy mechanism to establish refrigerant management policy—this is already being done through direct refrigerant regulations at CARB.[11]

[11] "Refrigerant Management Program." *California Air Resources Board.* https://ww2.arb.ca.gov/our-work/programs/refrigerant-management-program

II. Policy Framework

To reduce building GHG emissions 40 percent by 2030 and be on track to carbon neutrality by 2045, we need a market transformation initiative that converts existing buildings and ensures new buildings contribute to climate goals. Efficient, electric heat pumps currently make up a small share of heating appliances. To increase adoption of electric appliances, the state needs to incentivize market growth until the technology is established and cost effective. Once electric appliances are accessible, affordable, and widely adopted, performance-based standards will make electric appliances mandatory in all equipment replacements. This approach is modeled off the trajectory rooftop solar-PV technology has followed in California.

California Solar Initiative Example

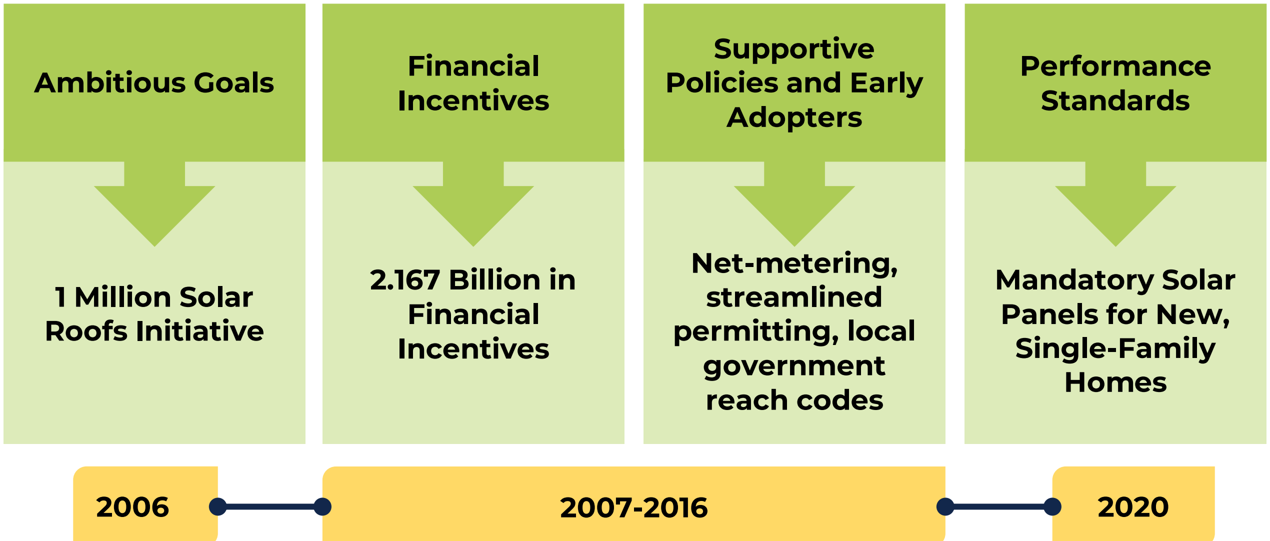
California solar PV adoption provides a successful example and timeline for achieving widespread adoption of clean energy. Building decarbonization programs should be similar in scale and ambition to the California Solar Initiative (CSI).

The CSI provided $2.167 billion in solar incentives for customers between 2007 and 2016.[12] The program supported both residential and non-residential customers and set a target of achieving 1,940 MWs of installed solar capacity.[13] Along with financial subsidies, the state supported solar development by setting renewable portfolio standards for utilities, instituting favorable electric rates, and streamlining permitting for new solar projects.

As costs of solar came down, and support for solar grew, local governments adopted reach codes to require solar PV on new construction. While local governments were early adopters of solar reach codes, the California Energy Commission soon followed suit, and updated the building to require solar PV on new low-rise residential buildings starting in 2020.[14]

[12] "About the California Solar Initiative." *Go Solar California*. 2020. https://www.gosolarcalifornia.ca.gov/about/csi.php
[13] "About the California Solar Initiative." *Go Solar California*. 2020. https://www.gosolarcalifornia.ca.gov/about/csi.php
[14] "2019 Building Energy Efficiency Standards." *California Energy Commission*. 2020. https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2019-building-energy-efficiency

Building electrification can follow the same trajectory to achieve widespread adoption. Key elements of California solar adoption included:



Building Decarbonization

To achieve market transformation in the building sector, we need to fund research and development, incentivize clean heating technologies, grow the market, and develop performance standards or regulations.

Some building decarbonization incentives and policies are advancing quickly. Several programs will provide financial incentives for heat pumps and other electric appliances, like SGIP, energy efficiency programs and the SB 1477 programs.[15]

California policies have set mid- and long-term carbon emission reduction goals. Local governments are adopting reach codes to encourage or require all-electric new construction. Utilities are proposing and implementing electric rates that are favorable for all-electric homes. Despite having these important elements in development, we lack the overarching vision and key policies necessary to achieve market transformation for both new and existing buildings.

To flush out the policy strategies to achieve building decarbonization, we need several key elements. These include ambitious goals, long-term funding for incentives and market development, supportive policies, early adopters, and performance-based standards.

[15] See Appendix 1. for more information.

Building decarbonization policy needs…

➠ Ambitious and specific goals

- Specific, actionable, and trackable goals that apply to building decarbonization. This should include goals by building type, appliance type, and occupancy characteristics.

➠ Substantial, sustained funding

- A dedicated source of funding to support building decarbonization, similar in scale and timeframe to the over $2 billion dedicated to solar adoption.

➠ Predictable and strategic incentives

- Incentives to drive adoption of clean heating technologies across building types, appliance types, occupancy characteristics, and geography in a sustained manner that drives industry investment in supplying equipment and training vendors and contractors.

➠ Supportive policies

- Rate redesign, streamlined permitting, workforce training, load management strategies, updated building codes, and manufacturer and supply chain incentives.

➠ Early adopters

- Early technology adopters to advance the market for electric space and water heating appliances. We also need local governments to lead on policy pilots and programs to test effective strategies for fuel switching existing buildings.

➠ Performance-based standards

- Building codes, appliance emissions standards, and building performance standards to require buildings meet statewide criteria for achieving near-zero emissions.

This framework provides a high-level view of the suite of strategies necessary to advance building electrification. While all elements of this framework deserve rigorous policy analysis, I focus on assessing the potential for predictable and strategic incentives to advance building decarbonization.

Incentives and Performance-Based Standards

Incentives are a key strategy for many environmental policies. Incentive programs offer financial support for adopting a technology—in this case, high efficiency, all-electric space and water heating appliances or electric cookstoves. Incentives can target manufacturers, distributors, installers, or consumers. In contrast to requirements or standards, incentives reward voluntary participation.

Performance-based standards require buildings meet certain energy intensity thresholds. Buildings can either reduce energy consumption or adopt efficient appliances to meet performance-based thresholds. There is flexibility built into performance-based standards, but fundamentally this approach adds requirements, rather than relying on voluntary participation.

As the state moves forward with fuel switching to reduce GHG emissions, both approaches will support long-term goals. Incentives are seen as the preferred policy in the near-term because they do not add additional requirements. However, it is unclear where incentives would be targeted, if they adequately address equity issues, how much they will cost, and how effective incentives will be.

Assessing the Role of Incentives

To assess the role of incentives, I defined the following criteria. I used this framework to guide my research and paper. First, I assessed the profile of buildings and equipment currently powered by gas to determine where incentives may be required. Secondly, I took into account potential equity issues and benefits. Third, I estimated the cost of fuel switching by end use. Finally, I assessed the potential effectiveness of incentives.

The details of incentive program design are complex and will be determined by program implementers and decision makers. This paper focuses on identifying the key building types, end uses, and appliances that would benefit from incentives, rather than specific details of incentive program implementation.

Target

- What are the characteristics of our building stock and building gas use?

Equity

- How do we advance equity with building decarbonization?
- Who is at risk of being left behind by new initiatives?

	**Cost** ● How much funding do we need to adequately incentivize adoption of all-electric heat pumps?
	**Effectiveness** ● How effective can incentives be? ● Can incentives deliver enough emissions reductions necessary to achieve our climate goals?

III. Market Characterization

- What are the characteristics of our building stock and building gas use?

To answer this question, I first looked at the characteristics of existing buildings. I summarized building characteristics like building age, sector, primary activity, and housing unit type. I then looked at characteristics of building occupants, including income, tenure status. And finally, energy use by fuel, end use, and appliance type. I include these characteristics because they will influence incentive program amount and design. Designing incentives based on building stock characteristics enable targeting of incentive programs to end uses and populations in a way that is most effective for each, while prioritizing GHG reduction opportunities and strategic market transformation.

Methodology

To better understand the existing building stock, I summarized existing building characteristics, energy use, and tenant characteristics. I selected key variables that impact the design of policies and incentives, including housing unit type, tenure status, building age, tenant income, fuel use, and energy consumption by end use. A unit refers to any occupied unit, either an entire single-family home or an apartment within a multifamily building.

Both American Community Survey (ACS) data and U.S. Energy Information Administration (EIA) data is already weighted to be population-level data, so I did not need to scale the microdata sample. For all relevant variables, I simply summed the number of units by category.

To complete my analysis of housing characteristics, I used data from the American Community Survey, reported for 2017 (5-year estimates).[16] To estimate energy usage for residential and commercial buildings, I used data reported by the EIA. For residential buildings, I used the 2009 Residential Energy Consumption Survey Microdata.[17] I filtered for data in California and estimated per-unit average consumption for housing units. I estimated consumption for a variety of unit

[16] "2013-2017 ACS Five Year Estimates." *United States Census Bureau*. 2018. https://www.census.gov/programs-surveys/acs/technical-documentation/table-and-geography-changes/2017/5-year.html

[17] Note that there is a 2015 RECS data set, but the study was designed to produce results for climate regions. California data is aggregated with data from Oregon and Washington. I chose to use 2009 data to create California-specific estimates. From: "2009 RECS Survey Data." *EIA*. Jan 2013. https://www.eia.gov/consumption/residential/data/2009/index.php?view=microdata

types, including unit size, household income of tenants, occupancy status (renter or owner), age of house, primary heating fuel, and end use.

To estimate commercial energy consumption data by end use, I used the 2012 Commercial Building Energy Consumption Data reported by the EIA for the Pacific region.[18] This includes Oregon and Washington as well as California, so actual energy consumption in California buildings may be moderately different. I scaled data based on population (California accounts for 77 percent of the region's population). The commercial building analysis is primarily to identify, in broad terms, the largest energy end-users. Note that for both sets of EIA data, RECS and CBECS microdata, the study was not designed to do detailed analysis within states. Sample sizes are often insignificant for categories of buildings across multiple dimensions (i.e. by income, building type, and tenure status).

Residential Buildings

Below are characteristics, major takeaways, and findings about the residential building sector. I created all graphs from RECS and Census data. For each graph or set of graphs, I list the high-level takeaway, significant facts, and implications for incentive program design.

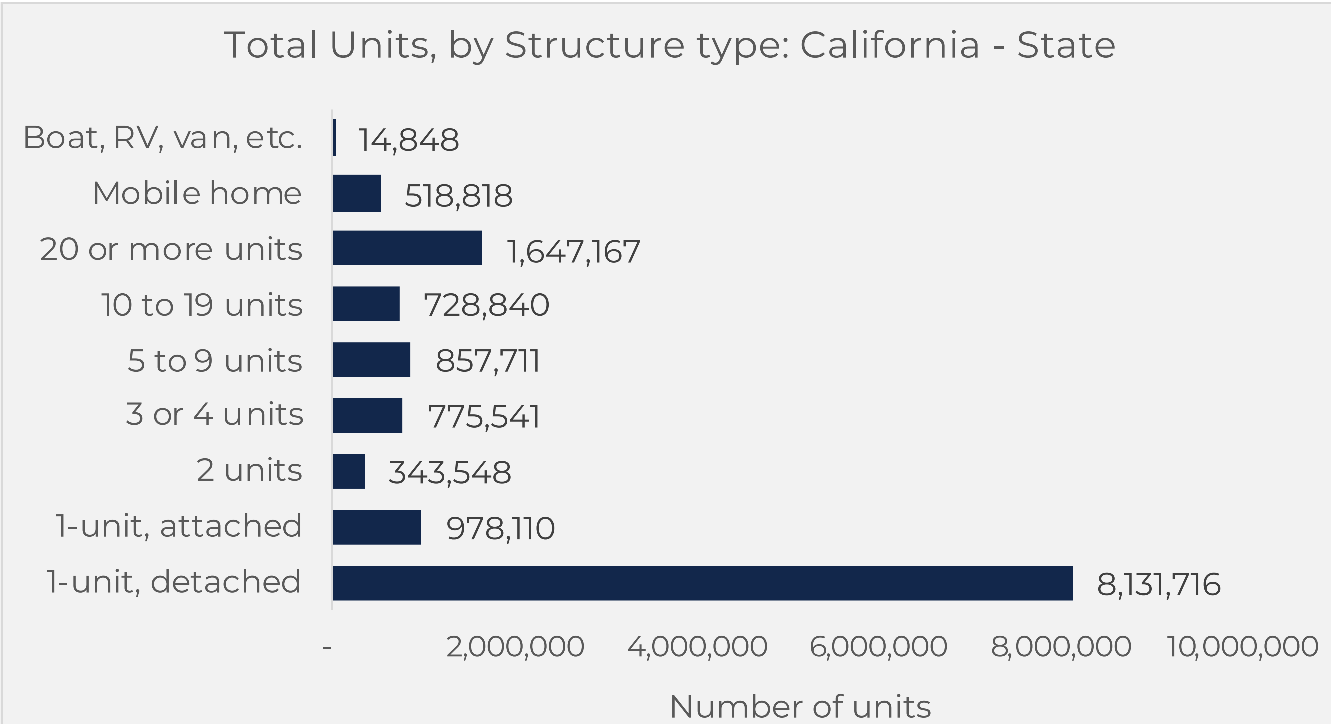
Basic Housing Characteristics

TAKEAWAY 1: The majority of California housing units are single family homes, mostly detached units.

- 65 percent of all housing units are either attached or detached single family units. Roughly 8 percent of units are small multifamily units, 2 to 4 units.
- 23 percent are medium to large multifamily units (with 5 or more units per building).

[18] "2012 CBECS Survey Data." *EIA*. 2016. https://www.eia.gov/consumption/commercial/data/2012/index.php?view=microdata

Figure 4. Number of existing housing units by type (data from ACS 2017)



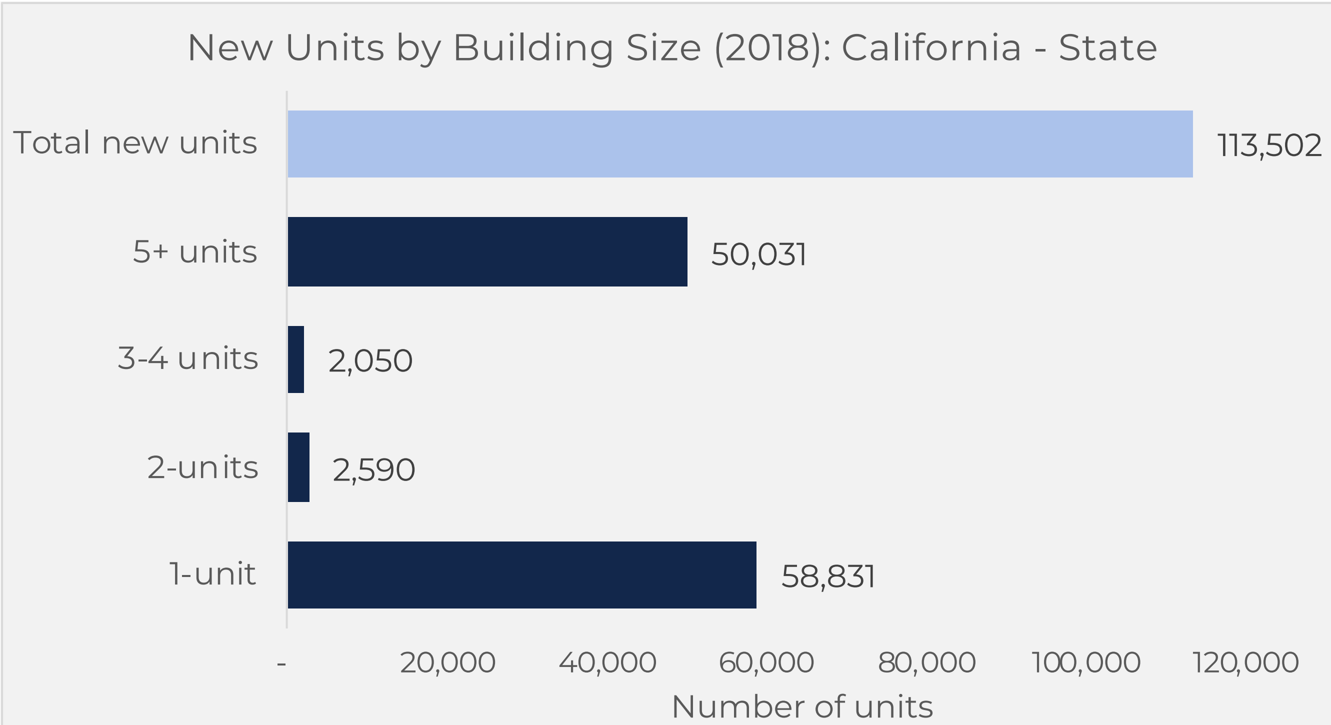
WHY IT MATTERS: Single family and multifamily homes often use different technologies, have different energy consumption, and can face different constraints. For example, single family units can replace existing gas furnaces with a central heat pump or a mini-split heat pump. Multifamily units have more variability in existing gas infrastructure. Gas furnaces may need to be replaced with split-heat pumps, central heat pumps, packaged terminal heat pumps, or Variable Refrigerant Flow HVAC systems (VRFs). Policies will need to target all of these technologies and their supply chains to ensure building owners can access all the options they need.

TAKEAWAY 2: Forecasted out to 2045, single family units will continue to be the majority of existing and new housing units, but high-rise multifamily buildings will also increase significantly.

- In 2018, there were approximately 114,000 new housing units built. Of new units in 2018, they were roughly split between large multifamily (in buildings with more than 5 units) and single family.[19]
- If this trend continues linearly, the number of California housing units will grow by 20 percent by 2045.[20]

[19] "New Residential Construction." *United States Census Bureau.* 2018. https://www2.census.gov/econ/bps/County/co2018a.txt
[20] Linear forecast based on 5-year average housing starts.

Figure 5. Number of new units by type (data from Census "New Residential Construction" 2018)



WHY IT MATTERS: As California's population and housing stock grow, new buildings could undermine the state's ability to meet reduction targets. It is essential that new buildings are all-electric to avoid increasing gas consumption. Incentives for new construction will need to target single-family and large-multifamily units.

TAKEAWAY 3: Most, existing California homes were built before the energy efficient code, Title 24, went into effect. Title 24 is California's energy code and has significant impacts on building energy efficiency and building construction.

- Energy efficiency is likely worse in older homes that have not been remodeled.
- Homes built before 1978 may have insufficient electric infrastructure to accommodate electric space and water heating appliances.

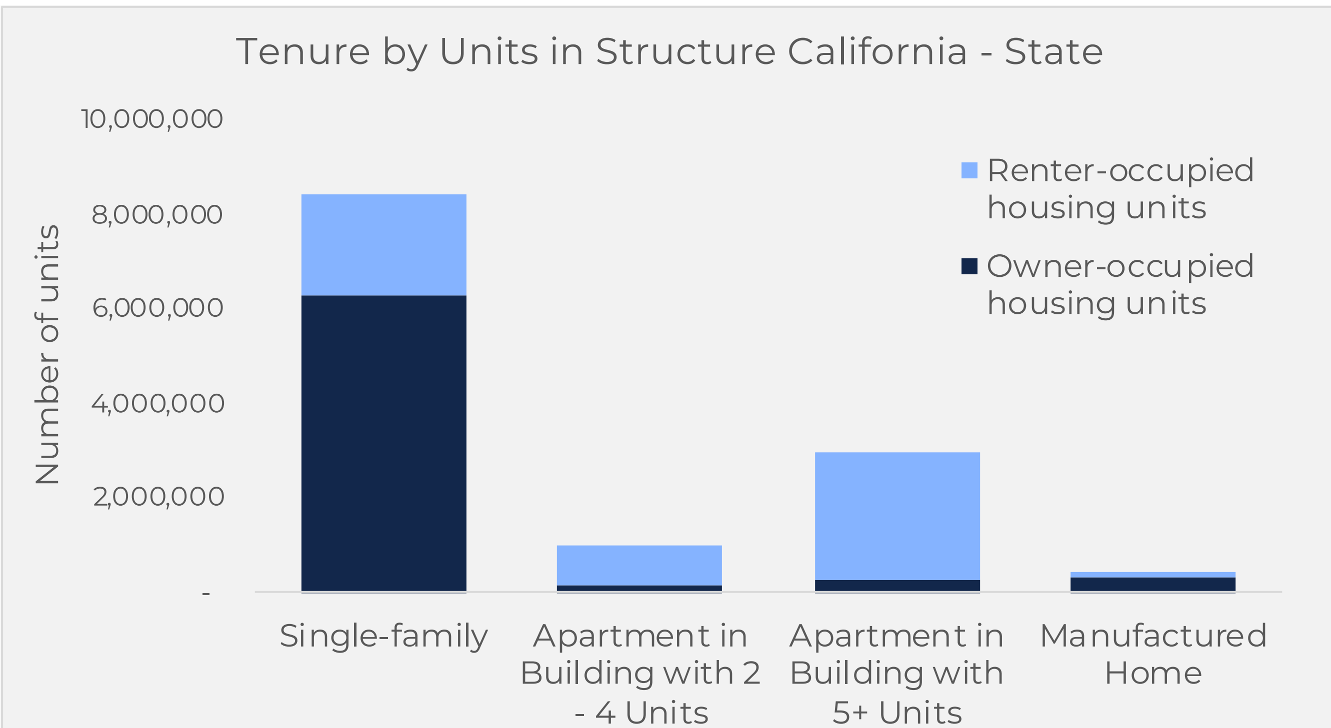
Figure 6. Percent of housing units built before and after 1980 (data from ACS 2017)

WHY IT MATTERS: Electric space and water heating appliances have high electric loads and require 200-amp electric service panels. Older homes, pre-1979, are less likely to have sufficient panel capacity.[21] The cost to upgrade electric service panels and wiring is significant and will be an influential factor in determining incentives for electrification. Additionally, the energy efficiency of homes will determine the utility bill impacts of electrification.

TAKEAWAY 4: Most single-family units are occupied by building owners and most multifamily units are occupied by renters.

- 90 percent of owner-occupied units are single family.
- Of total rental units, 37 percent are single family units, 15 percent are 2-4-unit apartments, and 46 percent are multifamily buildings with 5 or more units.

Figure 7. Number of Units by Tenure Status and Unit Type (data from ACS 2017)



WHY IT MATTERS: If a house is occupied by the owner, the owner has an incentive to improve the home with new appliances or energy efficiency upgrades like insulation because they benefit from those upgrades in bill savings, improved comfort, and resale value. But in housing units occupied by renters, the building owner often does not have a strong incentive to upgrade the building appliances. Renters typically pay utility bills, so the owner would not experience cost savings by upgrading to more efficient appliances. This presents a split incentives problem.

[21] Mahone, Amber, et al. "Residential Building Electrification in California." *Energy and Environmental Economics, Inc.* April 2019. https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf

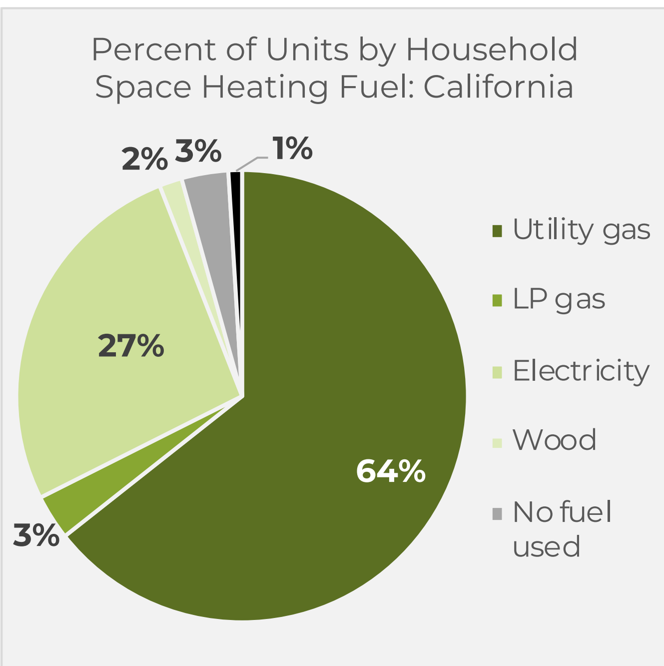
Fuel Type and Energy Consumption

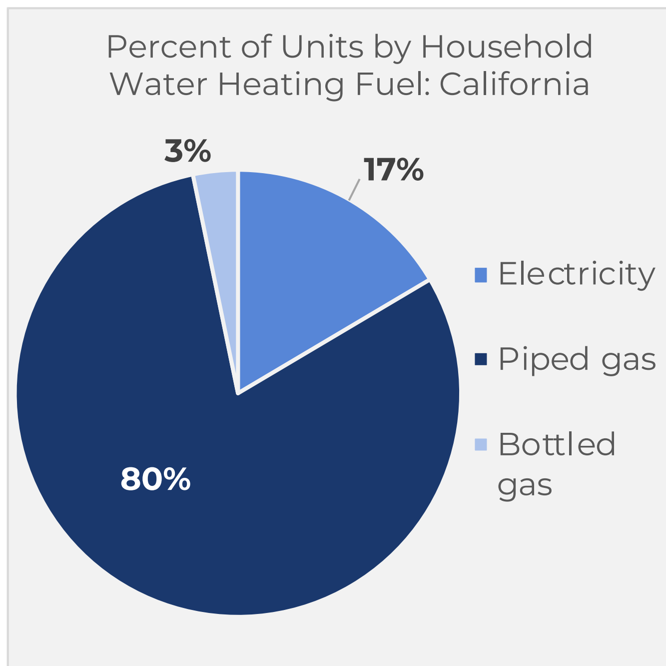
California homes use electricity, natural gas, propane, and other fuels to heat and operate buildings. Space and water heating account for the majority of California's residential, on-site energy combustion.

TAKEAWAY 1: The majority of housing units in California use utility-provided natural gas for space and water heating.

- 64 percent of housing units use utility gas for space heating, and 27 percent electricity (typically electric baseboards). Other energy sources include propane, wood, no heat, or other.
- Water heating is also primarily done with gas; 80 percent of California homes use gas for water heating.[22]
- Of gas space heating appliances, 74 percent are central furnaces. The other 25 percent are room heaters, either floor, wall, or other built-in room heaters.
- Housing units that rely on non-gas fuels—electricity, propane, wood, and other fuels—are often in rural areas.

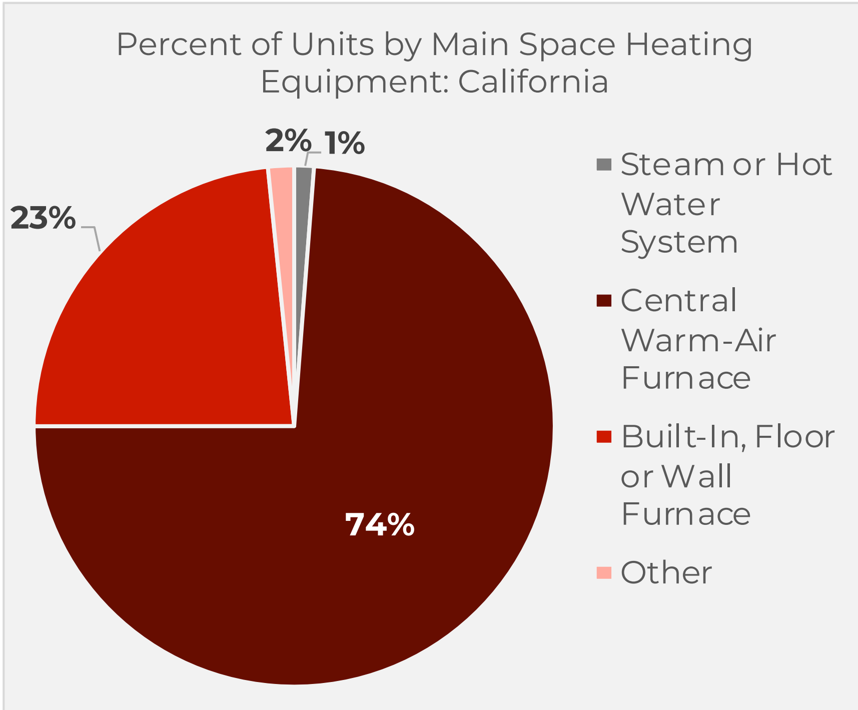
Figure 8. Percent of Units by Household Space Heating Fuel (data from ACS 2017) & Figure 9. Percent of Units by Household Water Heating Fuel (data from AHS 2017)





[22] "2017 California – Housing Unit Characteristics – All Housing Units." *American Housing Survey*. 2017. https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html?s_areas=00006&s_year=2017&s_tablename=TABLE0&s_bygroup1=27&s_bygroup2=1&s_filtergroup1=1&s_filtergroup2=1

Figure 10. Percent of Units Using Gas as a Primary Heating Fuel by Appliance Type (data from RECS 2009)



WHY IT MATTERS: We need to estimate the number of residential units, currently using gas, that need to be switched to electricity to reduce emissions from natural gas use. Understanding which appliances, specifically, will need to be replaced informs which electric technologies we will need to incentivize.

TAKEAWAY 2: In terms of energy consumption, utility-provided natural gas is the primary space and water heating fuel in California. Single family homes consume the most gas on a total and per unit basis.

- 52 percent of total residential energy consumption is to heat space or water.
- Of that energy allocated for heating consumption, natural gas is the primary heating fuel.
- The majority of gas is consumed in single family homes, either owned or rented.
- On a per unit basis, single family homes consume about 75 percent more gas per unit than housing units in large multifamily buildings.

Figure 11. Total energy consumption in MMBtus by fuel type, home type, and tenure status. (data from RECS 2009)

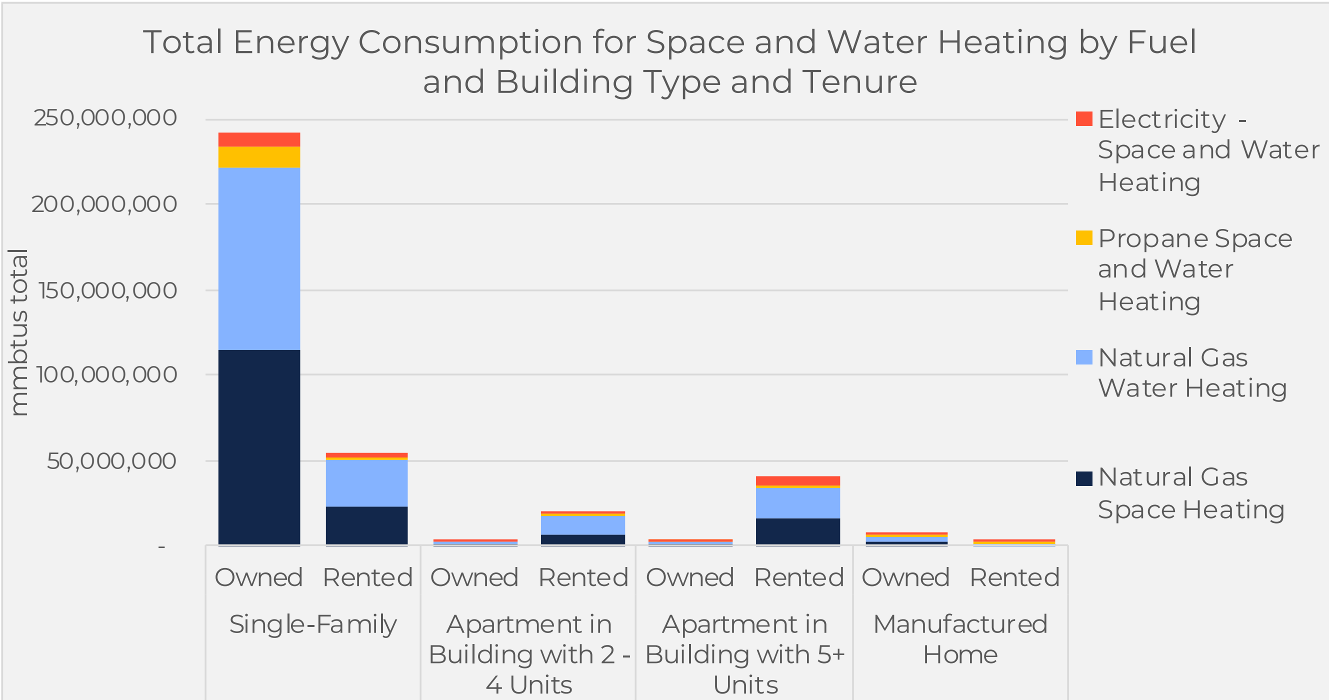
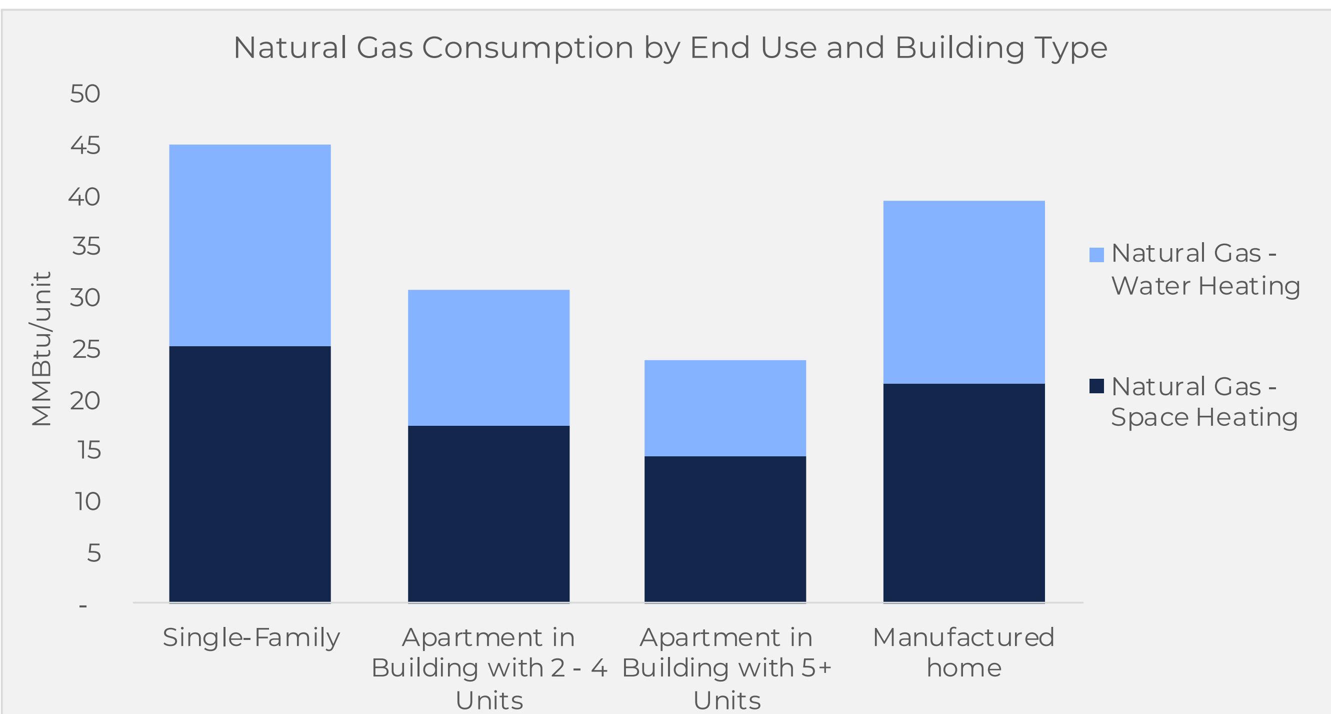


Figure 12. Natural gas consumption average per unit, by end use and building type (data from RECS 2009)

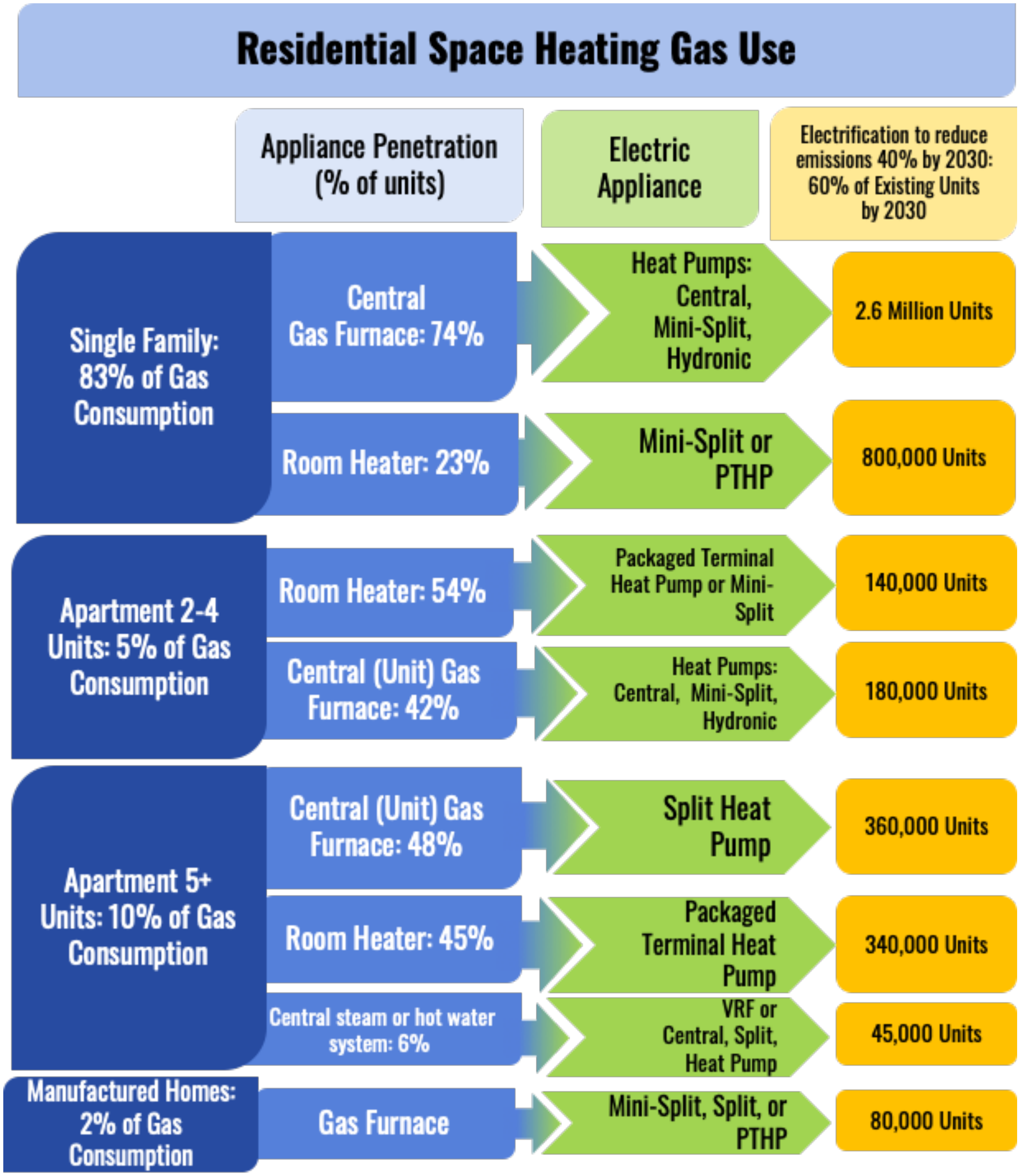


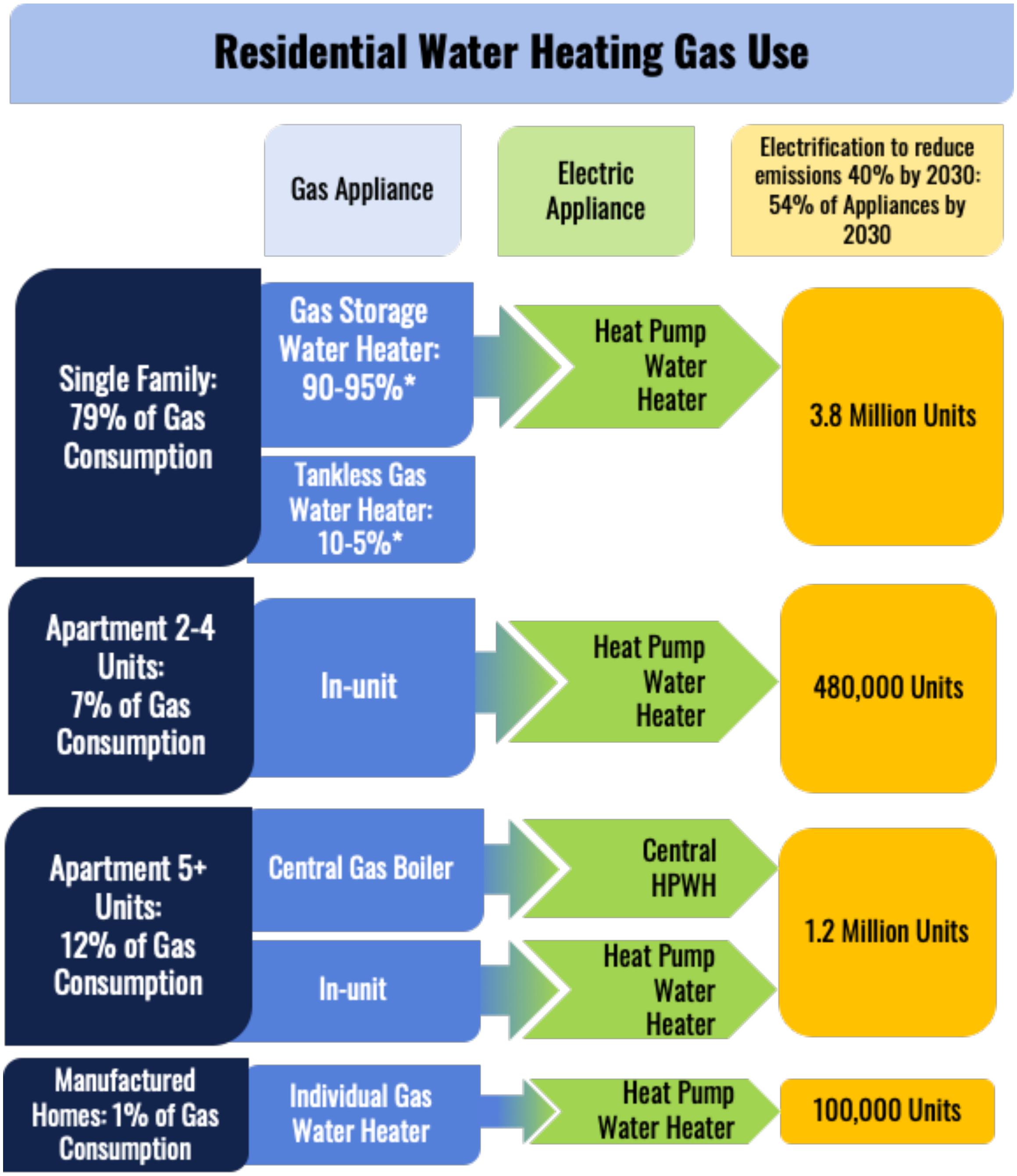
WHY IT MATTERS: Most of the natural gas burned for heat is in single family homes. Energy consumption is roughly equal between space and water heating so both end-uses offer potential emissions reductions. Figure 11. also demonstrates incentives will need to target both owned and rented buildings.

Fuel Switching Targets

Based on our understanding of baseline gas use in California homes, appliance saturation, and available electric alternatives, I estimated how many units would require new electric appliances by 2030 to meet AB 3232's goal of 40 percent below 1990 baseline.[23] I took into account the reduction in gas use needed and electricity emissions associated with fuel switching from gas to electricity. These are rough estimates, but they provide a sense of scale for what it would take to meet climate goals. See Appendix 2. for detailed methodology on target setting.

[23] Note that for multifamily units there is often not a one-to-one ratio of unit to appliance, so switching out one appliance could achieve emissions reductions in multiple units.


Residential Space Heating Gas Use
Appliance Penetration (% of units)
Electric Appliance
Electrification to reduce emissions 40% by 2030: 60% of Existing Units by 2030
Single Family: 83% of Gas Consumption
Central Gas Furnace: 74%
Heat Pumps: Central, Mini-Split, Hydronic
2.6 Million Units
Room Heater: 23%
Mini-Split or PTHP
800,000 Units
Apartment 2-4 Units: 5% of Gas Consumption
Room Heater: 54%
Packaged Terminal Heat Pump or Mini-Split
140,000 Units
Central (Unit) Gas Furnace: 42%
Heat Pumps: Central, Mini-Split, Hydronic
180,000 Units
Apartment 5+ Units: 10% of Gas Consumption
Central (Unit) Gas Furnace: 48%
Split Heat Pump
360,000 Units
Room Heater: 45%
Packaged Terminal Heat Pump
340,000 Units
Central steam or hot water system: 6%
VRF or Central, Split, Heat Pump
45,000 Units
Manufactured Homes: 2% of Gas Consumption
Gas Furnace
Mini-Split, Split, or PTHP
80,000 Units



*Estimate, based on conversations with experts

Commercial Building Characteristics

Below are characteristics, major takeaways, and findings about the commercial building sector. I created all graphs from CBECS or California Commercial Saturation Survey data.[24] For each graph or set of graphs, I list the high-level takeaway, significant facts, and implications for incentive program design.

Basic Characteristics

TAKEAWAY 1: By square footage, non-refrigerated warehouses and offices account for the largest share of commercial building space.[25] By square footage, water heating fuel use is split between gas and electricity. Space heating fuel use is majority gas, followed by electricity.[26]

- 40 percent of commercial building square footage is in non-refrigerated warehouses or office buildings
- In terms of square footage, water heating fuel use is roughly split between gas (46 percent) and electricity (49 percent)
- Space heating is mostly done using gas, 54 percent of square footage, and electricity is used for 40 percent of square footage.

[24] "2012 CBECS Survey Data." *EIA*. 2016. https://www.eia.gov/consumption/commercial/data/2012/index.php?view=microdata & "California Commercial Saturation Survey." *California Public Utilities Commission*. August 2014. http://calmac.org/publications/California_Commercial_Saturation_Study_Report_Finalv2.pdf

[25] From all estimates, excluded refrigerated warehouses, public order and safety, other, food sales, vacant, and religious worship building categories due to small sample size.

[26] Note that data is scaled by population from the CBECS designated Pacific region (which includes Oregon and Washington) to estimate California square footage and energy use.

Figure 13. Million square feet by principal building activity, (data from CBECS 2012)

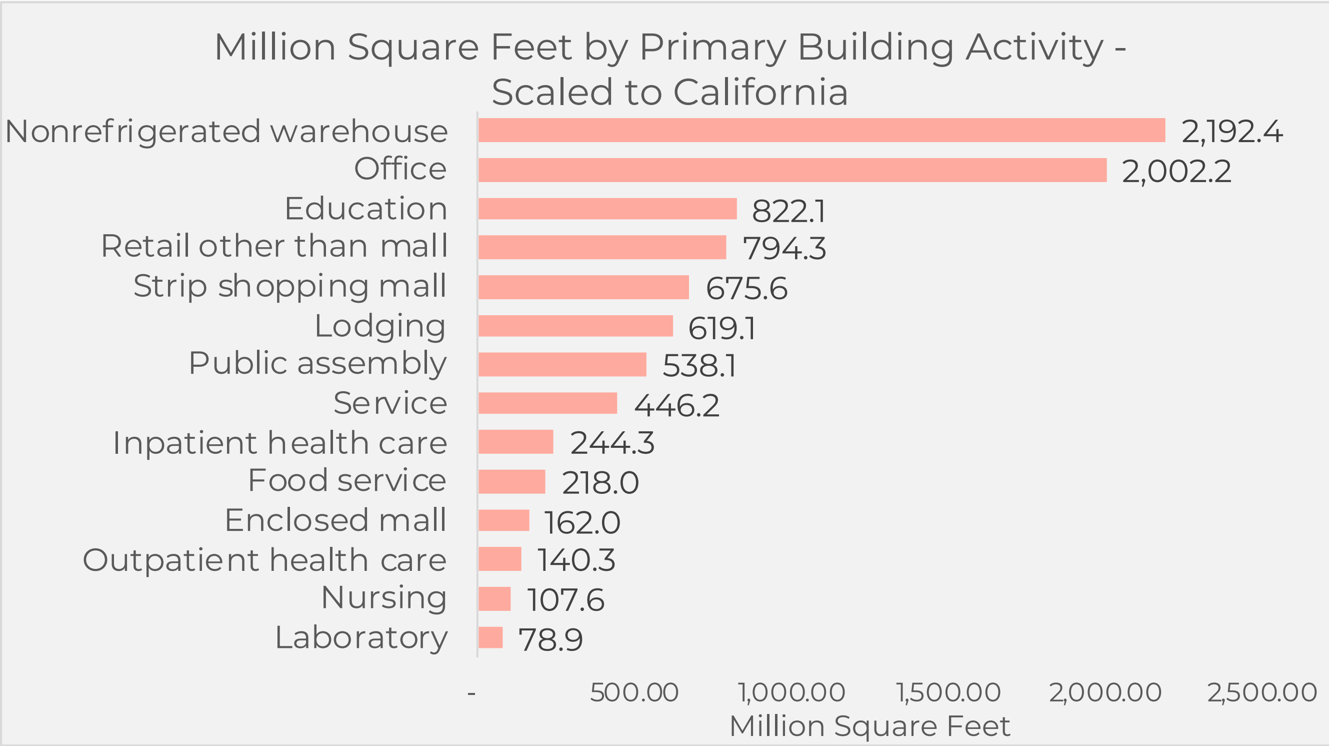


Figure 14. Water heating fuel type by primary building activity, million square feet (data from CBECS 2012)

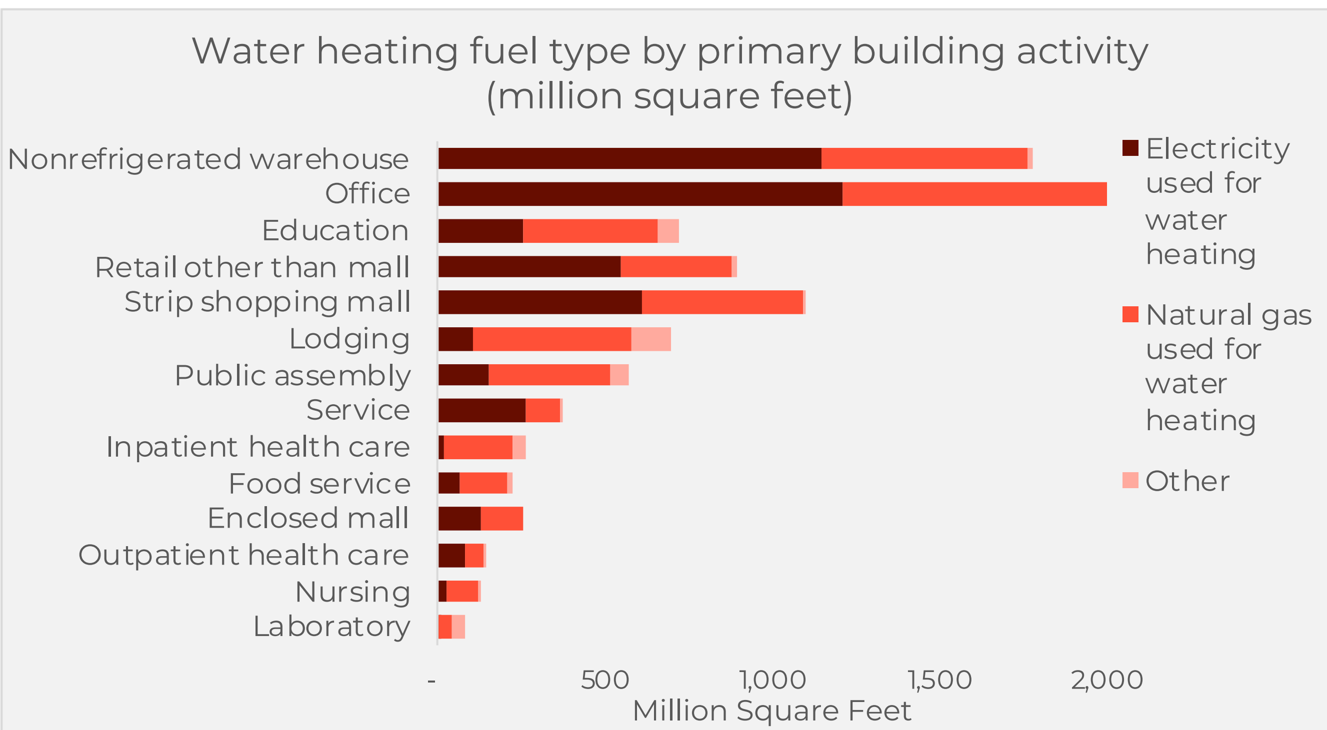
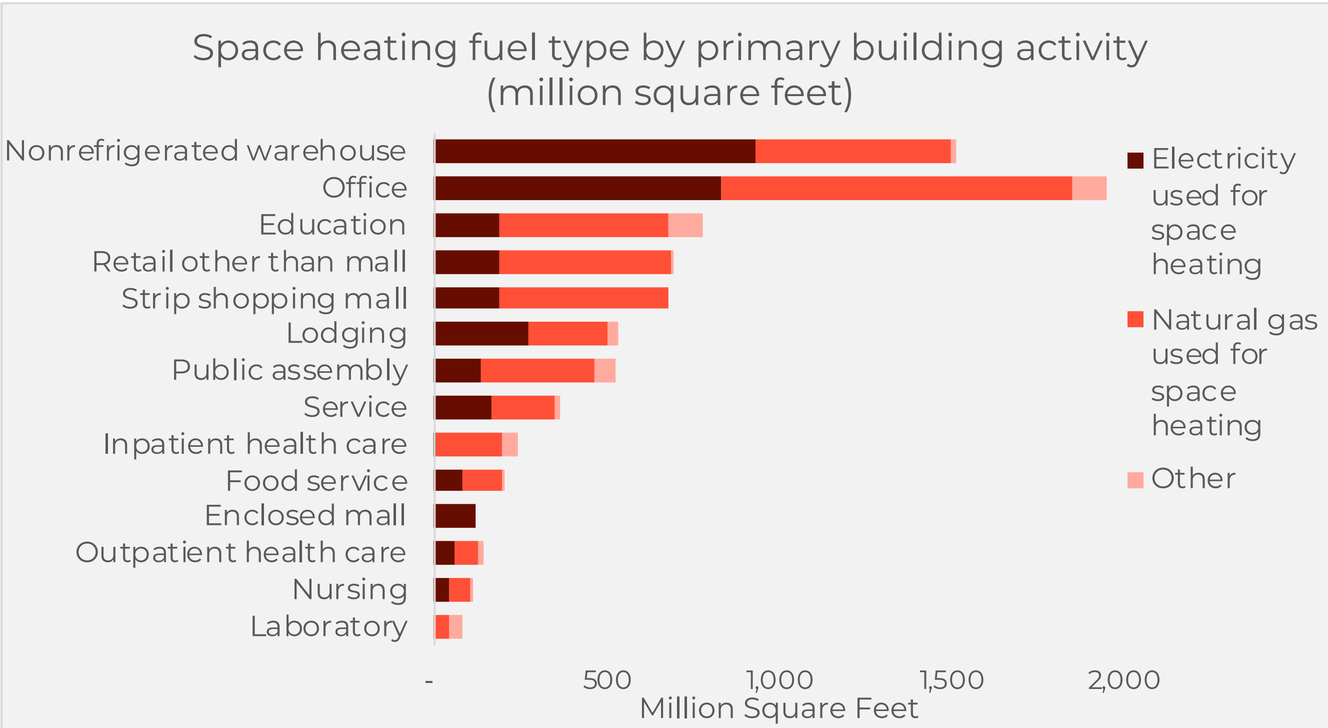


Figure 15. Space Heating Fuel Type by Primary Building Activity (data from CBECS 2012)

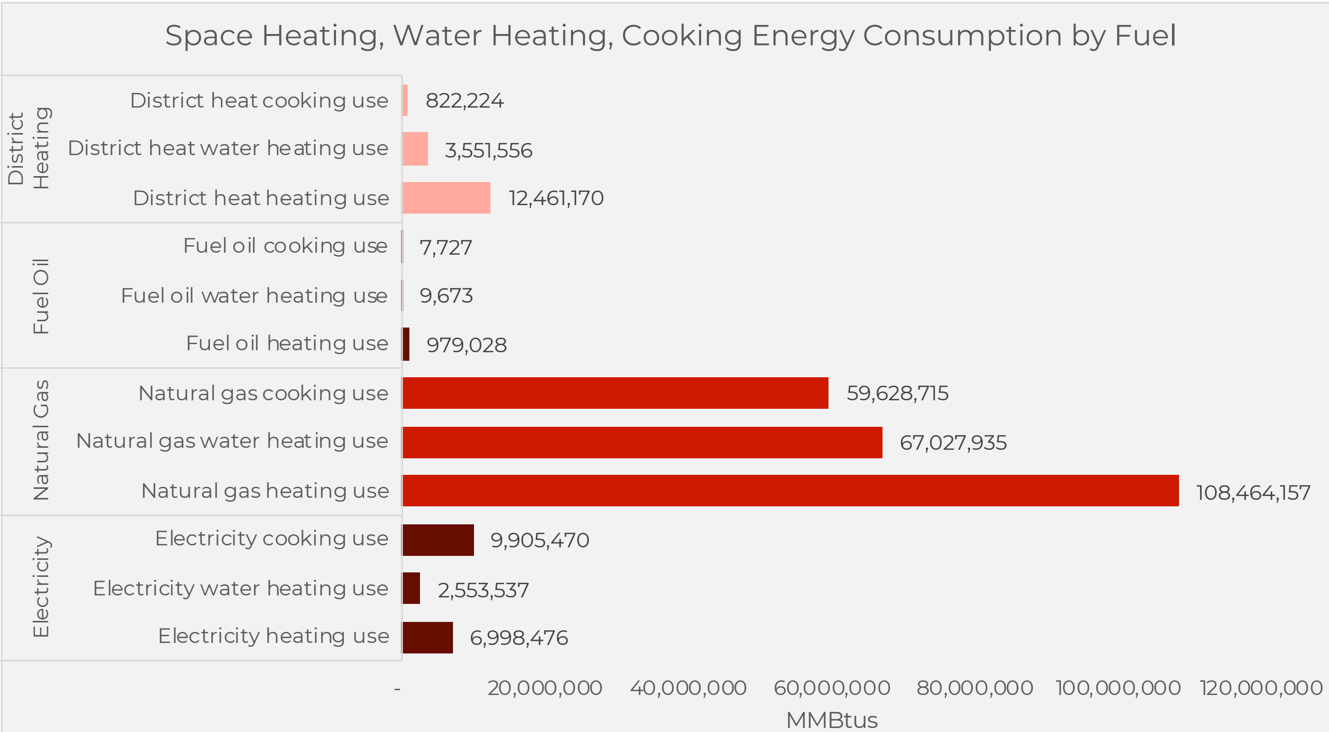


WHY IT MATTERS: When designing incentives, it's helpful to understand what the primary uses of commercial building space are. Some building types have substantial constraints on energy or fuel use. It may be more difficult to electrify some building types than others. It is also important to see that most commercial buildings types seem to be able to use electricity or natural gas for space and water heating.

TAKEAWAY 2: While a significant portion of building square footage is heated with electricity, the majority of energy consumption (in MMBtus) for space and water heating is from gas use.

- Gas space heating accounts for approximately 108,000,000 MMBtus while electricity heating uses only 7,000,000 MMBtus.
- Despite a roughly even split between commercial square footage heated by electricity and gas, most energy is consumed by gas appliances. Based on this discrepancy, it appears, buildings with high heating loads are more likely to use gas to heat their space or water.

Figure 16. Space and Water Heating, Cooking Energy Consumption by Fuel (data from CBECS 2012)



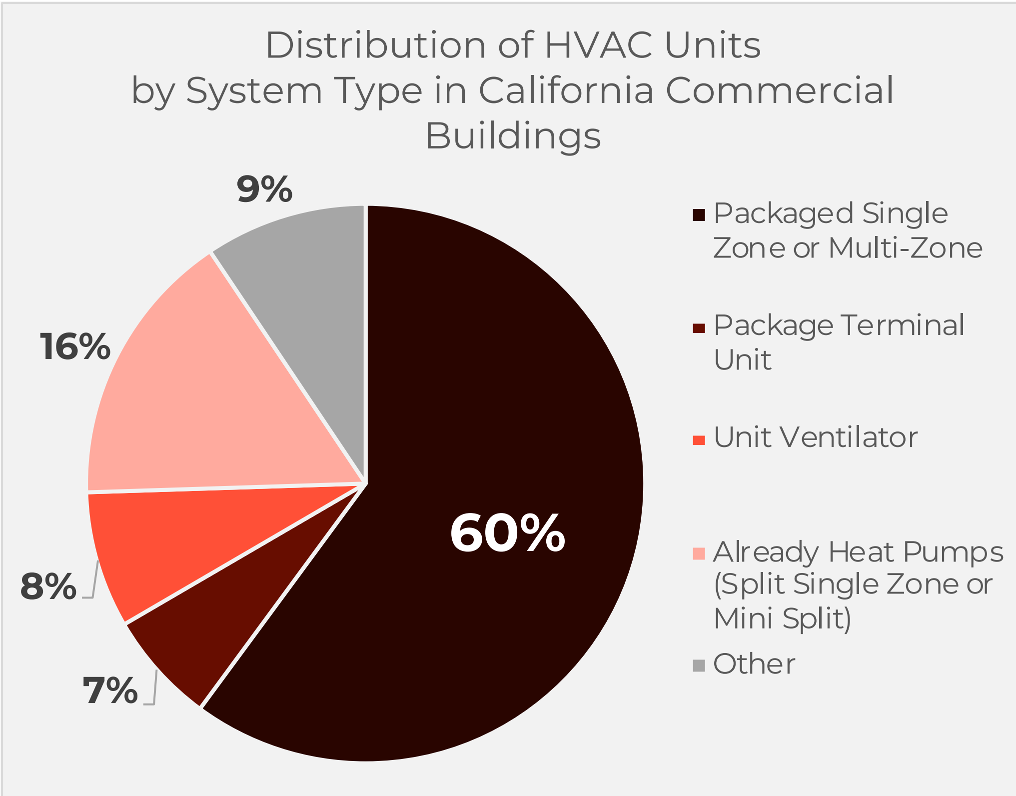
WHY IT MATTERS: This indicates the majority of space and water heating is being done with gas, even though electric appliances are common in commercial buildings. There may be reasons why buildings with higher energy consumption choose gas over electric appliances. This indicates there may be barriers to electrification among these building types and it warrants further research.

TAKEAWAY 3: Commercial building HVAC appliances are primarily gas furnaces or electric heat pumps. It is notable that a significant number of buildings already have electric heat pumps.

- The majority of HVAC units are packaged single- or multi-zone units, 60 percent of HVAC units in California commercial buildings. These are primarily RTUs or built up air handlers.[27]
- Approximately 16 percent of HVAC units are already heat pumps.

[27] "California Commercial Saturation Survey." *California Public Utilities Commission*. August 2014. http://calmac.org/publications/California_Commercial_Saturation_Study_Report_Finalv2.pdf

Figure 17. Distribution of HVAC Units by System Type in California Commercial Buildings (data from California Commercial Saturation Survey)



WHY IT MATTERS: This is useful to know how to target incentives. Providing market development support and incentives to switch from gas RTUs to electric heat pumps will impact the majority of HVAC units. Heat pumps are already a common appliance in commercial buildings. This indicates there is existing contractor and developer knowledge on how to design buildings with electric heat pumps, as well as sufficient market capacity to supply heat pumps.

Commercial Gas Consumption by Primary Building Type and End Use

TAKEAWAY 1: While non-refrigerated warehouses and offices account for the most commercial building square footage, strip shopping malls, health care facilities, offices, and food service buildings consume the most gas. The breakdown of gas consumption by end use varies significantly across primary building types.

- Across the commercial building sector, space heating accounts for about 45 percent of consumption, water heating accounts for 27 percent, and cooking accounts for 20 percent (see Figure 20).
- Strip shopping malls account for a disproportionate amount of gas consumption, compared to their square footage. As do food service buildings and health care facilities.
- In strip shopping malls, cooking accounts for about as much gas consumption as space heating.

- Food service gas consumption is primarily due to cooking, while this is a minor portion of gas use for most other building types.
- Office buildings have high gas use and almost all gas is used for space heating.

Figure 18. Total Gas Consumption by Primary Building Type (data from CBECS 2012)

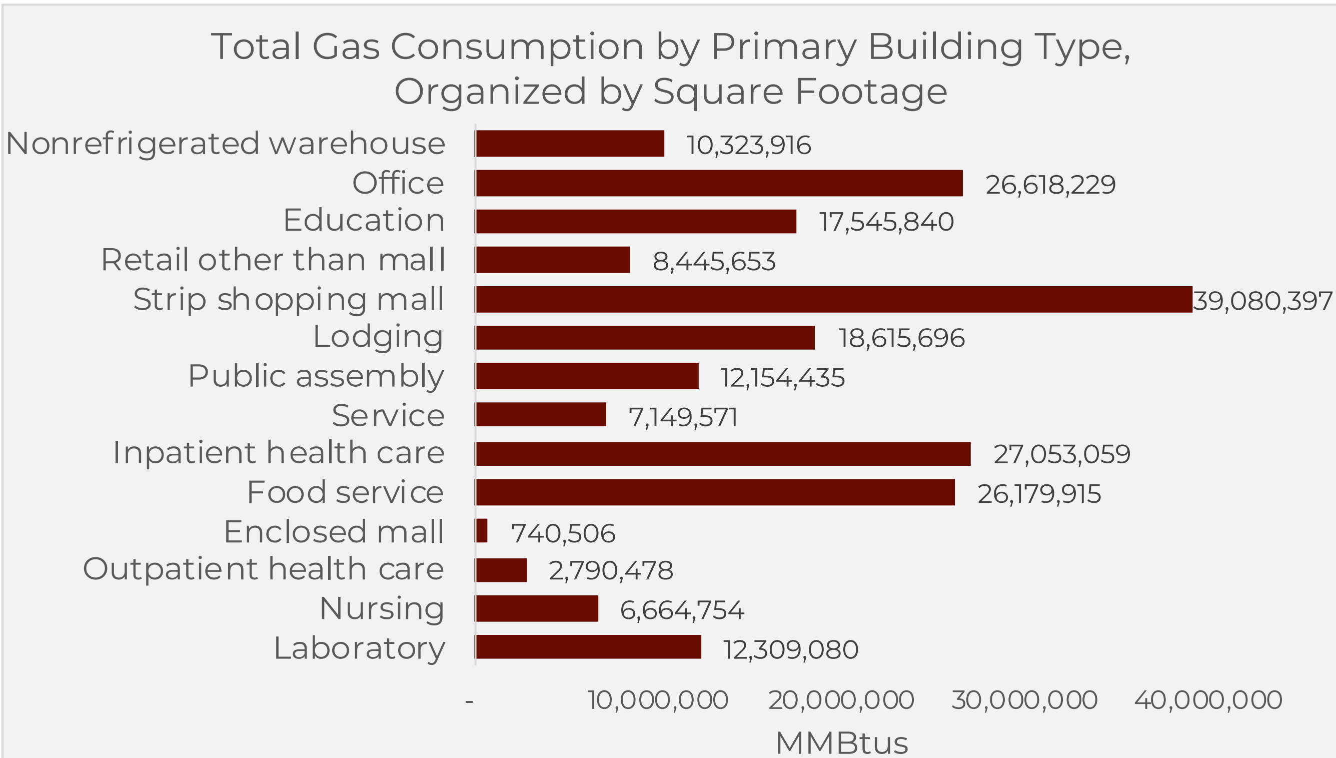


Figure 19. Gas Consumption by Principle Building Type, End Use (data from CBECS 2012)

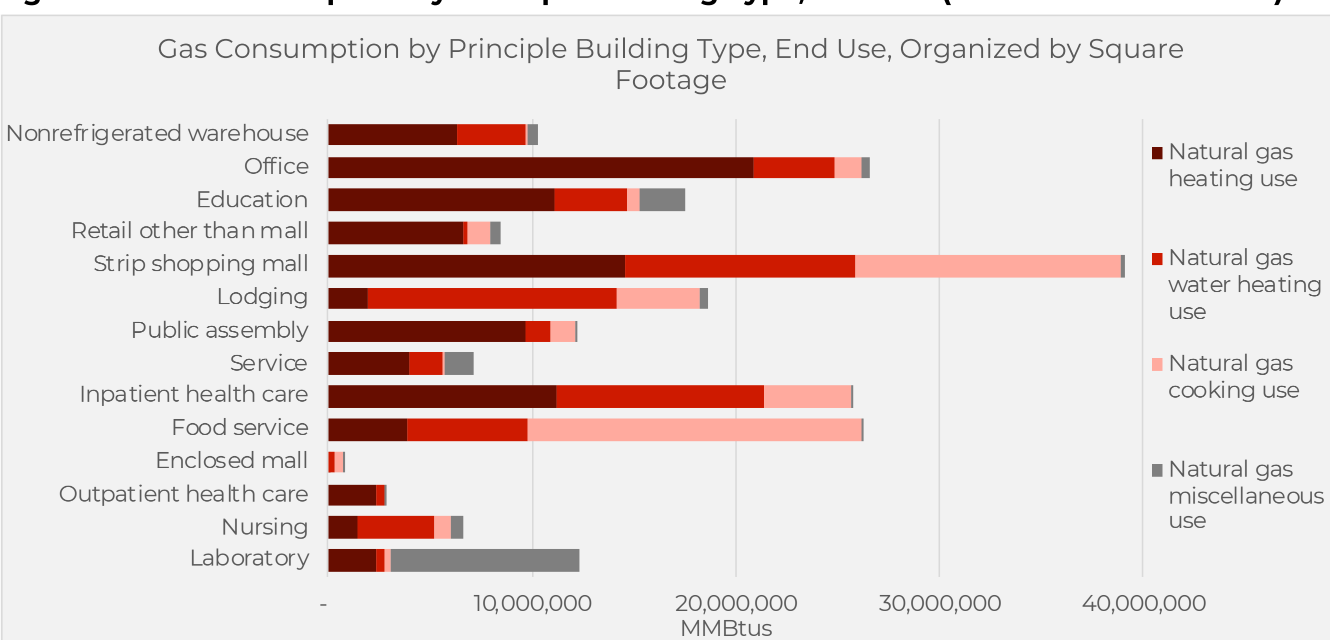
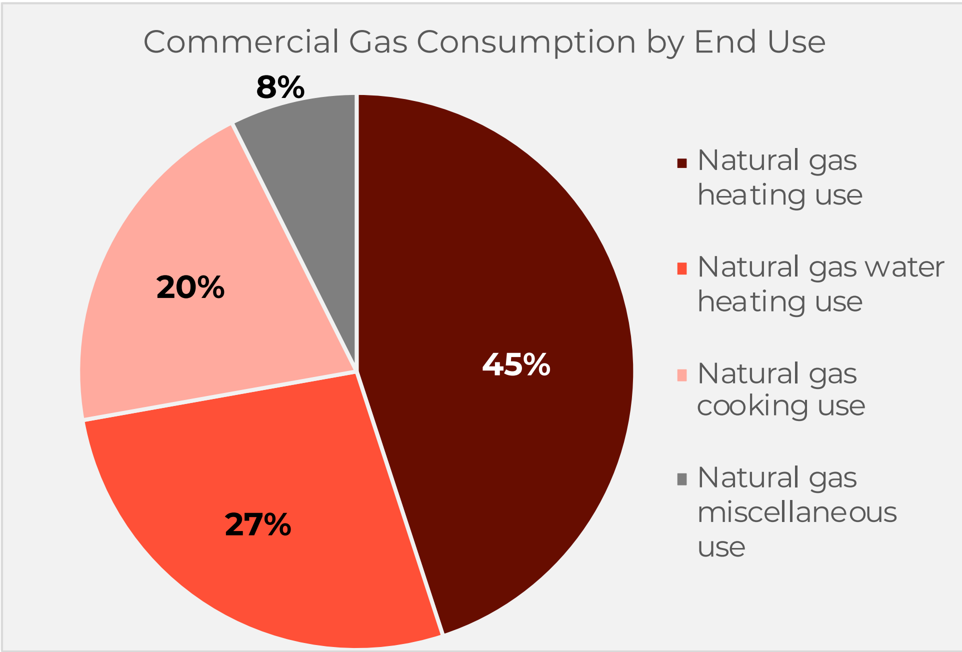
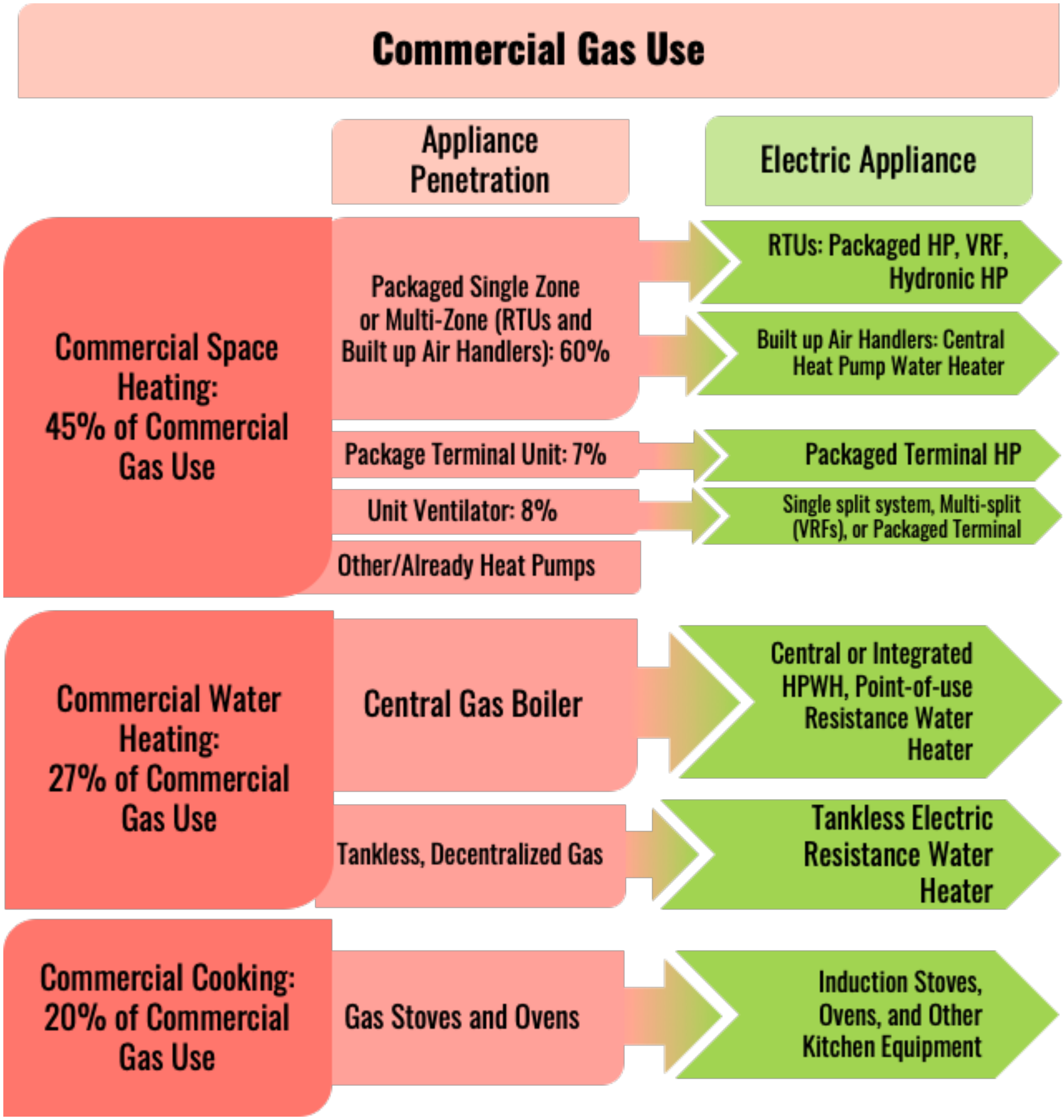


Figure 20. Commercial Gas Consumption by End Use (data from CBECS 2012)



Fuel Switching Targets

Based on our understanding of baseline gas use in California commercial buildings, appliance saturation, and available electric alternatives, I created a flow chart of where appliance replacements are needed. I do not have specific conversion efficiency for commercial appliance types, and it is difficult to create useful averages due to the amount of variation in building gas use by primary building type, so I did not create estimates for the number of appliances needed to fuel switch by 2030. See Appendix 2. for detailed methodology on target setting.


Commercial Gas Use
Appliance Penetration
Electric Appliance
Commercial Space Heating: 45% of Commercial Gas Use
Packaged Single Zone or Multi-Zone (RTUs and Built up Air Handlers): 60%
RTUs: Packaged HP, VRF, Hydronic HP
Built up Air Handlers: Central Heat Pump Water Heater
Package Terminal Unit: 7%
Packaged Terminal HP
Unit Ventilator: 8%
Single split system, Multi-split (VRFs), or Packaged Terminal
Other/Already Heat Pumps
Commercial Water Heating: 27% of Commercial Gas Use
Central Gas Boiler
Central or Integrated HPWH, Point-of-use Resistance Water Heater
Tankless, Decentralized Gas
Tankless Electric Resistance Water Heater
Commercial Cooking: 20% of Commercial Gas Use
Gas Stoves and Ovens
Induction Stoves, Ovens, and Other Kitchen Equipment

IV. Advancing Equity

- How do we advance equity with building decarbonization?
- Who is at risk of being left behind by electrification?

Ensuring Low-Income Households Participate in Benefits of Building Decarbonization

Low-income households face greater barriers to building decarbonization and are at a high risk of being left behind from the switch from natural gas to electric heating.

If most middle- and high-income households switch from gas to electricity, gas costs will rise dramatically for the remaining customers.[28] Fixed costs of the gas grid will remain the same, but be spread over a smaller customer base, leading to rate increases. At the same time, a warming climate and energy efficiency policies will reduce per household usage, further exacerbating this trend. If low-income households are left dependent on gas infrastructure while higher-income customers use electricity, gas bills will become a severe financial burden. There is a high-risk low-income household will be left behind without active efforts to engage them.

Again, we can draw parallels between solar PV adoption and building decarbonization. A portion of the CSI program is dedicated to incentivizing solar adoption in single and multifamily affordable housing; a minimum of 10 percent of total CSI Program funding was dedicated to low-income residential affordable housing.[29] However, significant discrepancies remain between disadvantaged communities and other communities in California—there are lower levels of solar PV adoption in disadvantaged communities.[30]

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[28] Aas, Dan, et al. "The Challenge of Retail Gas in California's Low-Carbon Future." *California Energy Commission.* April 2020. https://www.ethree.com/at-cec-e3-highlights-need-for-gas-transition-strategy-in-california/

[29] "Multifamily Affordable Solar Housing Semiannual Progress Report." *California Public Utilities Commission.* July 31 2019. https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy/Energy_Programs/Demand_Side_Management/Customer_Gen_and_Storage/SCE%20Semi-Annual%20MASH%20Progress%20Report%20July%202019.pdf

[30] Lukanov, Boris R. and Elena M. Krieger. "Distributed solar and environmental justice: Exploring the demographic and socio-economic trends of residential PV adoption in California." Energy Policy, Volume 134. https://doi.org/10.1016/j.enpol.2019.110935

Low-income households have numerous barriers to adopting new, clean heating technology. It is more difficult to secure high, up-front costs for new equipment. Low-income homeowners may not have funds to make costly, necessary upgrades in their buildings to accommodate electric technology. Poor energy efficiency may undermine potential savings from electric appliances. And many low-income households live in rental housing and depend on landlords to make upgrades to their housing.

Additionally, low-income households may be wary of participating in government-run home improvement programs even if they are well funded. This may further limit how many low-income households adopt electric heating appliances. Low-income residents may not participate in building decarbonization programs if they've previously had a bad experience with energy efficiency programs, are undocumented immigrants, do not speak English as a first language, or are afraid their utility bills will increase. There is also a concern that appliance and energy upgrade programs will be exploited by landlords to evict low-income residents or raise rents.[31] Incentive programs that fund improvements in rental housing will need to be accompanied by rent protections and conduct appropriate outreach to low-income communities.

However, fuel switching in disadvantaged communities is important. Households in disadvantaged communities can experience a myriad of benefits from upgrading to electric appliances. Gas appliances contribute to poor indoor air quality resulting in pollutant concentrations that exceed safe levels.[32] Low-income households are more likely to have bad ventilation and worse indoor air quality than other homes. Additionally, electrification could improve outdoor air quality, especially in areas that have high pollution burdens from particulate matter.[33] Long-term exposure to pollutants from gas consumption can increase the risk of asthma and other respiratory issues.[34]

In addition to offering air quality benefits, fuel switching in low-income homes can provide utility bill savings (particularly when combined with energy efficiency and solar), improve access to adequate heating and cooling, and yield significant GHG emission reductions.

[31] Miller, Carmelita, et al. "Equitable Building Electrification." *Greenlining Institute.* 2019. http://greenlining.org/wp-content/uploads/2019/09/Greenlining_EquitableElectrificationReport_2019_WEB.pdf
[32] Mullen, Nasim A., et al. "Impact of Natural Gas Appliances on Pollutant Levels in California Homes." *Lawrence Berkeley National Laboratory.* December 2012. https://indoor.lbl.gov/sites/all/files/impact_of_natural_gas_appliances.pdf
[33] Aas, Dan, et al. "The Challenge of Retail Gas in California's Low-Carbon Future." *California Energy Commission.* April 2020. https://www.ethree.com/at-cec-e3-highlights-need-for-gas-transition-strategy-in-california/
[34] Mullen, Nasim A., et al. "Impact of Natural Gas Appliances on Pollutant Levels in California Homes." *Lawrence Berkeley National Laboratory.* December 2012. https://indoor.lbl.gov/sites/all/files/impact_of_natural_gas_appliances.pdf

Profile of Low-Income and Rental Homes

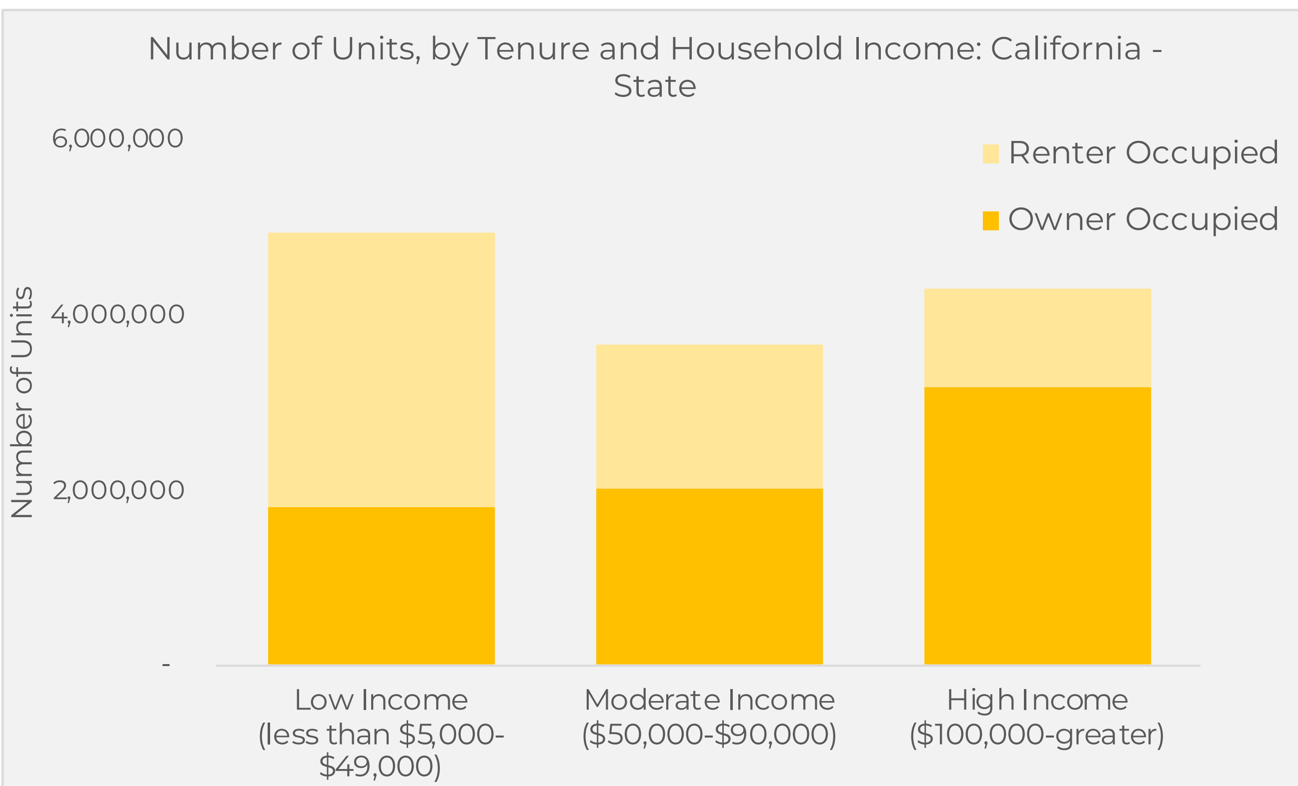
Key factors to assess low-income households include housing units by income, housing units by tenure status, gas consumption by income level, and appliance characteristics. Data is from the ACS and RECS.[35]

Tenure Status

TAKEAWAY 1: About two thirds of households with extremely low or very low household incomes live in rental housing. Renters are more likely to live in multifamily units although a substantial number of renters also live in single-family homes.

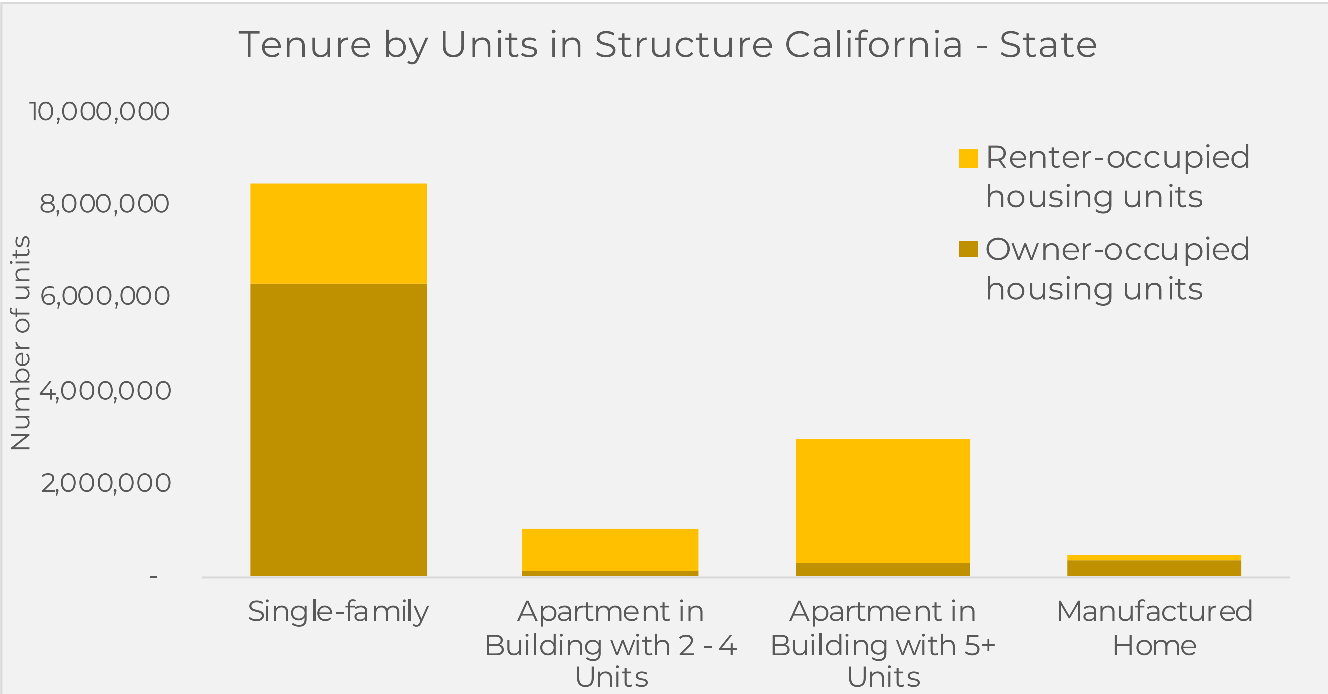
- Among households with the lowest incomes in the state, most live in rental housing.
- Wealthier households are far more likely to own their homes.
- About 40 percent of all California households are low income.
- Of these lower income households, the majority (60 percent) live in rental housing.
- 60 percent of all renters live in multifamily housing.

Figure 21. Number of Units, by Tenure and Household Income (data from ACS 2017)



[35] "2013-2017 ACS Five Year Estimates." *United States Census Bureau.* 2018. https://www.census.gov/programs-surveys/acs/technical-documentation/table-and-geography-changes/2017/5-year.html & "2009 RECS Survey Data." *EIA*. Jan 2013. https://www.eia.gov/consumption/residential/data/2009/index.php?view=microdata

Figure 22. Tenure by Units in Structure (data from ACS 2017)



WHY IT MATTERS: Almost 40 percent of California's households make less than $50,000 per year and are likely unable to pay for the capital cost of efficient electrification without some support. Additionally, most low-income households live in rental housing which means fuel switching will require landlords to take action, and these residents are vulnerable due to their tenure status. Rental housing is split between single family (40%) and multifamily (60%) units.

TAKEAWAY 2: Among all income groups, gas consumption is largely from single family homes and the majority of gas consumption occurs in owned, rather than rented, homes.[36]

- While the high-income category has the highest total gas use, the gas use in low-income households adds up to about 40 percent of total gas consumption.
- The majority of gas consumption (occurs in owned, rather than rented (30%), homes and apartments.

[36] Note that RECS data is based on 2009 survey results and income data is somewhat outdated compared to data sources from 2017.

Figure 23. Natural Gas Space and Water Energy Consumption by Income and Building Type (data from RECS 2009)

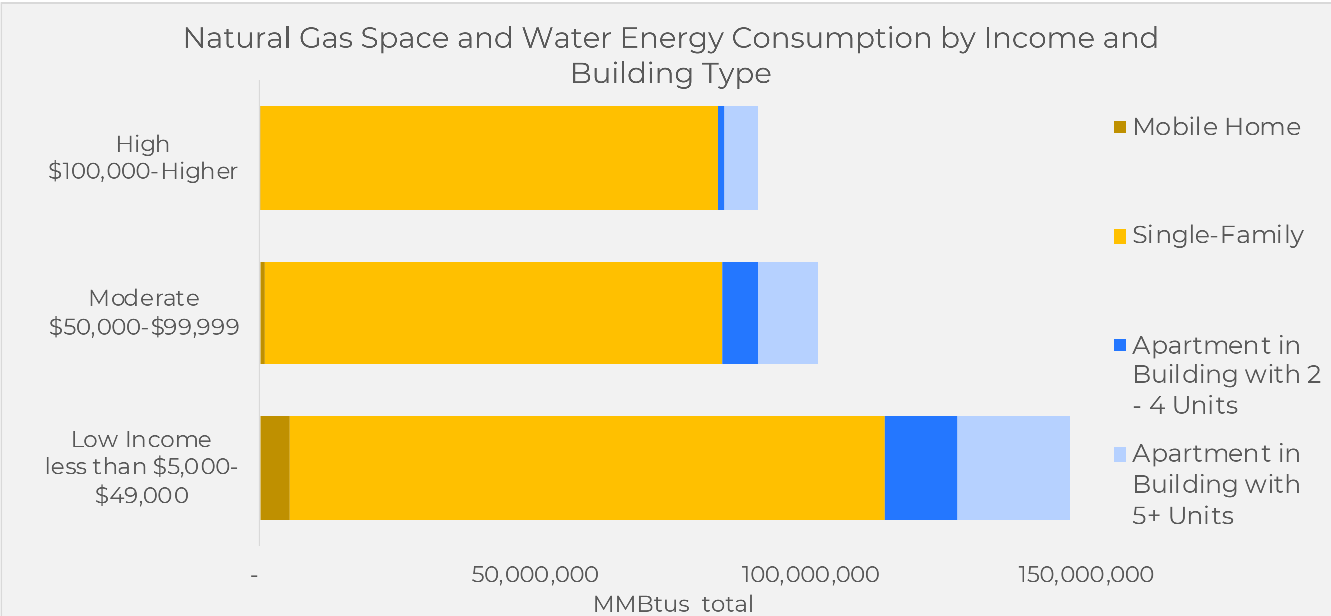
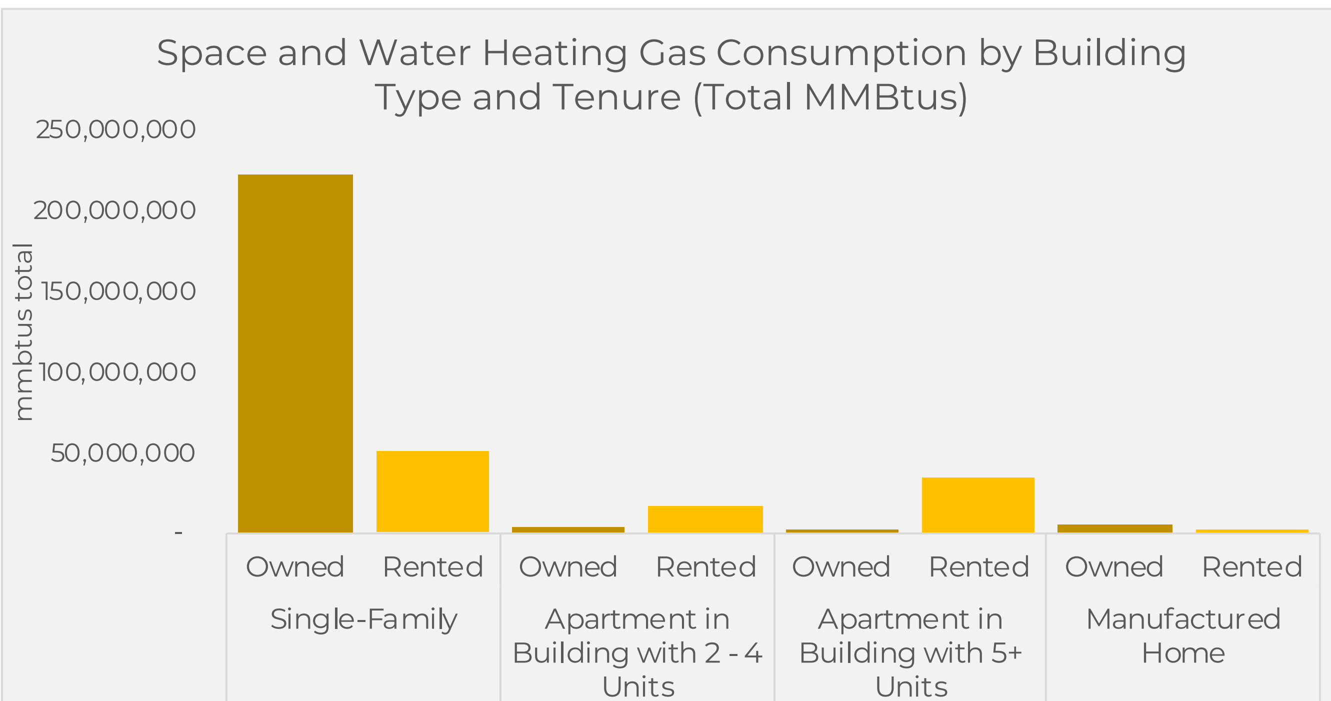


Figure 24. Space and Water Heating Gas Consumption by Building Type and Tenure (data from RECS 2009)



WHY IT MATTERS: All low-income households are unlikely to be able to afford electrification without substantial incentives. This is a substantial portion of gas consumption that will need to be strongly incentivized. Single-family homes consume the most gas and incentives will need to target single-family homes across all income levels. Additionally, most gas consumption occurs in owned homes, which has implications for incentive program design.

TAKEAWAY 3: Appliances in rental housing are more likely to be 20 years or older, as compared to appliances in owned housing.

- 52 percent of the gas space heating appliances in rental units are older than 20 years, versus 30 percent in owned units.
- 18 percent of the gas water heating appliances in rental units are older than 20 years, versus 11 percent in owned units.

Figure 25. Age of Main Water Heating Equipment - Gas Appliances (data from RECS 2009)

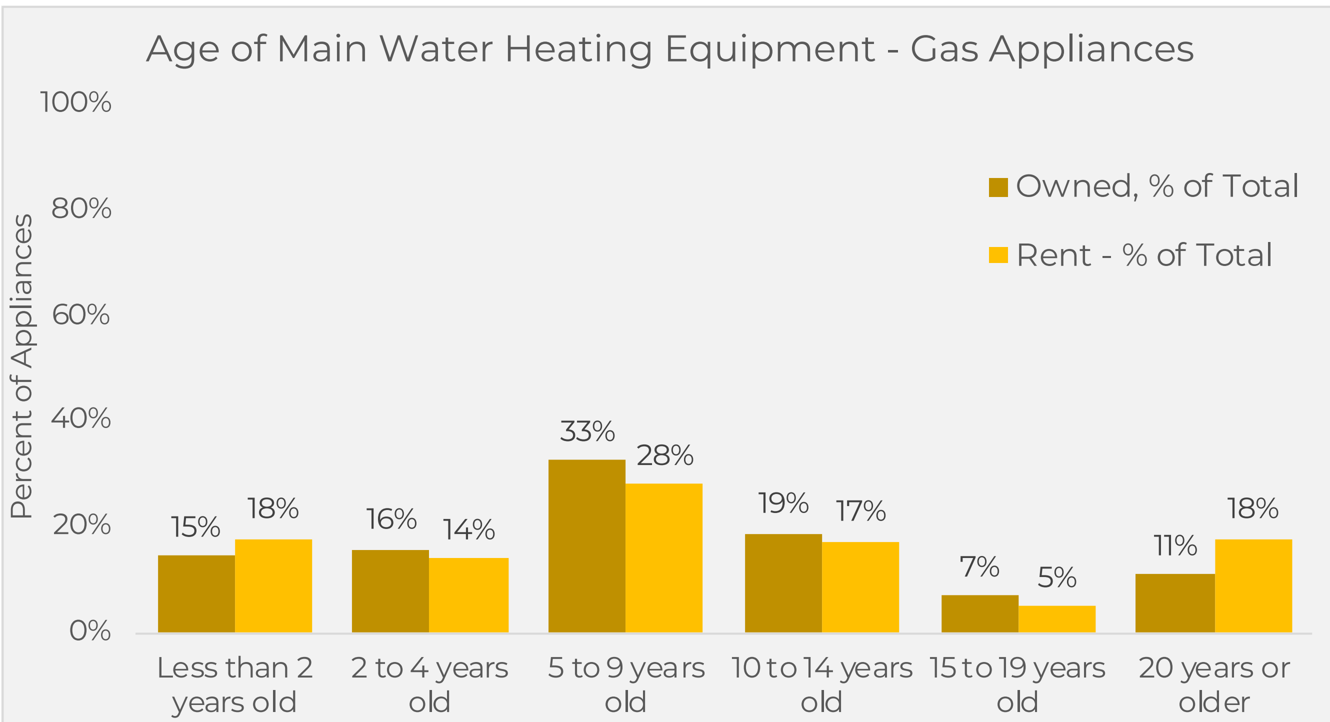
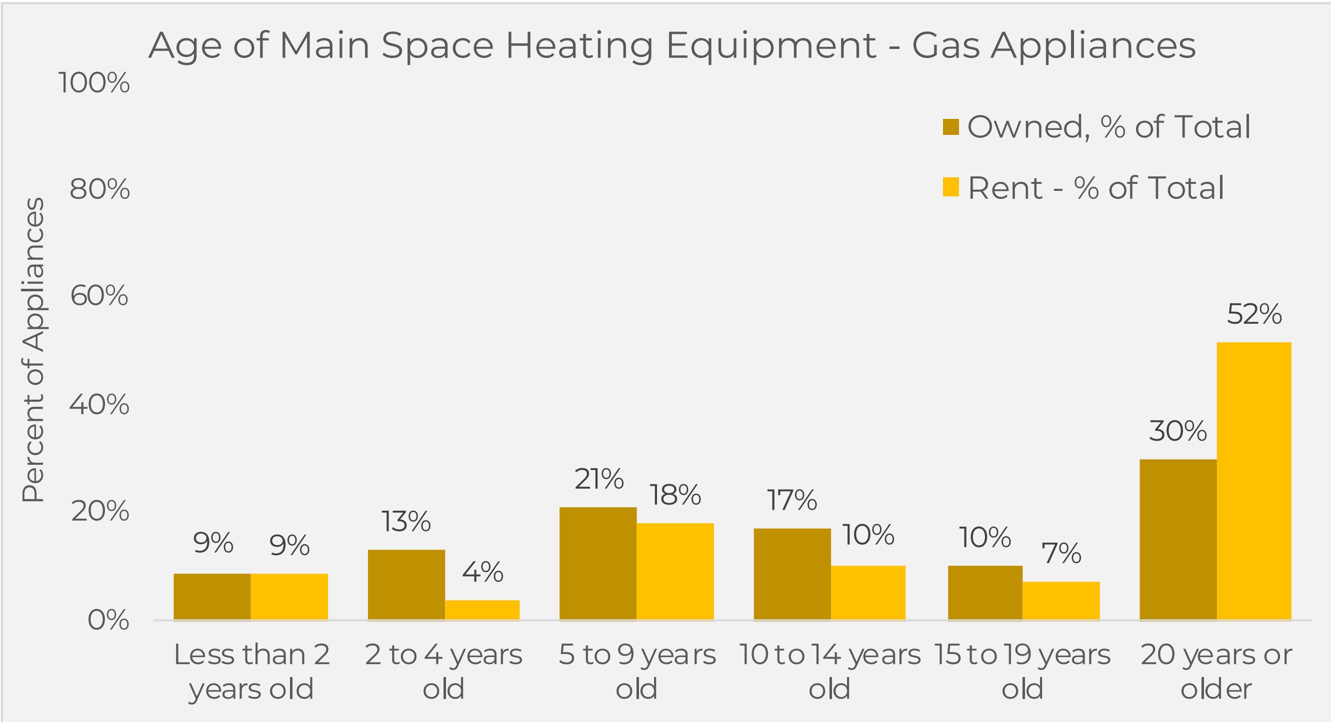


Figure 26. Age of Main Space Heating Equipment - Gas Appliances (data from RECS 2009)



WHY IT MATTERS: Rental and income status of buildings have implications for the housing quality and appliance quality. Older appliances are inefficient and replacing them reduces gas consumption. This also has severe implications for the lifespan of inefficient appliances and undermines our ability to achieve emissions reductions by 2030 by relying on the natural turnover of appliances. It implies we will need incentives and preemptive retirement for the oldest gas appliances.

Tenure Status and Incentives Takeaways

✓	**Robust Incentives and Supportive Programs** A substantial portion of gas (40% of residential gas demand) is consumed in low-income households with limited ability to pay for electrification. These households will need the incremental costs of electrification to be heavily subsidized.
✓	**Performance Standards** Landlords may be less inclined to respond to incentives than owner-occupied homes. The rental sector may need performance standards coupled with incentives. There are mechanisms to regulate performance in rental housing markets. For example, Boulder, CO requires all rental housing to meet basic energy efficiency standards and ensures regulation with the program through rental

	housing licenses.[37] Additionally, some rental units are "deed-restricted" to use by income-qualified residents and these units could be incentivized to adopt electric appliances without risk of landlords evicting residents. However, of about 4 million total multifamily units, only about 480,000 are deed restricted affordable units.[38]
✓	**Preemptive Retirement** Many space heating appliances (52%) and some water heaters (18%) in rental housing are more than 20 years old. Models that project fuel switching through incentives at time of burnout rely on 12-15-year lifetimes. However, if a significant portion of appliances are used for over 20 years, they will not be captured by incentives that wait for appliances to burn out.
✓	**Renter Protections** Renters may be vulnerable to displacement and rent increases as housing is upgraded from gas to electric appliances. Programs targeting rental housing will need to include renter protections to ensure residents do not experience eviction or rent increases.

[37] "Smart Regs." *City of Boulder, Colorado*. 2020. https://bouldercolorado.gov/plan-develop/smartregs

[38] "California's Housing Future: Challenges and Opportunities." *California Department of Housing and Community Development*. January 2017.

V. Estimating Costs

- How much money do we need to adequately incentivize adoption of efficient heat pumps?

It is hard to determine what level of incentive is needed to convince home or building owners to fuel switch when their gas appliances burn out. Fuel switching costs vary substantially depending on the building type, unit size, and existing characteristics. For new construction, electric appliances can save thousands in infrastructure costs. For existing buildings, electric appliances can require expensive, new wiring and electric panel upgrades. Long-term impacts on utility bills can also vary. Energy bill costs or savings are largely determined by the ratio of electricity to gas costs set by the utility, as well as the local climate (often measured in heating degree days). This means that in some areas the typical house could save hundreds on utility bills. In other areas, fuel switching could increase utility costs.

Even if we can predict expected costs of fuel switching by building type, it is still unclear what level of incentive is needed to persuade consumers to fuel switch. Is simply ensuring that electric appliances are cheaper than gas appliances enough? Or are there other strong preferences influencing peoples' choices? Another complicating factor is that people generally do not actively shop around and choose their water or space heaters. These appliances are typically replaced when they break, so people make quick decisions and rely on contractors to select new appliances.

In this section, I do not assess or recommend specific incentive program design. This is best left to program implementers and will vary depending on each market. Instead, I focused on estimating the total incremental costs of fuel switching for different building types in the current early state of the market in California. This is useful to approximate the total amount of money needed to kickstart market development and start bringing these technologies down the cost curve.

Below, I summarize costs for residential electrification in new and existing buildings. I also estimate costs for low income buildings, new commercial buildings, and some existing, commercial building technologies.

Residential

New All-Electric, Low-Rise Construction

New all-electric buildings are less expensive than mixed fuel (gas and electric) buildings from an up-front and lifecycle cost perspective. Cost estimates are for low-rise residential buildings, including single family units and low-rise multifamily units. For low-rise multifamily, cost is estimated to be shared among 6-8 units.[39] High-rise multifamily building costs are highly variable and more similar to commercial buildings than low-rise residential.

Costs

Low Rise Residential Electric Home Costs		Estimated Cost Difference
Avoided Gas Infrastructure Costs	All-new electric buildings can avoid costs of gas infrastructure. These costs are highly variable depending on the site characteristics. Costs include both exterior and in-building gas infrastructure costs. Assume gas lines run to the water heater, furnace, dryer, and cooktop.[40]	**-$10,000** *main line extension* **-$1,686** *service lateral* **-$150** *meter* **-$200** *gas line per appliance in single family* **-$150** *gas line per appliance in multifamily*
Additional Electric Infrastructure Costs	Electric service upgrades are required for all-electric appliances to run 220V service to each appliance. Assume no electric panel upgrade.[41]	**+$200** per appliance in single family **+$150** per appliance in multifamily
Incremental Capital Costs of Appliances	An electric heat pump typically offers savings compared to a gas furnace and AC system. Heat pump water heaters are estimated to cost the same as gas tankless water heaters. Other appliances, clothes dryers and cooktops, are estimated to cost the same as gas alternatives.[42]	**-$221** for electric HVAC heat pump **$0** for heat pump water heater **$0** for clothes dryer **$0** for cooktop
Operating Costs	Annual operating costs are highly variable based on climate zone, utility rates, appliance efficiency, and building characteristics. Estimated operating costs	**-$40 to +$90** per year for HPWH vs. gas tankless **-$350 to -$50** per year for HVAC heat pumps compared

[39] Mahone, Amber, et al. "Residential Building Electrification in California." *Energy and Environmental Economics, Inc.* April 2019. https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf

[40] "...for a new subdivision in an undeveloped area requiring the installation of natural gas infrastructure, including a main line...assume $10,000 for extension of a gas main, $1,686 for a service lateral, and $150 for the meter. 2019 Cost-Effectiveness Study: Low-rise Residential New Construction," *Frontier Energy, Inc.* August 2019.

[41] 2019 Cost-Effectiveness Study: Low-rise Residential New Construction," Frontier Energy, Inc. August 2019.

[42] 2019 Cost-Effectiveness Study: Low-rise Residential New Construction," Frontier Energy, Inc. August 2019.

Low Rise Residential Electric Home Costs		Estimated Cost Difference
	range from moderate cost increases to substantial cost savings.[43]	to gas furnace + AC
Estimated Incremental Cost of All-Electric New Construction:		**-$12,060** upfront capital costs per building **-$390 to +$40** annual operating costs per unit

New All-Electric, Mid-Rise Construction

There are few studies estimating the costs of all-electric multifamily construction. A preliminary study from California Energy Codes and Standards modeled costs of mixed-fuel and all electric mid-rise multifamily units. Their prototype building is a 6 story mixed-use building with 4 stories of residential space. They estimated costs for the residential portion of the building, which included 8 studios, 40 1-bed units, 32 2-bed units, and 8 3-bed units, totaling 88 units and 136 bedrooms.[44] The prototype assumes the HVAC systems are split heat pumps and the baseline water heater is a gas central boiler with solar thermal.[45] The all electric model including energy efficiency and solar PV, Including up-front equipment costs, maintenance costs, utility costs, and solar PV and efficiency costs, finds all-electric construction is cost effective and code compliant for all climate zones.[46] Without solar PV, some climate zones are not cost effective.

Mid-Rise Residential Electric Multifamily Unit Costs		Estimated Cost Difference
Avoided Gas Infrastructure Costs	Gas infrastructure costs include natural gas plan review, service extension, meter, and plumbing distribution.[47]	**-$12,322 total** residential portion of gas infrastructure costs

[43] Cost estimates for utility bills are highly variable depending on the study. I selected estimates from Figures 3-9 and 3-11 in E3's paper "Residential Building Electrification in California." Studies reviewed include estimated costs: savings of $200-$500 annually ("Decarbonization of Heating Energy Use in California Buildings," Synapse Energy Economics, October 2018.); cost increases of $97-$575 for homes without solar PV to $87-$613 in savings for homes with PV (2019 Cost-Effectiveness Study: Low-rise Residential New Construction," Frontier Energy, Inc. August 2019.); cost increases of $50-$387 in some climate zones to savings of $14-$91 in other areas ("Impacts of Residential Appliance Electrification," Navigant Consulting, August 2018.); and estimated operating costs of -$40 to +$90 for HPWH vs. gas tankless and -$350 to -$50 for HVAC heat pumps compared to gas furnace + AC ("Residential Building Electrification in California," Energy and Environmental Economics, April 2019.)

[44] German, Alea, Bill Dakin, & Misti Bruceri. "Mid-Rise Multifamily Residential Cost-effectiveness Study PRELIMINARY Results." *California Energy Codes & Standards*. 11 March 2020.

[45] German, Alea, Bill Dakin, & Misti Bruceri. "Mid-Rise Multifamily Residential Cost-effectiveness Study PRELIMINARY Results." *California Energy Codes & Standards*. 11 March 2020.

[46] German, Alea, Bill Dakin, & Misti Bruceri. "Mid-Rise Multifamily Residential Cost-effectiveness Study PRELIMINARY Results." *California Energy Codes & Standards*. 11 March 2020.

[47] German, Alea, Bill Dakin, & Misti Bruceri. "Mid-Rise Multifamily Residential Cost-effectiveness Study PRELIMINARY Results." *California Energy Codes & Standards*. 11 March 2020.

		-$140 per unit
Incremental Capital Costs of Appliances and Electric Infrastructure Costs	Clustered HPWHs, supplying hot water for 4-5 units would cost $126,778 compared to central gas boiler cost and solar thermal of $141,178 in initial equipment costs.[48]	**-$14,400 total** incremental cost **-$163 per unit** incremental cost **+$3,200 per housing unit** for solar PV
Operating Costs	Without solar PV, over a 30-year period, utility costs range from an increase of $1,073 to savings of $513 depending on climate zone. Of the 16 climate zones, 10 see utility cost increases and 6 see cost savings. With solar PV, there are substantial utility cost savings, up to $9,596 and is cost effective in all climate zones.[49]	**-$513 to +$1,073** in utility bill costs over 30-yr period per apartment without solar PV **-$5,099 to -$9,596** in utility bill cost savings over 30-yr period per apartment with solar PV
Estimated Incremental Cost of All-Electric New Construction:		**+$2,897 per unit, including solar PV**

Space and Water Heating Retrofits of Existing Low-Rise Residential

It is cost effective to retrofit most existing, low-rise residential homes. E3's study "Residential Building Electrification in California," estimates the costs for electric retrofits in single family and low-rise multifamily homes.[50] They estimate electric infrastructure costs in old homes (pre-1978) and newer homes (post-1978). The E3 study models residential infrastructure costs, incremental appliance costs, and operating costs based on estimated energy use. The model includes estimates for six California climate zones to account for variability in heating loads and utility energy prices.[51]

Low Rise Residential Electric Home Costs		**Estimated Cost Difference**
Additional Electric Infrastructure Costs	Electric service panels in older buildings are often insufficient to handle increased electric loads from electric appliances. Service panel upgrades are expensive, but it is unknown how many	**+$4,256** electric service panel in single family home **+$2,744** electric service panel upgrade in multifamily

[48] German, Alea, Bill Dakin, & Misti Bruceri. "Mid-Rise Multifamily Residential Cost-effectiveness Study PRELIMINARY Results." *California Energy Codes & Standards.* 11 March 2020.
[49] German, Alea, Bill Dakin, & Misti Bruceri. "Mid-Rise Multifamily Residential Cost-effectiveness Study PRELIMINARY Results." *California Energy Codes & Standards.* 11 March 2020.
[50] Mahone, Amber, et al. "Residential Building Electrification in California." *Energy and Environmental Economics, Inc.* April 2019.
[51] Mahone, Amber, et al. "Residential Building Electrification in California." *Energy and Environmental Economics, Inc.* April 2019.

Low Rise Residential Electric Home Costs		Estimated Cost Difference
	homes need service panel upgrades.[52]	
Incremental Capital Costs of Appliances	There is substantial variability in costs of appliances and installation based on existing home characteristics, labor costs, and equipment type. HVAC retrofit costs are variable, but generally cost effective at burnout for homes with AC.[53] Heat pump water heaters generally cost more than gas storage water heaters.[54]	**-$17,000 to +$8,000** to replace gas furnace and AC with an electric system (packaged terminal, mini-split, or ducted split heat pump) **+$400 to +$2,700** to replace gas storage furnaces with electric HPWH
Operating Costs	Operating costs are highly variable based on climate zone, utility rates, appliance efficiency, and building characteristics. Estimated operating costs range from moderate cost increases to substantial cost savings.[55]	**$0 to -$600** for HVAC bill costs **$0 to -$150** for HPWHs
Estimated Incremental Cost of Electric Space and Water Heating Retrofits:		**+$15,000 to -$16,600** upfront capital costs per building **$0 to -$750** annual operating costs per unit

Low-Income, Low-Rise Residential Retrofits

Very low-income households will need decarbonization programs to fully cover appliance and retrofit costs, provide bill protection, and community outreach. The only California example of a building decarbonization pilot in low income communities is the San Joaquin Valley Electrification Pilot. The San Joaquin Valley pilots are fully funding building electrification in homes that previously used propane or wood appliances. This is fundamentally a different program than future, low income programs focused on gas to electric fuel switching for space and water heating. However, some elements of the pilot would be applicable to all low-income programs. Those elements include money allocated to upgrade electric panels, $5,000/unit to

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[52] Mahone, Amber, et al. "Residential Building Electrification in California." *Energy and Environmental Economics, Inc.* April 2019.

[53] For HVAC: cheapest electric option from most expensive gas option ($7k minus $24k) and most expensive electric option from cheapest gas option ($12k minus $20k) Mahone, Amber, et al. "Residential Building Electrification in California." *Energy and Environmental Economics, Inc.* April 2019.

[54] For HPWH: gas storage costs range from $2,000-$2,600 and electric HPWH range from $3,000-$4,700. Mahone, Amber, et al. "Residential Building Electrification in California." *Energy and Environmental Economics, Inc.* April 2019.

[55] Cost estimates for utility bills are highly variable. I selected estimates from Figures 3-9 and 3-11 in E3's paper "Residential Building Electrification in California." Studies reviewed included estimated bill savings of $500-$800 for HVAC heat pumps (Decarbonization of Heating Energy Use in California Buildings," Synapse Energy Economics, October 2018.); bill increases for all electric home of $50-387 and savings of $14-$91 ("Impacts of Residential Appliance Electrification," Navigant Consulting, August 2018).

rewire homes and increase energy efficiency, $500/unit to protect utility bills, and support for a community energy navigator to conduct culturally appropriate outreach.

The chart below includes the electric service panel costs and incremental capital cost of appliances from E3's study "Residential Building Electrification in California."[56] The energy efficiency and electric infrastructure upgrade costs, community energy navigator costs, and bill savings cost are from the San Joaquin Valley Pilot program.[57]

Low-Income Retrofits		**Estimated Cost Difference**
Additional Electric Infrastructure Costs	Electric service panels in older buildings are often insufficient to handle increased electric loads from electric appliances. Service panel upgrades are expensive, but it is unknown how many homes need service panel upgrades.[58]	**+$4,256** electric service panel in single family home **+$2,744** electric service panel upgrade in multifamily
Incremental Capital Costs of Appliances	There is substantial variability in costs of appliances and installation based on existing home characteristics, labor costs, and equipment type. HVAC retrofit costs are variable, but generally cost effective at burnout for homes with AC.[59] Heat pump water heaters generally cost more than gas storage water heaters.[60]	**-$17,000 to +$8,000** to replace gas furnace and AC with an electric system (packaged terminal, mini-split, or ducted split heat pump) **+$400 to +$2,700** to replace gas storage furnaces with electric HPWH
Energy Efficiency and Electric Infrastructure Costs	Home electric wiring and efficiency retrofit costs of up to $5,000.[61]	**+$5,000** per unit for energy efficiency and electrical work
Community Energy Navigator	Contract for a local organization to help participants participate in the	**+$500** per unit

[56] Mahone, Amber, et al. "Residential Building Electrification in California." *Energy and Environmental Economics, Inc.* April 2019.
[57] Based on San Joaquin Valley Pilot Proposed Decision budget. "Decision Approving San Joaquin Valley Disadvantaged Communities Pilot Projects." *CPUC*. 9 November 2018.
[58] Mahone, Amber, et al. "Residential Building Electrification in California." *Energy and Environmental Economics, Inc.* April 2019.
[59] For HVAC: cheapest electric option from most expensive gas option ($7k minus $24k) and most expensive electric option from cheapest gas option ($12k minus $20k) "Residential Building Electrification in California," Energy and Environmental Economics, April 2019.
[60] For HPWH: gas storage costs range from $2,000-$2,600 and electric HPWH range from $3,000-$4,700. "Residential Building Electrification in California," Energy and Environmental Economics, April 2019.
[61] "Decision Approving San Joaquin Valley Disadvantaged Communities Pilot Projects." *CPUC*. 9 November 2018.

Low-Income Retrofits		Estimated Cost Difference
	pilot, support engagement in a culturally appropriate manner, provide energy education.	
Bill Savings Protection	Funds to protect residents' bills in case of utility cost increases due to participation in the pilot program.	**+$500** per unit
Estimated Costs of Low-Income Fuel Switching Program		**-$16,600 to +10,700** for appliances **+$2,744 to +$4,256** for electric service panel **+$6,000** for additional retrofits, support, and bill protection

Commercial

New All-Electric Commercial Construction

The 2019 study, "2019 Nonresidential New Construction Reach Code Cost Effectiveness Study," prepared for the California Energy Code and Standards program, estimates costs for new, commercial construction. Modeled building types include medium office buildings, medium retail, and a small hotel. The small hotel can be used as a proxy for high-rise multifamily housing. The study created several packages to estimate costs, including an electric federal code minimum package, an all-electric plus energy efficient package, an all-electric plus energy efficiency and solar package, and a high efficiency electric package.

All-Electric Commercial Building Costs		Estimated Cost Difference
Avoided Gas Infrastructure Costs	Avoiding the gas plan review, service extension, meter, and plumbing offers savings.[62]	**-$18,949** Medium Office **-$28,027** Medium Retail **-$56,020** Small Hotel
Electric Infrastructure Costs	Additional costs associated with electrification include more electric panel capacity and additional wiring.[63]	**+$27,802** for all
Incremental Capital	There is variability in the incremental costs	**-$45,029 to -$96,106** for

[62] "2019 Nonresidential New Construction Reach Code Cost Effectiveness Study." *California Energy Codes & Standards*. 25 July 2019.
[63] "2019 Nonresidential New Construction Reach Code Cost Effectiveness Study." *California Energy Codes & Standards*. 25 July 2019.

Costs of Appliances	associated with all electric systems based on commercial building type and climate zone. There are savings in some places and costs in others[64]	Medium Office HVAC **+$6,256 to -$4,477** for Medium Retail HVAC **-$1,277,845 to -$1,284,121** for Small Hotel HVAC and Water Heating Systems
Operating Costs	Operating costs are highly variable depending on the building type, climate zone, and level of energy efficiency assumed as part of the construction.	*Too variable to provide useful ranges*
Estimated Incremental Cost of All-Electric New Construction[65]:		**-$36,176 to -$87,253** Medium Office **-$21,762 to -$32,113** Medium Retail **-$1,294,276 to -$1,300,552** for Small Hotel

Fuel Switching Retrofits

It is difficult to estimate fuel switching costs for commercial building retrofits because they are highly variable based on existing building characteristics. There are few studies estimating costs of commercial building electrification retrofits, but several examples of successful electrification pilots.

RTUs

At this point, data on electrification conversions is all based on select pilot projects to convert RTUs to heat pumps. Data is incomplete but provides an early indication of project costs. Estimates below draw from a study for the Northwest Energy Efficiency Alliance to retrofit existing HVAC systems, typically gas or electric RTUs, to VRF, multi-zone ductless heat pumps, or split system heat pumps.[66] Pilot projects included a variety of commercial building types, including offices, restaurants, and government buildings.

[64] "2019 Nonresidential New Construction Reach Code Cost Effectiveness Study." *California Energy Codes & Standards*. 25 July 2019.
[65] All Electric Federal Code Minimum Package Costs: "2019 Nonresidential New Construction Reach Code Cost Effectiveness Study." *California Energy Codes & Standards*. 25 July 2019.
[66] Stephens, Charlie. "Very High Efficiency HVAC Systems for Small and Medium-sized Commercial Buildings." *Ventacity*. March 2020. https://tpkhhcn8.pages.infusionsoft.net/?inf_contact_key=bd118d3390f718c7d7e3ee60b3ef8f22680f8914173f9191b1c0223e68310bb1

All-Electric Commercial Building Costs		Estimated Cost Difference
Project Cost Per Square Footage Building Space	Project costs to convert the existing system, if optimized, were low.[67]	**+$15 to +$20** per square foot for most projects.
Operating Costs	Due to the efficiency of replacement heat pumps, electricity demand savings increased compared to previous years, even if space heating was electrified.[68]	**20-40%** electricity demand savings
Estimated Incremental Cost of All-Electric New Construction:		**+$15 to +$20** per square foot *Plus, not estimated, but substantial energy cost savings*

Designing Incentives

New construction of residential and commercial buildings is already cost effective in many cases; however, they are not being built yet as a standard practice in California. Financial incentives to build all electric homes are needed in the short term to encourage technology investment, market growth, and developer and contractor awareness. However, longer term incentives should not be needed to advance electric homes because they are already cost effective. For new construction, short term incentives and then performance standards that require all-electric new buildings may be the most effective strategy.

Incentives are necessary in the short and medium term for existing buildings retrofits. Costs to retrofit existing, low-rise residential buildings from gas to electric space and water heating vary substantially. Two key factors greatly influence the cost effectiveness of heat pumps: (1) existing electric service panel capacity and (2) existing air conditioning system. Insufficient service panel capacity is expensive to upgrade. And it is generally cost effective to retrofit homes with AC to heat pumps, but not for homes without AC. Incentives will need to account for the entire costs to upgrade homes.

Additionally, low income homes need incentives to support adoption of heat pumps, as well as other costs associated with building electrification. Low income programs need to account for

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[67] Stephens, Charlie. "Very High Efficiency HVAC Systems for Small and Medium-sized Commercial Buildings." *Ventacity*. March 2020. https://tpkhhcn8.pages.infusionsoft.net/?inf_contact_key=bd118d3390f718c7d7e3ee60b3ef8f22680f8914173f9191b1c0223e68310bb1

[68] Stephens, Charlie. "Very High Efficiency HVAC Systems for Small and Medium-sized Commercial Buildings." *Ventacity*. March 2020. https://tpkhhcn8.pages.infusionsoft.net/?inf_contact_key=bd118d3390f718c7d7e3ee60b3ef8f22680f8914173f9191b1c0223e68310bb1

additional expenses associated with installing appliances in substandard housing, as well as costs associated with supporting community outreach and utility bill protection.

There are some existing programs that incentivize heat pump adoption. For example, Palo Alto provides up to $1,500 for residents purchasing an efficient HPWH to replace a gas water heater.[69] Sacramento Municipal Utility District (SMUD) offers incentives for residential electrification to encourage all-electric upgrades. SMUD provides incentives for electric appliances (a $2,500 rebate for heat pump space heaters and a $2,500 rebate for HPWHs), efficiency upgrades, and service panel upgrades, totaling up to $13,750 for full electrification.[70]

There are few, existing commercial incentive programs for electric heat pumps. The City of Palo Alto Utilities offers some commercial HPWH rebates and Green Mountain Power in Vermont offers financing for commercial customers to install heat pumps.[71] Additionally, California utilities already offer rebates for many other commercial building energy efficiency measures. Similar programs could be adopted to support commercial heat pump adoption.[72]

[69] "Strategies and Approaches for Building Decarbonization." *Building Decarbonization Coalition*. January 2019.
[70] "Strategies and Approaches for Building Decarbonization." *Building Decarbonization Coalition*. January 2019.
[71] "Strategies and Approaches for Building Decarbonization." *Building Decarbonization Coalition*. January 2019.
[72] "Business Rebate Catalog." *Pacific Gas and Electric.*

VI. Effectiveness

- How effective can incentives be?
- Can incentives deliver enough emissions reductions necessary to achieve our climate goals?

Effectiveness: Emissions Reductions Possible with Incentives

To estimate the potential effectiveness of incentives, I created a model of one sector—low-rise, residential space and water heating—as an example. This is not meant to be a holistic model of all potential strategies or emissions sources, but one example to illustrate the opportunities and challenges associated with relying on incentives to drive fuel switching upon appliance burnout. I forecasted emissions associated with gas use for residential space and water heating in new and existing buildings. I also forecasted the estimated emissions associated with different levels of incentives.

Methodology

To forecast new housing construction in California before 2045, I used California Department of Finance data on new unit housing starts by building size.[73] I assumed a linear increase in housing growth based on an average of the past five years of construction data.

To forecast greenhouse gas emissions of building energy use through 2045, I used energy consumption data calculated from RECS averages, electricity emission factors from the CPUC, and natural gas emission factors from the EPA's "2018 Emission Factors for Greenhouse Gas Inventories."[74] I used the linear forecast of housing growth and assumed energy intensity of new housing was the same as existing housing.

The major inputs to estimate fuel switching include:

1. An estimate of the number of gas space and water heaters that will reach their natural end of life per year.

[73] "Population and Housing Estimates for Cities, Counties, and the State." California Department of Finance. 2020. http://dof.ca.gov/Forecasting/Demographics/Estimates/E-5/

[74] Electricity EFs From: Table 2. "Fuel Substitution Technical Guidance for Energy Efficiency Version 1.1." CPUC. 2019. & "Emissions Factors for Greenhouse Gas Inventories." *EPA*. March 2018. https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf

2. The percent of those appliances that could be incentivized to fuel switch at time of replacement.

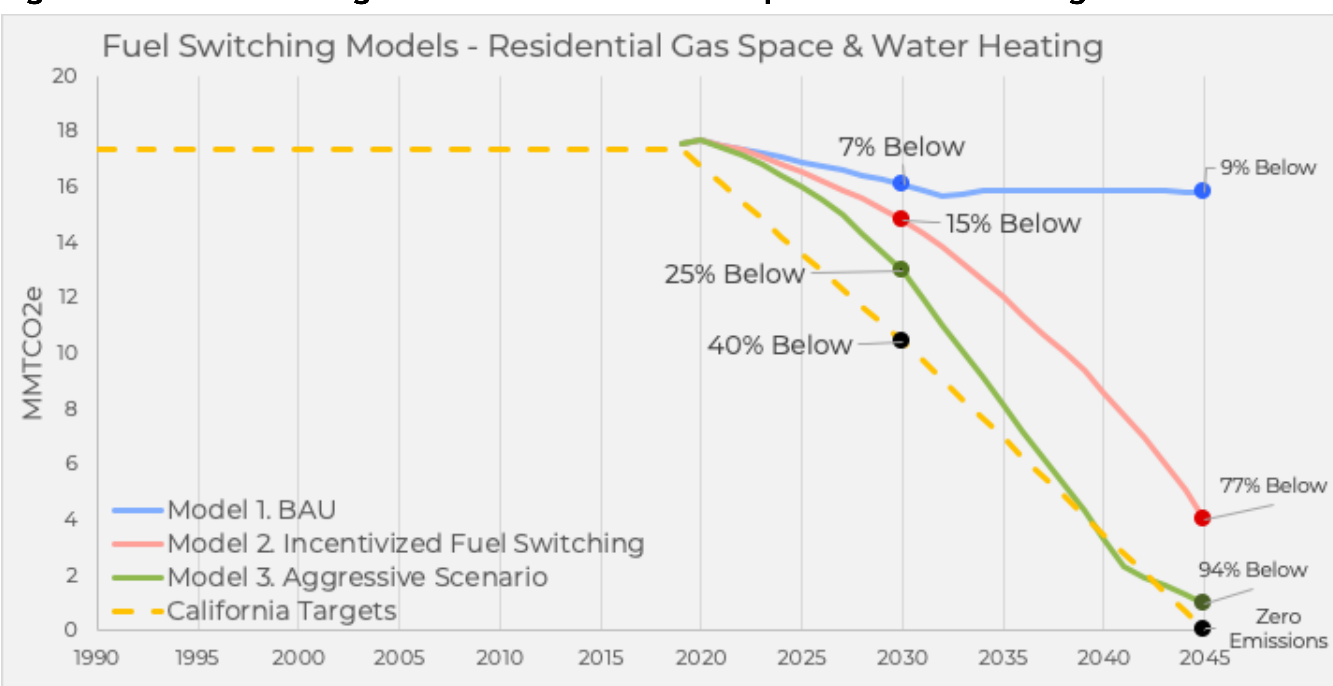
This means the total, aggregate number of space or water heaters that can be fuel switched by 2030 is limited. Even if we started electrifying 100 percent of gas appliances at burnout in 2021, only two-thirds of gas appliances could be electrified by 2030.

I estimated the number of gas space and water heating appliances that will reach their natural end of life per year, based on an assumed lifespan of 15 years. As noted above, this is optimistic. 50 percent of space heaters in rental housing are over 20 years old, well beyond their expected, operational lifespans.

I created three scenarios. Model 1. is a business-as-usual (BAU) forecast which assumes existing renewable energy standards (SB100) and a 15 percent reduction in energy use by 2030 (SB350). The Model 2. presents a moderate scenario using incentives, no preemptive appliance retirement, and very few new homes built with gas. It assumes an S-curve adoption rate for electric appliances. Model 3. is the most ambitious scenario which assumes all new homes are built all-electric and by 2032, 100% of gas appliances are replaced with electric appliances at replacement. This model is not meant to be realistically, but more to illustrate the scale of action required to achieve California climate goals.

Results

Figure 30. Fuel Switching Models - Residential Gas Space & Water Heating



Model 1. Business as Usual	**New buildings**: 25% of new buildings are all-electric by 2023, 50% by 2030, & 100% by 2035 **Existing gas buildings**: buildings are 15% more efficient by 2030, no additional electrification
Model 2. Incentivized Fuel Switching	**New buildings:** 100% of new buildings are all-electric by 2023 **Existing gas buildings:** ● Buildings are 15% more efficient by 2030 ● Linear increase to 33% of space and water heaters at their natural end-of-life are fuel switched from gas to electricity by 2030, 100% by 2045 ● Results in 10% of total gas space and water heaters are electrified by 2030
Model 3. Aggressive Scenario	**New buildings:** 100% of new buildings are all-electric by 2021 **Existing buildings:** ● Buildings are 15% more efficient by 2030 ● Linear increase to 100% of space and water heaters at their natural end-of-life are fuel switched from gas to electricity by 2030 ● Results in 33% of total gas space and waters are electrified by 2030
General Model Assumptions:	Using 2017 data as proxy for 2019 Baseline
	Assume 1:1 ratio of number of units to number of appliances
	Assume fuel type ratios are the same for new construction as existing (64% of new units are gas)
	Assume once unit switches from gas to electric they do not switch back at next appliance replacement

Forecast Takeaways

Although this forecast only models one of many emissions sources in buildings, forecast takeaways are relevant to multifamily residential and commercial buildings as well.

Below are a few key takeaways based on modeled scenarios:

- Assuming a 15 year, predicted lifespan of gas appliances, it will be extremely difficult to rely solely on incentives to drive electrification to meet 2030 emissions reduction goals.
- There is not a realistic pathway to achieve 40% emissions reductions without early retirement of gas appliances.
- To avoid adding additional gas demand, we need to ensure all new buildings are all-electric.

VII. Findings and Recommendations

Key Findings

Market Characterization

Existing Residential Buildings

Almost 80 percent of residential gas consumption occurs in single family homes. Single family homes consume the most gas both per unit and in total.

Among single family homes, relevant characteristics for designing incentives and determining cost include tenure status (rented or owned) and the household income of the occupants. Approximately 77 percent of single-family homes are occupied by their owner and 23 percent are occupied by renters. Other key determinants of cost and incentives include existing use of air conditioning, heating load, and electric and gas utility.

- **Target impact** is the estimated percent of total residential gas consumption for space and water heat.[75]
- **Equity** impacts are rated as high for unit types that are primarily occupied by low income residents and low for units primarily occupied by high income residents.
- **Costs** are highly variable even within housing unit types and tenure status. Costs are rated as low to high based on the cost analysis section and income status. I assume low income retrofit costs are more expensive than moderate to high income retrofits.

Building Type and Unit Characteristics	Target Impact (%)	Equity	Cost
Owned, Single-Family, Mod-High Income	30-40%	Low	Low-Medium
Owned, Single-Family, Low Income	30-40%	High	High
Rented, Single-Family, All Incomes	20%	Medium-High	Low-High

[75] Assume 77 percent of single-family units are occupied by owner and 23 percent are occupied by renters for all income levels. Applied equally to single family high- and low-income homes, but this should likely be weighted more towards low-income single-family homes.

Low-Rise Multifamily	6%	High	Low-Medium
High-Rise Multifamily	11%	High	Unknown
Manufactured Homes	2%	High	Unknown

Existing Commercial Buildings

Existing commercial buildings consume less gas than residential buildings but are still significant gas consumers. By primary building activity, strip shopping malls, health care facilities, offices, and food service buildings consume the most gas. Space heating (45%), water heating (27%), and cooking (20%) are the primary gas end uses. It is difficult to generalize criteria for assessing the impacts of commercial fuel switching incentives due to the variability in building types, technology types, and existing characteristics.

- **Target impact** represents the estimated gas consumption by end use and technology. This is reported qualitatively because we don't have exact estimates of gas consumption by technology type. Most gas space heaters in California are packaged single- or multi-zone systems (approximately 60%).
- **Equity** impacts are estimated to be low for space and water heating end uses. Commercial gas stove equity impacts are estimated to be high. Gas stoves create unhealthy indoor air pollution and cooks who spend all day working over gas stoves are at risk for health impacts.[76]
- **Costs** are highly variable and largely unknown for commercial building retrofits. Costs are rated as low to high. Costs for some, specific space heating technologies and water heating retrofits are unknown.

Building Type and Unit Characteristics	Target Impact	Equity	Cost
Commercial Space Heating, Packaged Single- or Multi-zone	High	Low	Low
Commercial Space Heating, Other Technologies	Low	Low	Unknown
Commercial Water Heating	Medium	Low	Unknown
Commercial Gas Stoves	Medium	Medium-High	Low-Medium

Both new, residential and commercial buildings can be built all-electric, save money, reduce emissions, and advance equity.

[76] Zhu, Yifang, et al. "Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California." *UCLA Fielding School of Public Health*. April 2020.

Equity

Key Takeaways

- ➔ **Low income households require support to pay for fuel switching.**
  The costs of electric appliances and necessary upgrades are expensive. Up-front capital costs are too high for many households to afford, even if fuel switching provides lifecycle cost savings. These homes will need incentives to cover electric infrastructure upgrades. Additionally, low-income households are at risk of being left behind by fuel switching efforts and vulnerable to increasing gas costs. As fuel switching programs are implemented, tracking equity outcomes will be important to ensuring participation.
- ➔ **Gas appliances in rental housing are older than appliances in owned housing and many are far older than their predicted life expectancy.**
  Half of space heating appliances in rental housing are 20 years or older. These appliances are inefficient, resulting in high energy bills for current residents. Additionally, this indicates appliances are not being replaced after their predicted useful life of 15-20 years, which undermines our ability to achieve 2030 emissions reduction goals by relying on fuel switching upon appliance burnout. Landlords do not have a strong incentive to fuel switch because residents pay utility bills, so incentives alone may not be effective. Additionally, low income residents are vulnerable to displacement. Fuel switching programs will need to incorporate renter protections.

Policy Implications

Takeaway	Policy Implications
Low income families need support to fuel switch ➔	**1.** Dedicate funding allocations for fuel switching in low income households. **2**. Design programs to fund household fuel switching, necessary electric and efficiency upgrades, local community engagement, and utility bill protection. **3.** Track and report equity outcomes, develop equity metrics, and adjust funding to ensure fuel switching is accessible for low income households.

Takeaway	Policy Implications
Gas appliances in rental housing are old	**1.** Create a retirement program (like Cash for Clunkers) to retire 20+ year old gas appliances. **2.** Institute performance standards for rental housing and provide incentives for fuel switching in residential housing. **3.** Ensure renter protections as part of incentive programs.

Estimating Costs

Key Takeaways

- **All-electric new construction is cost effective and up-front costs are generally lower than mixed fuel homes.**
  Lifecycle costs for all-electric new construction are currently cost effective for low- and mid-rise residential construction, are likely cost effective for high-rise residential construction (assuming they have similar costs to small hotels), and are currently cost effective for commercial office, retail, and small hotels.
- **Space and water heating fuel switching retrofits are cost effective in many low-rise residential homes.**
  For low-rise, residential homes that do not need electric service panel upgrades and have air conditioning, fuel switching can save upfront costs. In many cases, fuel switching provides operating cost savings. Electric service panel upgrades are expensive ($2,000-$4,000) and it is unknown how many homes will need upgrading.
- **Fuel switching incentives for low-rise, low-income housing units will need to support fuel switching and associated costs.**
  Low-rise residential housing units will require incentives to cover fuel switching costs, including appliance costs, efficiency and electric upgrades, community outreach, and bill protection.
- **Commercial HVAC fuel switching retrofits can be cost effective and reduce operating costs.**
  Data on commercial building fuel switching is limited, but one pilot indicates costs associated with electrifying gas HVAC units are low and reduce utility bills.

Policy Implications

Takeaway	Policy Implications

Finding	Recommendations
All-electric, new construction is cost effective	**1.** Create and distribute funding over the next 5 years to incentivize developers to build all-electric housing units. **2.** Update the building energy code to strongly incentivize and ultimately require efficient and flexible all-electric new construction over the next 5 years.
Retrofits are cost effective in most low-rise residential units	**1.** Create and distribute funding to incentivize low rise residential fuel switching retrofits, electric service panel upgrades, and low-income energy efficiency over the next 5 years to jump-start market development for electric heating appliances. **2.** Invest in training and developing the supply chain to deliver and install electric appliances. **3.** Support and encourage local governments to pilot existing building retrofit programs.
Incentives for low income units needs to cover associated costs	**1.** Ensure incentive programs provide community outreach, home energy efficiency retrofits, and bill protection.
Commercial HVAC retrofits are low-cost and reduce utility bills	**1.** Create and distribute incentives over the next 5 years for HVAC retrofits in commercial buildings to drive adoption of efficient, electric appliances and drive market development. **2.** Institute performance standards in commercial buildings to help ensure appliances are highly efficient.

Effectiveness

Key Takeaways

- **Incentives alone are insufficient to induce sufficient turnover of gas appliances by 2030 to meet statewide emission goals.**
  Even in extremely optimistic scenarios of incentive effectiveness, it will be impossible to rely exclusively on voluntary adoption of electric space and water heating appliances to meet 2030 building emission reduction goals.
- **Growth in gas use due to new construction can undermine the state's ability to meet 2030 emission goals.**
  New construction of homes that use gas for heat offset gains made through fuel switching in existing buildings. Additionally, it is much cheaper to build homes electric than to retrofit them later, so requiring all-electric new construction saves money for the state and homeowners. Electric new construction helps drive market development for heat pumps because every new home will need one.

Policy Implications

Incentives alone are insufficient

1. Advance market development for electric heating technologies and requirements for electric appliance installation as quickly as possible to capture the maximum number of appliance replacements before 2030.
2. Invest in programs to encourage or require pre-emptive retirement of gas appliances.

New, gas construction undermines climate goals

1. Update the building energy code to require all-electric new construction.
2. Implement changes quickly to ensure a minimal number of new gas buildings are constructed.

Other Opportunities

Beyond financial incentives administered by state agencies or utilities, there are several other policy mechanisms at the state and local level that can promote adoption of electric appliances.

There are also other opportunities to target standards and incentives to increase adoption of heat pumps.

Electric-to-Electric, Propane, and Wood Retrofits

One key challenge to rapidly adopting heat pumps is that the market in California is currently underdeveloped. While gas to electric fuel switching is the key target to achieve emission reductions, there are other opportunities to advance adoption of heat pumps. For example, replacing electric resistance heaters with heat pumps provides electricity savings. There are also benefits to focusing on fuel switching existing propane and wood appliances to electric heat pumps.

Fuel switching from propane and wood to electricity improves local air quality. Electric heat pumps would also provide cost savings compared to propane heat. Another opportunity to grow heat pump market penetration is to encourage households installing air conditioning to install an HVAC heat pump. This would provide households with improved heating and cooling capabilities and encourage market development.

Appliance Standards

Fuel switching from gas to electricity provides air quality benefits and would support California's efforts to reduce PM2.5 and ground level ozone, particularly in pollution-burdened communities. Gas appliances release NOx emissions, which enables the formation of harmful, criteria air pollutants. Additionally, combusting gas indoors leads to unhealthy levels of indoor air pollution.[77] State agencies or regional air quality districts could set appliance standards to limit NOX emissions of residential and commercial appliances. This would also result in GHG emissions reductions as well.

Local Government Initiatives

Local governments can advance fuel switching through local code development. Local governments can require all-electric new construction through city ordinances, either banning new gas infrastructure or passing a "reach code" to exceed the state building energy standards. Local governments can also institute programs at crucial intervention points—like time of sale or time of lease—that require appliances to reach certain efficiency standards. Additionally, local governments play a key role in permit enforcement. Many HVAC appliances have been installed without permits, which makes them difficult to regulate. Local governments can require permit verification for all appliances at time of sale or time of lease. This would ensure compliance with state and local building codes.

[77] Zhu, Yifang, et al. "Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California." *UCLA Fielding School of Public Health*. April 2020.

Conclusion

Retrofitting every home and commercial building in California that currently uses gas is a monumental task and essential to address climate change. To meet climate goals, California needs substantial investments, incentives, market development, and ultimately, performance and appliance standards. This challenge presents invaluable opportunities to grow clean energy jobs, ensure all California residents can afford their utility bills, improve the quality of low-income homes, and contribute to healthy air for everyone.

State agencies are beginning to plan for this transition, set long-term goals, and designate funding to incentivize fuel switching. The AB 3232 planning process will serve an essential role in informing ongoing and new efforts to decarbonize buildings. To accelerate fuel switching, the state needs to designate billions of dollars in funding to rapidly provide incentives for adoption of residential and commercial electric appliances. Incentives will play a key role in driving down technology costs and sparking market development, ultimately enabling building performance and appliance standards to ensure the transition to electric heating.

In light of unprecedented layoffs due to the COVID-19 pandemic, it is clear the state will need to spur economic activity and create jobs. Forthcoming state investments are a unique and important opportunity to fund the clean energy transition. Establishing incentives and funding market development to facilitate fuel switching will support economic growth and reduce emissions, ultimately enabling California to be on track to achieving long-term climate goals.

Appendix

1. Existing Funding for Electric Heating Technology Adoption

There are several programs and policies that provide funding for building electrification, however funding is administered through different agencies and programs and not organized into to provide market transformation. The AB 3232 report provides a unique opportunity to set a coordinated vision for building decarbonization and identify the scale of funding necessary to achieve climate goals.

A brief overview on existing programs that fund, or support building electrification are provided below.

➔ SELF GENERATION INCENTIVE PROGRAM (SGIP)

The SGIP Program is administered by the CPUC and provides incentives to fund distributed energy generation. As part of this program, the Commission approved **$41 million** to invest in electric **heat pump water heaters** between 2020 and 2024.[78]

➔ 1477 BUILD and TECH

SB 1477 allocates $200 million to be distributed over four years to fund two programs to incentivize building electrification. The CPUC proposed allocating 40 percent of the $200 million budget to the BUILD program. The BUILD program will aim to increase adoption of near-zero emission building technologies in new, residential housing units. 30 percent of that funding is specifically set aside for low-income residential housing. The TECH program will receive 60 percent of the funding and target market development of electric technologies.[79]

➔ Energy Efficiency Funding

California spends a billion dollars annually on energy efficiency programs. As of August 2019, this funding can now be used to fund fuel switching from gas to electric appliances.[80]

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[78] "Self-Generation Program Revisions Pursuant to Senate Bill 700 and Other Program Changes." *CPUC*. 16 January 2020.
[79] "Proposed Decision Establishing Building Decarbonization Pilot Programs." *CPUC*. 12 February 2020.
[80] https://www.nrdc.org/experts/merrian-borgeson/ca-billion-efficiency-now-open-electrification

➔ Market Transformation Initiatives

The CPUC approved the $250 million over five years for market transformation initiatives on energy efficiency. Among other things, the initiative will include increasing the availability of efficient electric heat pumps.[81]

➔ Energy Savings Assistance Program

The ESA Program provides free, energy efficiency upgrades for low-income households. This includes attic insulation, efficient appliances, and building envelope repairs. This program can provide heat pumps to low income residents.[82]

➔ Low Income Weatherization Program

The LIWP provides low income households with solar PV and energy efficiency upgrades for free.[83]

2. Analysis Overview

RECS 2009

Guide to Spreadsheet

- This spreadsheet uses 2009 RECS microdata, available here: https://www.eia.gov/consumption/residential/data/2009/index.php?view=microdata
    - I chose to use 2009 data because it includes state estimates for California and the 2015 data clumps California with Oregon and Washington.
- I downloaded the RECS microdata and filtered for REPORTABLE_DOMAIN = 26 and copied this selection of data into the **CA_RECS_data tab** (using the entire data set slows down the excel sheet). The **Codebook tab** has the codes for the RECS data. I highlighted ones I used.
    - **Assumption**: I assumed the NWEIGHT column – which is designed to scale up the data for nationwide estimates, was approximately representative of how the data should be scaled to estimate California-wide housing energy consumption. This means our data is not exactly tailored to match California. Notably, there is a significant difference between house heating fuel units with gas in the ACS data vs. the RECS data. If you have suggestions on how to better scale this, let me know! See the **Building check tab.**
- The **CA_RECS_data tab** includes data downloaded from EIA (columns A through AJE). Columns in grey (AJF-AJM) I calculated by multiplying the BTU consumption by the net weight value by 1000 (BTU energy use is reported in thousands).
- The **energy_graphs tab** summarizes data on units by heating fuel. The formulas generally follow the format of summing the weighted btu data (in grey) for each value that meets relevant characteristics.

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[81] https://www.utilitydive.com/news/california-approves-new-energy-efficiency-frameworks-expected-to-boost-emer/569164/
[82] https://www.cpuc.ca.gov/esap/
[83] https://www.csd.ca.gov/Pages/Low-Income-Weatherization-Program.aspx

- The **emissions_graphs tab** calculates emissions using data from the **Emissions assumptions tab**. For electricity calculations, I convert MMBtu consumption to MWhs and estimate emissions using 2019 emission factors in million metric tons CO2e/MWh. For other fuels, I estimated total MMTCO2e per MMBtu using the EPA's Emission Factors for Greenhouse Gas Inventories, copied on the (**EPA_EFs tab**).
- **income categories tab -** I estimated income categories using the California Dept. of Housing and Community Development income limits: https://www.hcd.ca.gov/grants-funding/income-limits/index.shtml. I retrieved CA median income from here: https://www.huduser.gov/portal/dataset/fmr-api.html and categorized income categories to approximate the AMI ranges.

CBECS 2012

Guide to Spreadsheet

- This spreadsheet uses 2012 CBECS microdata available here: https://www.eia.gov/consumption/commercial/data/2012/index.php?view=microdata
- I filtered for census region 9, "Pacific," which includes CA, OR, and CA. This data is in the **tab CBECS_2012.** The codebook is in the **CBECS_codebook tab**.
    - I weighted energy consumption (in BTUs) and square footage in the grey and green columns AQC-ARM.
- The **graphs tab** has graphs on energy use and emissions organized by principle building activity. The formulas generally follow the format of summing the weighted btu data (in grey) for each value that meets relevant characteristics. I also estimate emissions on this tab. For electricity calculations, I convert MMBtu consumption to MWhs and estimate emissions using 2019 emission factors in million metric tons CO2e/MWh. For other fuels, I estimated total MMTCO2e per MMBtu using the EPA's Emission Factors for Greenhouse Gas Inventories, copied on the (**EPA_EFs tab**). See the **Emissions assumptions tab** for assumed values.
- The **scaling by pop tab** estimates the portion of buildings attributable to California, based on the populations of OR, WA, and CA.
- The **Res_Comm** graph tab summarizes data from the 2017 GHG inventory, estimated residential emissions from the RECS data analysis, and commercial data.

Target Setting_v1

Methodology

Residential space and water heating gas use totals (top total MMBtus) and percentages (far left columns) are based on the EIA's 2009 Residential Energy Consumption Survey microdata. 2009 gas use is a reasonable proxy for current gas use; 2020 gas use is estimated to be 1.8 percent less than 2009 gas use.[84]

[84] Table 3: Comparison of CED 2017 Revised and CED 2015 Mid Case Demand Baseline Forecasts of Statewide End-User Natural Gas Consumption: "California Energy Demand 2018-2030 Revised Forecast - Docket 17-IEPR-03." *California Energy Commission*. February 2018.

To create greenhouse gas reduction targets for gas use, I forecasted both back, to 1990, and forward, to 2030 to estimate gas consumption using the IEPR energy demand forecast mid-energy demand scenario.[85] I used the AB 3232 target to calculate a 40 percent reduction in emissions from 1990 and estimate the 2030 emissions reductions target. I estimated baseline gas use per sector (residential or commercial), by end use (space and water heating and commercial cooking) and by building type. I assumed there was one appliance per unit to calculate the emissions reductions needed per unit.[86]

I then estimated the emissions reductions possible by converting from gas to electric appliances. I used natural gas emissions factors from the EPA.[87] I used electricity emission factors forecasted out to 2030 that take into account RPS standards.[88] To estimate the impact of switching from gas to electric appliances in terms of energy use, I made the following assumptions about gas and electric appliance efficiency.

Efficiency estimates for gas and electric appliances (percentage of energy delivered converted to heat)		
Efficiency of Gas Appliances	Space heating	80%
	water heating	60%
	Cooking	30%
Efficiency of Electric Appliances	Residential Electric Heat Pumps	250%
	Residential Electric HPWH	250%
	Commercial Electric Heat Pumps	300%
	Commercial Electric HPWH	250%
	Electric Cookstoves	80%

Based on the efficiency of electric replacements, I took into account increased electricity emissions due to fuel switching. Simply eliminating 40 percent of gas use does not achieve a 40 percent reduction in emissions due to the associated increase in electricity use (and electricity emissions). This is partially due to increased gas use between 1990 and 2009.[89]

[85] Table 3: Comparison of CED 2017 Revised and CED 2015 Mid Case Demand Baseline Forecasts of Statewide End-User Natural Gas Consumption: “California Energy Demand 2018-2030 Revised Forecast - Docket 17-IEPR-03.” *California Energy Commission*. February 2018. file:///Users/Olivia/Downloads/TN223244_20180419T154213_California_Energy_Demand_20182030_Revised_Forecast%20(1).pdf
[86] Note that for multifamily buildings that use central space or water heating, you may only need to replace one appliance to achieve fuel switching emissions reductions in several units.
[87] Gas emissions estimated to be 53.1145 kg CO2e per MMBtu from: “Emissions Factors for Greenhouse Gas Inventories.” *EPA*. March 2018. https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf
[88] Electricity emissions factors from Table 2. "Fuel Substitution Technical Guidance for Energy Efficiency Version 1.1." *CPUC*. 2019.
[89] “California Energy Demand 2018-2030 Revised Forecast - Docket 17-IEPR-03.” *California Energy Commission*. February 2018.

To meet the 40 percent reduction from a 1990 baseline goal, taking into account associated, increased electricity emissions, I estimate we would need:

Total 40 percent reduction in emissions by 2030 from 1990 baseline:

- 60 percent of residential gas space heating units to fuel switch
- 54 percent of residential gas water heaters to fuel switch
- 55 percent of commercial gas space heating
- 53 percent of commercial gas water heating
- 63 percent of commercial gas cooking

Guide to Spreadsheet

Target Setting_v1

- This spreadsheet uses data from both the RECS 2009 Spreadsheet and CBECS 2012 spreadsheet to estimate the emission reduction potential from fuel switching

Gas Use

- The **Target Set tab** starts with data copied from RECS data on gas consumption by housing unit type (2009) and CBECS data on gas consumption by end use (2012).
- I then used the IEPR forecast to estimate both 1990 gas consumption (forecasted backwards) and 2030 data (forecasted forward). On the **IEPR gas demand tab**, I used Mid Energy Demand Estimates from Table 3. from the CED 2017 forecast. I created annual estimates for 1990-2030 based on the 2017 average annual growth rates. I then calculated the total change between years 1990-2009 and 2009-2030 (for residential gas use) and 1990-2012 and 2012 for 2030 (for commercial gas use). I used this total percent change in gas use to forecast gas consumption (MMBtus) backwards and forwards on the **Target Set tab**.

Emissions

- I calculated emissions for gas use using the MMTCO2e/MMBtu natural gas emissions factor from the **Emissions assumptions tab**. (This is calculated from EPA emission factors in the Model spreadsheet).
- I estimated an emission target 40% below 1990 emissions – labeled "Target"

Conversions

- The conversion step converts all gas consumption forecasted for 2030 to electricity, modelling what would happen to emissions if all gas was fuel switched.
- This uses assumptions and emissions factors detailed on the **Emissions assumptions tab.**
- I assume the electricity emissions factor is .168 metric tons CO2/MWh in 2030 from: *Table 2. "Fuel Substitution Technical Guidance for Energy Efficiency Version 1.1." CPUC. 2019.*
- I calculated associated electricity emissions from fuel switching by converting assumed reductions in gas use to increases in electricity using the following equation:

MMBtus x Efficiency of Gas Appliance x Conversion factor of MMBtus to MWh / Efficiency of Electric Appliance x Electricity Emission Factor = *Electricity Emissions Associated with Fuel Switching*

- I calculated the increase in electricity emissions associated with the decrease in gas consumption for space and water heating

Target Setting

- I then calculate the reduction target in natural gas necessary to achieve the 40% below 1990 baseline target.
- I used the Goal Seek function in Excel to find the necessary reduction target, taking into account the associated increase in electricity emissions for residential space heating, water heating, and commercial gas use.

Turnover Required by 2030

- In this section, I work backwards from the amount of gas we need to reduce to estimate the number of units per sector and building type we need to fuel switch by 2030.
- I use the average per unit gas consumption from RECS data to calculate the number of units by building type
- I use commercial square footage from CBECS data to estimate the number of square footage to fuel switch by 2030