CALIFORNIA BUILDING DECARBONIZATION

WORKFORCE NEEDS AND RECOMMENDATIONS

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UCLA Luskin Center for Innovation

INCLUSIVE ECONOMICS

AUTHORSHIP

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DISCLAIMER

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EXECUTIVE SUMMARY

This study is the first to estimate the potential employment impacts of building decarbonization, which has been identified by the California Energy Commission and California Air Resources Board as a core strategy to achieve California's long-term climate goals. Building decarbonization requires both energy efficiency improvements and reducing the use of fossil fuels in residential and commercial buildings.

Greenhouse gas (GHG) emissions from California's buildings sector account for more than a quarter of the state's total emissions. Direct emissions from building fossil fuel use account for 10–15 percent of the total. These emissions result primarily from both the combustion of gas in buildings for cooking, heating, and water heating as well as from methane leaks throughout the gas distribution system. Reducing building emissions requires reducing the quantity of natural gas delivered to and used in buildings. Replacing gas with efficient electric appliances in existing buildings and constructing new building as all-electric is the primary approach to building decarbonization. This is referred to as building electrification, which is the main focus of this paper.

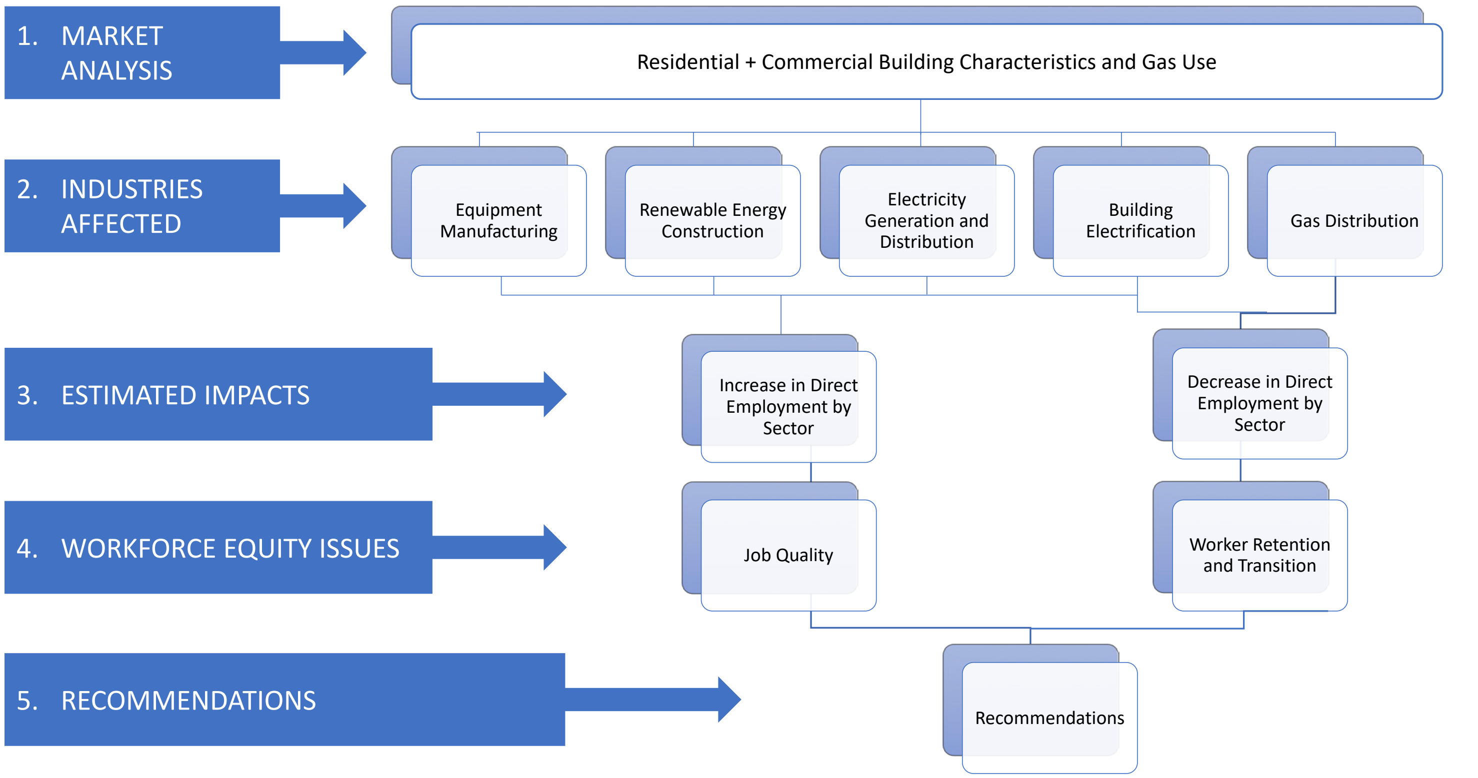
Building electrification will impact several employment sectors. Most obvious is growing the work performed in the process of electrifying more than 14 million homes and more than 8 billion square feet of commercial building space in California; construction jobs associated with efficiency improvements, building modifications, and equipment installations. In addition, there may be jobs in the manufacturing of electrical equipment and appliances needed for installation. There is also work required to ensure that the electricity system can support new demand loads driven by building electrification, which may require new renewable energy and grid infrastructure. Utility jobs to support increased electricity sales represent another area of job growth.

In addition to the increased demand for workers in these areas, there will be a reduced need for workers in other areas. All-electric new construction of buildings eliminates the need for plumbers and pipefitters to extend gas lines and connections; and reduced gas sales could cut the number of utility workers needed to provide gas service to customers, depending on the pattern of reductions. This study assesses all of these impacts.

To guide workforce planning and engagement, this study discusses the distribution of the positive and negative employment effects by market segment and by industry. It provides recommendations for engaging skilled and trained workers in the transition to clean energy generation and electric buildings. Suggestions to minimize and mitigate potential job losses from decreased natural gas consumption are also presented.

ES Figure 1 shows the summary of the study scope. A more detailed graphic on the scope and steps taken to derive employment estimates is provided in Appendix A. Study Scope and Steps.

ES Figure 1. Summary of Study Scope



METHODOLOGY

To estimate the employment effects of building decarbonization, we first calculated market potential by residential and commercial building structure, use, and gas consumption. We identified typical decarbonization pathways for each building type and estimated the cost of each and the total cost of decarbonization based on market potential. We also calculated the change in demand for gas and electricity. Using the economic modeling program IMPLAN, we allocated these cost estimates across relevant industries to determine the direct employment effects from these changes in spending. This allocation is shown in Appendix H. IMPLAN Inputs.

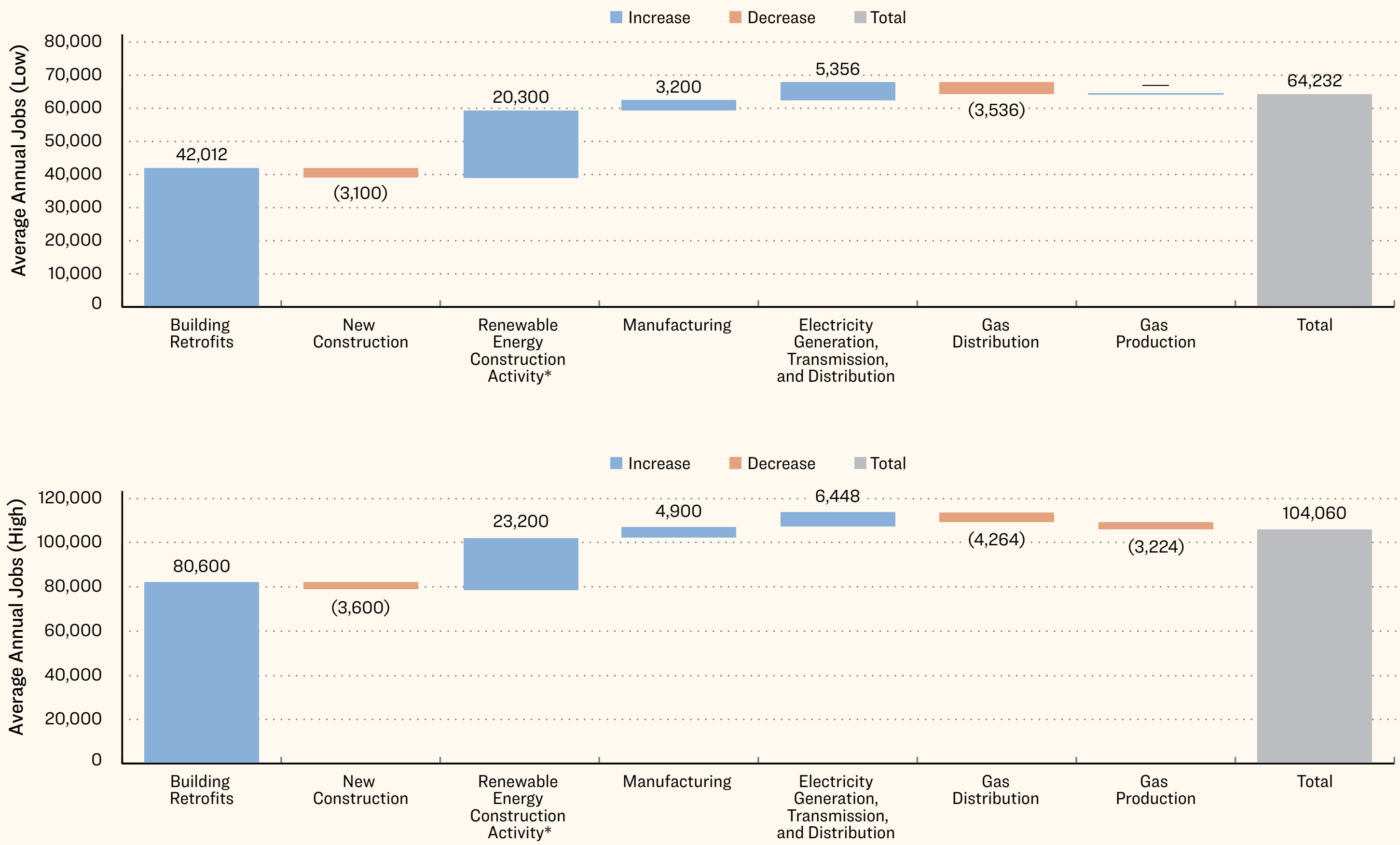
FINDINGS

This analysis reveals that the estimated investments required to electrify 100 percent of California's existing and new buildings — a goal aligned with Governor Brown's 2018 Executive Order B-55-18, which calls for carbon neutrality (zero net GHG emissions) by 2045 — would require over 100,000 full time workers in the construction industry (even after accounting for the labor savings of all-electric new construction) and up to 4,900 full-time manufacturing workers. By 2045, assuming the state has achieved full building electrification, there could be an additional 12,400 full-time electricity generation and distribution jobs and 5,400–6,800 fewer full-time gas distribution jobs.[1]

California imports 90 percent of the natural gas it uses, so the state could eliminate gas in buildings without reducing in-state oil and gas production jobs at all. Eliminating commercial and residential gas use would reduce statewide gas use by only 30 percent, and this could be fully achieved by reducing gas imports. At most, building electrification could result in 6,200 fewer in-state gas extraction jobs.[2]

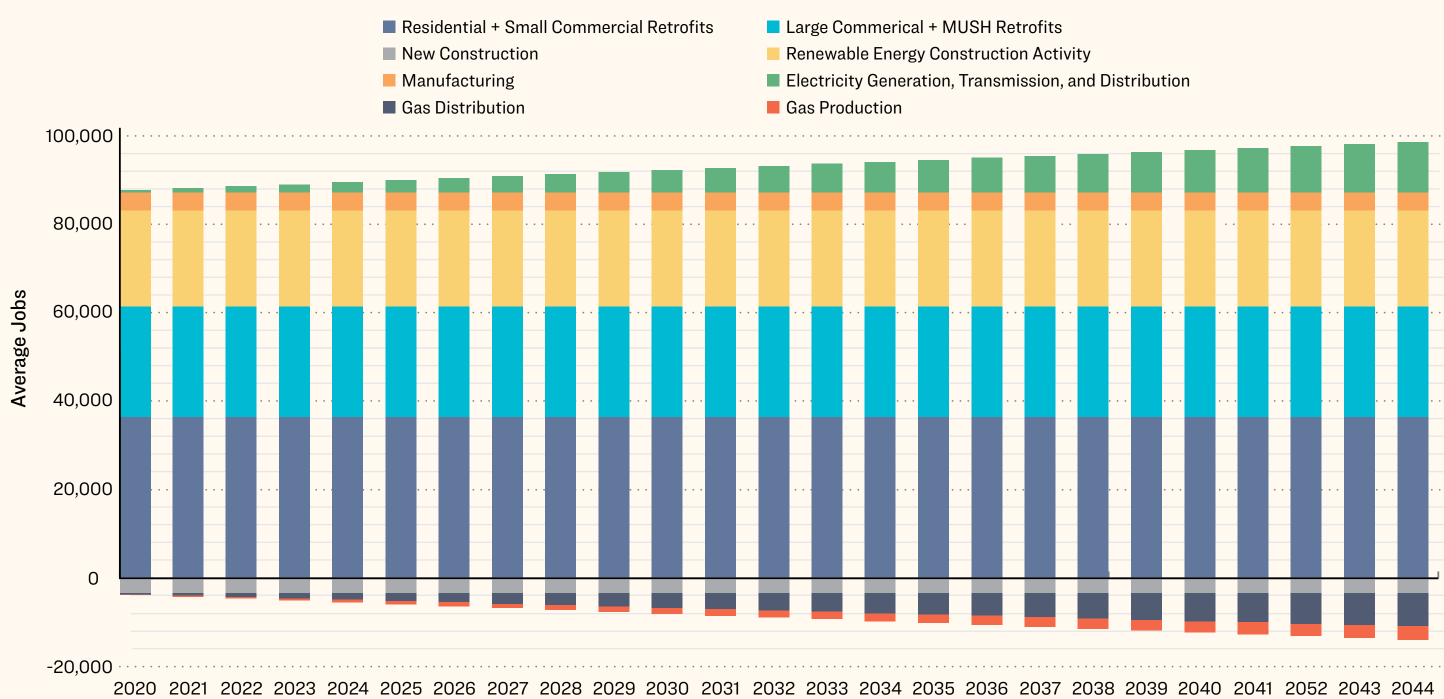
These findings are detailed by sector in the tables below.[3] In total, building electrification in California could support an average of 64,200–104,100 jobs annually, after accounting for losses in the gas industry. *ES Figure 2* shows the average annual employment impacts by industry. The average annual jobs (Figure 2) are slightly different from the total job impacts upon 100% electrification shown in the tables. The areas of greatest increase are building retrofits and renewable energy construction, while the greatest decrease is in gas distribution followed by labor-saving all-electric new construction (but these negative impacts are much smaller than the positive impacts.)

ES Figure 2. Employment Impacts by Industry, Low and High Estimates (Average Annual)



ES Figure 3 shows the average employment impacts by industry, by year. This assumes that the construction activity involved in electrifying buildings takes place at a uniform rate, but that as energy demand shifts from gas to electricity, more workers are required to meet increasing electricity demand and fewer are needed to meeting decreasing gas demand. The majority of the work, shown by the blue sections of the columns, is in building retrofits.

ES Figure 3. Average Annual FTE Jobs Due To Building Electrification



ES Table 1. Potential Employment Impacts — Construction (Excluding Operations and Maintenance)		
Type of Work	**Sector**	**Average Annual Change in Employment (2020–2045)*** **
Existing Building Electrification Construction Activity	Residential Retrofits	26,000–39,300
	Small and Medium Commercial Retrofits	1,700–4,500
	Large Commercial and Municipal, University, School, and Hospital (MUSH) Retrofits **	11,000 –30,900
	District Energy Systems[4],**	3,300–5,900[5]
	Subtotal	**42,000–80,600**
All-Electric New Building Construction Activity	All-Electric New Residential Construction	(3,100)–(3,600) *
Renewable Energy Construction Activity*	Solar Photo Voltaic**	16,400–18,800
	Land-based Wind**	1,000–1,100
	Geothermal**	600–700
	Infrastructure for Grid Connectivity**	2,300–2,600
	Subtotal	**20,300–23,200**
CONSTRUCTION TOTAL		**59,200–100,200**

Note: Construction jobs include both blue- and white-collar workers, in a ratio of approximately 2:1, respectively.

**This study assumes that all-electric new residential construction is less expensive than gas-dependent construction due, in part, to the avoided cost of natural gas piping associated with the service and meter connection. These avoided costs translate to reduced labor requirements. In the commercial sector, the cost difference between mixed-fuel and all-electric buildings is minor, so this study does not project a net change in employment for commercial new construction, although some work would shift from plumbing to electrical work.*

***These are sectors with the greatest opportunity for construction union participation.*

**** In this study, a "job" is a full-time equivalent (FTE). Some jobs in construction and manufacturing are "temporary" resulting from one-time investments, and other jobs in maintenance and energy distribution are "permanent" because they are sustained by ongoing annual spending. In order to use common nomenclature, "temporary" and "permanent" jobs are reported together as average annual jobs from 2020–2045 or annual jobs in 2045.*

The projected increases in employment shown in *ES Table 1* reflect the increased investment needed to fully decarbonize California's residential and commercial buildings. Much of this work involves building construction activity to install new circuits, plumbing, ductwork, and appliances. It also involves construction work to expand electricity generation capacity to meet new electric demands.

In addition to construction jobs, building decarbonization is very technology dependent requiring manufacturing new equipment. In this sector, building decarbonization could support 3,200–4,900 jobs annually as shown in *ES Table 2* or more if in-state manufacturing were to grow.

ES Table 2. Potential Employment Impacts — Manufacturing		
Type of Work	**Sector**	**Average Annual Change in Employment (2020–2045)**
Manufacturing	Large Electric Appliances and Equipment	3,200–4,900

Note: Electrification requires swapping out gas appliances for efficient electric ones. If more electric appliances were manufactured in California, the state could see an increase in jobs.

Adding electricity load and shrinking gas throughput will affect energy production and delivery operations. *ES Table 3* shows that, full building electrification could add 10,400–12,400 direct jobs in electricity generation and distribution. *ES Table 4* shows that this would have a negative effect of 6,800–14,400 jobs in the gas industry, including up to 6,800 gas utility workers.

ES Table 3. Potential Employment Impacts — Electricity Generation and Distribution		
Type of Work	**Sector**	**Change in Employment (2045)***
Electricity Generation, Transmission, and Distribution	Solar	3,800–4,900
	Wind	900–1,000
	Geothermal	500–600
	Out-of-state	NA
	Distribution and Transmission	3,600–4,100
	Public Purpose Charge and Other	1,500–1,800
	Subtotal	**10,400–12,400**

**These jobs are estimated from the annual sales of energy; therefore, they are assumed to be ongoing jobs. The number here, is the total estimated upon reaching 100 percent building electrification.*

ES Table 4. Potential Employment Impacts — Gas Distribution

Type of Work	Sector	Change in Employment (2045)*
Gas Extraction and Distribution	Core Procurement	0–(6,200) TOTAL** [0–(2200) blue-collar] [0–(4,000) white-collar***]
	Transmission, Distribution, and Storage	(5,400)–(6,800) TOTAL**** [2,200–2,900 blue-collar] [3,200–3,900 white-collar]
	Public Purpose Charge	-1,400
Extraction and Distribution Total	Employment upon full building electrification	(6,800)–(14,400) TOTAL [(2,200)–(5,100) blue-collar] [(3,200)–(7,900) white-collar]

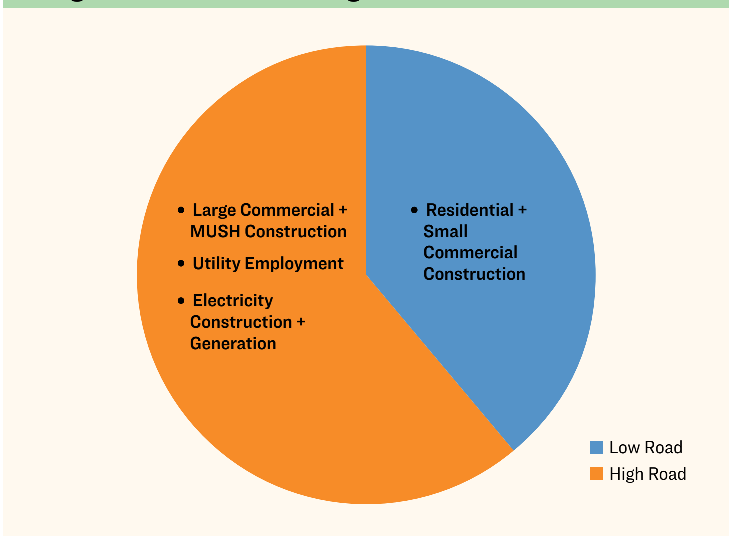
**These jobs are estimated from the annual sales of energy; therefore, they are assumed to be ongoing jobs. The bottom line total, is the total loss of jobs by 2045 upon reaching 100% electrification.*

*** California imports 90 percent of the natural gas it consumes, and could reduce the statewide use of gas by 90 percent without affecting in-state gas extraction jobs. The high end of this range is the current jobs associated with building gas use. Public policy and economics will influence the ratio of fossil fuel imports going forward.*

****This range assumes that a 100% building electrification target would cause a 75–100% reduction in the workforce related to residential and commercial building sales.*

***** The division of blue- and white-collar workers is based on Quarterly Census on Employment and Wages data. Blue-collar workers have skills more specialized to the natural gas industry, while white-collar workers have skills that can be readily deployed in other industries.*[6]

ES Figure 4. Distribution of High-Road and Low-Road Jobs



As *ES Figure 4* shows, three out of five jobs required to meet building electrification goals would be in "high-road" sectors, in which firms compete on the basis of skill, experience, and qualifications and worker pay tends to increase with training and experience. Two out of five jobs would be in traditionally "low-road" sectors in which low cost is the primary driver of competition between firms, and there are low barriers to entry and high turnover of workers.

This is distribution between high-road and low-road jobs is due, in part, to the need for new electricity generation capacity to meet increased demand. The right set of policy interventions can reform the competitive dynamics in in traditionally "low-road" industries like residential and small-commercial construction to improve the quality of jobs and engage more highly skilled workers. Such efforts are not necessarily compatible with lowest upfront cost work, but they do help ensure quality work is performed resulting in satisfied customers, accelerated market transformation, and availability of skilled workers.

Despite the promise of building electrification as a fundamental GHG emission mitigation strategy, there is not yet a clear policy mechanism or plan to achieve the gas reductions needed by 2045. Costs, warmer weather, and climate concerns will continue to nudge consumers to reduce their gas use. This decline in gas sales could raise gas prices further for remaining customers, accelerating further shifts away from gas for consumers able to invest in alternatives. This feedback loop likely will destabilize the gas industry, with severe consequences for the state's businesses, workers, and residential customers. Industry destabilization can, and should, be avoided with sound planning and the right set of policy tools.

RECOMMENDATIONS

California policy makers should aim to expand high-road opportunities that offer family-sustaining wages, benefits, and job security for workers. Because they procure services — climate and energy agencies, utilities, and local governments exert the most influence on the labor market through demand-side strategies. By establishing (or failing to establish) workforce standards, agencies set the bar for the level of skill and training of workers in the labor market, particularly in emerging industries. Agencies can, with deliberate effort, support high-road workforce development, or they run the risk of inadvertently supporting a low-road environment. Often, concerns about project costs lead to decision makers seeking ways to reduce soft costs—especially for labor.[7] But reducing labor expenses has high costs for society, for individual workers, and for businesses that train and employ skilled workers.[8]

The ten recommendations in this study fall into three basic categories: **(A)** Engage affected workers and unions; **(B)** Prioritize demand-side strategies; and **(C)** Target investments in supply-side (training) strategies. The demand and supply-side strategies can be implemented at the local level, where building decarbonization work is already underway. Transition planning is best managed at the utility or state level.

A) Engage with Affected Unions to Grow Good Jobs and Minimize Job Loss

1. **Create conditions that attract skilled workers.** Engage local building trades councils and Labor Management Cooperation Committees (LMCCs) to identify where goals align. Building electrification is complex work requiring skilled and trained building professionals across a range of occupations. The building trade unions and their signatory contractors co-invest in the best-in-class training for construction professionals: apprenticeship. Working with apprenticeship coordinators to ensure training curriculum covers electrification work and technology presents a solid path to developing a skilled and trained workforce for this work. Furthermore, ensuring work opportunities for apprenticeship-trained workers ensures those skills and knowledge will be deployed in real-world environments.

2. **Plan an orderly transition.** Engage labor, ratepayer advocates, utilities, and other stakeholders and experts in long-term planning process. The goal is to methodically contract and eventually decommission the natural gas distribution system in California in a way that is safe, economical for remaining customers, and minimizes worker displacement. This should include avoiding new investments in gas system expansion that will not be recoverable.

3. **Develop a fund for gas worker retention and transition assistance.** Worker transition assistance should include bridges to retirement for older workers and wage replacement, retraining, and job placement assistance for younger workers. In addition, as California's natural gas system is condensed, it is paramount to retain a skilled and trained workforce to ensure safety and reliability of the system as it contracts.

B) Prioritize Demand-side Strategies

Demand-side interventions to support high-road employment include: investing in high-road sectors and opportunities (those that require and appropriately compensate a skilled and trained workforce), aggregating smaller projects, and establishing workforce standards for programs and policies. Local jurisdictions should:

4. **Pre-qualify contractors.** Agencies can help to stimulate market transformation and improve consumer confidence by pre-qualifying contractors as eligible to receive public or ratepayer incentives for heat pump or other electrification appliances.[9] Ideally, this would be coordinated at the statewide level, but individual jurisdictions could also implement a contractor vetting process.

5. **Condition incentives on skill standards or offer incentives (i.e., accelerated permitting, financial remuneration, etc.) for projects that meet certain workforce criteria.** Condition rebates and incentives for electrification on skill standards and/or responsible contractor criteria to attract high-performing contractors, ensure work quality, and prevent wage and labor law violations common in the residential construction market. Heating, ventilation, and air conditioning (HVAC) skill standards should be applied to building decarbonization policies and programs at all levels (i.e., local government and utility programs, Title 24 building code compliance, state policy, etc.)[10]

6. **Lead with the large commercial and municipal, university, school, and hospital (MUSH) sector.** The large commercial and MUSH sector draws workers from registered apprenticeship programs and the unionized construction workforce. By

prioritizing decarbonization and electrification in this sector, the state can utilize the best-in-class training for skilled construction workers and seed a qualified electrification workforce in California. Through project labor agreements or community workforce agreements, these projects can provide training opportunities for workers facing barriers to employment.

7. **Pursue aggregated community-scale decarbonization.** Targeting projects in regions or neighborhoods planned for new natural gas infrastructure or in need of upgrades is a smart way to "prune" the natural gas distribution system and minimize future stranded assets. Aggregating or bundling small commercial and residential projects can improve the economies of scale, reduce contractor marketing expenses, accelerate market adoption, and enforce skill standards to enhance both the quality of the work performed and the quality of jobs for workers. Geographic pilots should adopt and enforce prevailing wage and targeted hire standards to improve job quality and access for disadvantaged workers.

8. **Invest in decarbonized district energy.** Decarbonization of existing and the expansion of new district energy systems provide a carbon-free pathway to create and sustain good jobs for California's gas workers, plumbers, and pipefitters as well as a new line of business for gas utilities. Like the gas system, district energy systems rely on underground networks of pipes, but instead of moving gas, they move hot water to provide heating and cooling directly to buildings. District energy systems can be powered by a wide array of renewable energy sources, reducing reliance on the electric grid, and their use could be expanded beyond current applications to new residential developments, redevelopment zones, campuses, business parks, and whole neighborhoods. (See Decarbonized District Energy Addendum for more information).

C) Target Investments in Supply-side (Training) Strategies

Most people think about workforce development as a set of training programs and activities, but it is important to recognize that only when training is calibrated to market demand do positive outcomes ensue. Creating stand-alone training programs or over-investing in training, can lead to negative results in the labor market, such as flooding it with more workers than there are jobs, suppressing wages, and diluting the skill of the workforce. Thoughtfully targeted training interventions can avoid these outcomes and more effectively support clean energy goals. Local jurisdictions should:

9. **Support the up-skilling of workers through stackable credentials.** Workforce training is needed to support quality work: however, specialized training should be used in addition to (not instead of) broad occupational training. The trades most needed for building decarbonization are electricians, sheet metal and HVAC workers, and plumbers and pipefitters. Building decarbonization training will be most effective if it is targeted to workers with licenses in these trades rather than to general contractors or other market actors. Programs like California Advanced Lighting Control Program (CALCTP), a training for electricians for advanced lighting controls, or Electric Vehicle Infrastucture Training Program (EVITP) for electric vehicle infrastructure, are good examples of the type of stackable credential training that will likely by most effective for building electrification.

10. **Structure the work to create opportunities for disadvantaged workers.** Support high-road construction careers (HRCCs) for construction and develop high-road training partnerships (HRTPs) for manufacturing and other skills needed for building decarbonization. California's HRCCs and HRTPs work to improve job access for disadvantaged workers and support their career development. Community-based organizations are well-positioned to serve the specific needs of individuals in their communities. When these frontline training organizations have formal agreements with employers, agencies, and apprenticeship programs, better job training and placement outcomes are achieved. Forging stronger partnerships between different facets of the workforce development and support system is key to improving outcomes for disadvantaged workers.

Pursuing a high-road path to building electrification can further demonstrate California's commitment to broadly shared prosperity in a low-carbon future.

CALIFORNIA BUILDING DECARBONIZATION

WORKFORCE NEEDS AND RECOMMENDATIONS

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TERMINOLOGY

C-4 License, Boiler, Hot Water Heating, and Steam Fitting Contractor	A boiler, hot-water heating and steam fitting contractor installs, services, and repairs power boiler installations, hot-water heating systems and steam fitting, including fire- and water-tube steel power boilers and hot-water heating low pressure boilers, steam fitting and piping, fittings, valves, gauges, pumps, radiators, convectors, fuel oil tanks and lines, chimneys, flues, heat insulation and all other equipment associated with these systems, including solar heating equipment.
C-20 License, Warm-Air Heating, Ventilating, and Air-Conditioning Contractor	A warm-air heating, ventilating and air-conditioning contractor fabricates, installs, maintains, services, and repairs warm-air heating systems and water heating heat pumps, complete with warm-air appliances; ventilating systems complete with blowers and plenum chambers; air-conditioning systems complete with air-conditioning unit; and the ducts, registers, flues, humidity and thermostatic controls and air filters in connection with any of these systems. This classification shall include warm-air heating, ventilating and air-conditioning systems which utilize solar energy.
C-10 License, Electrical Contractor	An electrical contractor places, installs, erects, or connects any electrical wires, fixtures, appliances, apparatus, raceways, conduits, solar photovoltaic cells or any part thereof, which generate, transmit, transform, or utilize electrical energy in any form or for any purpose.
C-36 License, Plumbing Contractor	A plumbing contractor provides a means for a supply of safe water, ample in volume and of suitable temperature for the purpose intended and the proper disposal of fluid waste from the premises in all structures and fixed works. This classification includes but is not limited to: *(a)* Complete removal of waste from the premises or the construction and connection of on-site waste disposal systems; *(b)* Piping, storage tanks, and venting for a safe and adequate supply of gases and liquids for any purpose, including vacuum, compressed air and gases for medical, dental, commercial, and industrial uses; *(c)* All gas appliances, flues, and gas connections for all systems including suspended space heating units. This does not include forced warm air units; *(d)* Water and gas piping from the property owner's side of the utility meter to the structure or fixed works; *(e)* Installation of any type of equipment to heat water, or fluids, to a temperature suitable for the purposes listed in this section, including the installation of solar equipment for this purpose; and *(f)* The maintenance and replacement of all items described above and all health and safety devices such as, but not limited to, gas earthquake valves, gas control valves, back flow preventers, water conditioning equipment, and regulating valves.
Combined Heat & Power (CHP)	The use of heat engine or power station to generate electricity and useful heat at the same time. This is also called co-generation.
District Energy	Hot water (heated from waste heat, electricity, geothermal, sewer heat, or other renewable source) in a central plant and moved through a network of underground pipes and heat exchangers in buildings to serve a large number of buildings' heating, cooling, and hot water needs.
GHGs	Greenhouse gases, including carbon dioxide, methane, and others.
Heat Pump	A device that extracts heat from a source and transfers it to a sink at higher temperature, moving heat against the spontaneous flow of thermal energy.
Heat Recovery Chillers	A device specifically designed to remove heat from a liquid.
High-road	A description of work in which skill, experience, and work quality are key elements driving competitive dynamics between firms.
HVAC	Acronym for heating, ventilation, and air conditioning.
IMPLAN	An economic impact assessment system developed and maintained by the Minnesota IMPLAN Group.
Job-year	One full-time job equivalent for one year. A job year is typically equal to 2080 work hours.
Low-road	A description of work where low cost is the key element driving competitive dynamics between firms.
MUSH	Acronym for municipal, university, school and hospital facilities

INTRODUCTION

This study is the first to estimate the potential employment impacts of building decarbonization, which involves both energy efficiency improvements and reducing the use of fossil fuels in residential and commercial buildings.

Direct emissions from fossil fuel use in buildings account for 10–15 percent of California's total greenhouse gas (GHG) emissions.[i] These emissions result primarily from both the combustion of gas in buildings for cooking, heating, and water heating as well as from methane leaks throughout the gas distribution system. Reducing building emissions requires reducing the quantity of natural gas delivered to and used in buildings. Replacing gas with efficient electric appliances in existing buildings and building new all-electric is the primary approach to building decarbonization. This is referred to as building electrification, which is the main focus of this paper.

Building electrification has been identified by researchers, the California Energy Commission (CEC) and California Air Resources Board (CARB) as a core strategy to achieve California's long-term climate goals.[11,12] In 2018, Energy and Environmental Economics, Inc. (E3) published a paper examining the GHG emissions reductions possible with a variety of technologies and mitigation strategies, and determined that a high-electrification scenario — using high-efficiency heat pumps for heating, ventilation, and air conditioning (HVAC) and water heating — offers the most promising pathway to achieving California's GHG emissions reduction targets in the least costly manner.[13]

Electrification of buildings presents an immediate opportunity for emission reductions because cost-effective, proven technology already exists and is widespread in many parts of the world. The CEC's 2018 Integrated Energy Policy Report Update published in early 2019, highlights the rationale behind and prioritization of building electrification as a GHG emissions reduction strategy, "There is a growing consensus that building electrification is the most viable and predictable path to zero-emission buildings. This consensus is due to the availability of off-the-shelf, highly efficient electric technologies (such as heat pumps) and the continued reduction of emission intensities in the electricity sector."

Given the necessity of reducing gas use in buildings, several studies have explored different aspects of this challenge, ranging from cost effectiveness, technology efficiency, and regulatory barriers. Others have explored the economic and employment benefits of economy-wide decarbonization. Despite all of this attention, there is not yet a clear policy mechanism or plan to ensure gas reductions in the buildings sector. In fact, at the time of writing this paper, there remain legal and regulatory barriers to building electrification.

Rather than comparing the full range of building decarbonization pathways, this study focuses on the most likely decarbonization strategy: the replacement of gas appliances with efficient electric alternatives. It also explores decarbonized district energy systems, a centralized approach to building decarbonization for campuses, neighborhoods, and building complexes.

Natural gas use in buildings has been slowly declining since 2010, particularly in the residential sector.[14] The projections in this study do not account for this business-as-usual trajectory. Other strategies to reduce emissions from buildings, such as increased use of renewable or synthetic

i When accounting for the associated methane leaks, building gas use represents 15% of the state's emissions. https://www.nrdc.org/experts/joe-vukovich/real-climate-impact-californias-buildings gas, have not been demonstrated at the scale or cost needed for widespread building decarbonization and are also not considered in this study.

The potential employment estimates in this study are based on a total conversion of California's existing mixed-fuel buildings to all-electric plus all-electric new construction. These estimates are not premised on any particular policy driver (e.g. building codes, equipment manufacturing and sales mandates, utility incentives, public expenditures, etc.) but on the total investment required to achieve this transformation. We calculated and allocated the total investment across the different industries that will play a part in building electrification. This distribution across industries was input to IMPLAN (2017), an input-output economic model, to determine the employment impacts associated with this change in spending. We also accounted for the reduction in consumer spending in the gas industry, and the employment impacts of the shift in spending from gas to electricity purchases.

Building electrification will impact several employment sectors. Most obvious is the work performed in buildings themselves; construction jobs associated with efficiency improvements, building modifications, and equipment installations. In addition, there may be jobs in the manufacturing of electrical equipment and appliances needed for installation. There is also work required to ensure that the electricity system can support new demand loads driven by building electrification, which may require new renewable energy and grid infrastructure. Utility jobs to support increased electricity sales represent another area of job growth.

In addition to the increased demand for workers in these areas, there will be a reduced need for workers in other areas. All-electric new construction of buildings reduces the need for plumbers and pipefitters to extend gas lines and connections; and reduced gas sales could reduce the number of utility workers needed to provide service to customers, depending on the pattern of reductions. This study assesses all of these impacts.

We make no assumptions about where the money to transform the building stock will come from or where the financial savings to consumers will go. Building electrification work costs money upfront, and it can also save money long-term. These lifecycle effects, and their resulting ripples in the economy, are not considered. This study does not estimate any of the following impacts: indirect and induced employment effects;[ii] other economy-wide impacts of electrification; changes in consumer spending on energy; and alternative investment scenarios.

Instead, this study highlights the direct impacts (employment in the industries directly engaged) of building electrification. These include jobs in residential construction, commercial construction, manufacturing, renewable energy construction, electricity generation and delivery, and gas extraction and delivery. As such, it is not intended to persuade building owners to electrify or convince policy makers to act more aggressively to implement electrification policies. Instead, its intended use is for workforce planning and engagement to inform the design and implementation of building decarbonization policies.

To guide workforce planning and engagement, this study discusses the distribution of the job gains and losses by market segment and by industry. It also identifies recommendations to support the engagement of a skilled and trained workforce in the transition to clean energy and electric buildings. The study also provides recommendations to minimize and mitigate potential job losses from decreased natural gas consumption.

AN ORDERLY AND PLANNED TRANSITION

Shrinking the natural gas distribution system in a safe and reliable way is more challenging than its construction. The system is highly connected and networked, and even if individual consumers choose to reduce or end their usage, the system must remain intact to provide service to others continuing to use gas in their homes and businesses.

Without planning and policy intervention to encourage targeted geographic pruning,[iii] gas throughput will likely

ii Direct jobs are in the primary industries involved in the activity being studied. Indirect jobs are those along the supply chain that provide intermediate inputs for carrying out decarbonization efforts (e.g., workers processing raw materials for the assembly of capital equipment, truckers delivering goods, vendors selling appliances at retail locations, etc.). Induced jobs are those that provide goods and services to workers with direct and indirect jobs when they spend their income (e.g., grocery store clerks selling household products, afterschool providers caring for children, doctors treating patients, etc.).

iii If the gas system represents a tree, then the main trunk represents the main transmission pipeline running north to south through the middle of the state, and limbs and branches represent the distribution pipes that move gas to buildings and homes. Removing a single building from a distribution line does not reduce decline in a fragmented fashion, driven by individual consumers replacing individual appliances upon the end of their useful life or choosing early retirement of gas appliances for safety, health, or environmental reasons.

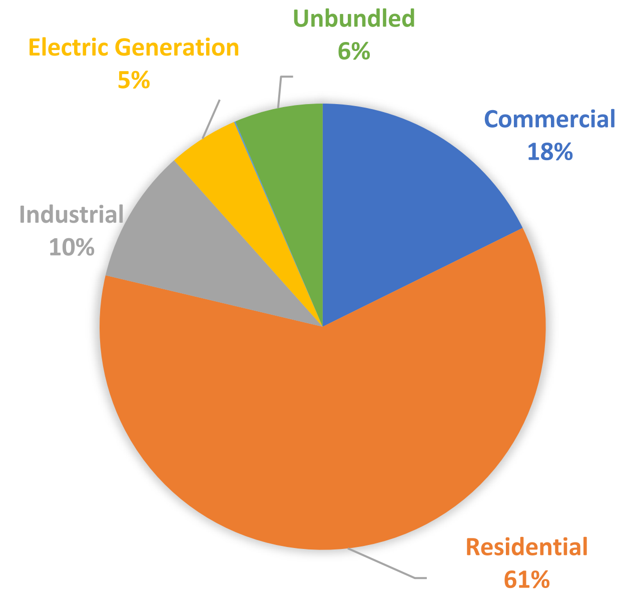
Relying on voluntary action to achieve widespread building electrification within the next 25 years is unlikely to achieve the full GHG emissions reduction potential of these measures. Building systems and appliances can last for 20 years or longer, so even if all gas equipment is phased out upon burnout, starting today, there could still be gas equipment in homes and buildings in 2045, the date Governor Brown established for achieving zero net emissions statewide.

Today's piecemeal approach to building electrification raises important economic concerns as well. The costs of maintaining the system are a function of the size of the network pipelines and the pressure maintained within them, rather than the quantity of gas moving through the pipes. Unless an entire cluster of customers on a terminal branch of the distribution system chooses to give up gas, the system cannot be pruned. Without shrinking the size of the system, the fixed costs of maintenance are not reduced and will be spread among fewer consumers, thereby raising gas prices.[15]

In addition, the majority of the revenue required to maintain the system comes from residential and commercial users who account for less than 40 percent of gas use (see Figure 1 and Figure 2 for gas revenue and usage by customer type). Because of this imbalance, reduced sales (less throughput) to residential and commercial customers could increase gas prices for remaining customers (i.e., industry, electricity generators, and other residential and commercial customers), particularly if the costs of maintaining the gas distribution system are not simultaneously reduced. The consequences of higher gas prices could ripple throughout the economy causing job losses, industry leakage, and energy affordability challenges, the effects of which are difficult to estimate.

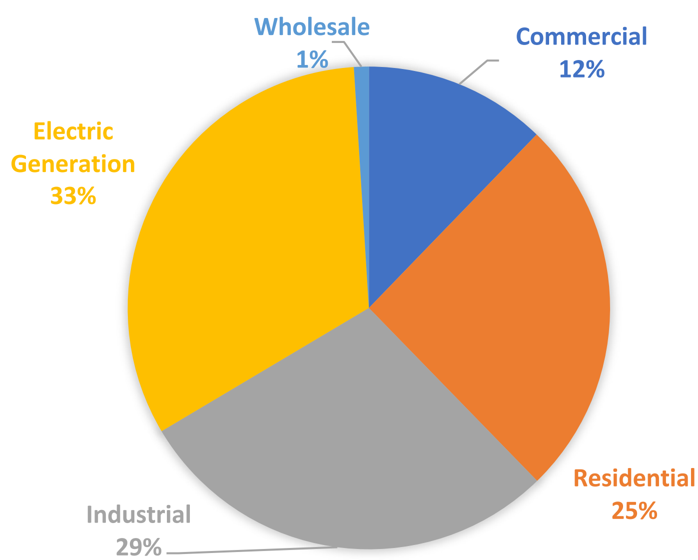
maintenance needs for that branch. If all of the buildings on a certain branch can be disconnected, that branch of the distribution system can be decommissioned. This is referred to as "pruning" because it is like trimming a tree.

Figure 1. PG&E 2018 Distribution Of Direct Use Revenue ($)



Given this uncertainty, this study optimistically assumes a simultaneous shrinking of both gas revenue and the costs of maintaining the gas system, thereby stabilizing the gas sector and averting a death spiral—a reinforcing feedback loop that makes an industry unviable. This simultaneous reduction of revenue and costs would also protect remaining

Figure 2. PG&E 2017 Distribution Of Direct Use Gas Throughput (Therms)



Source: Pacific Gas and Electric Company (2019)16 gas customers from price spikes. This balancing act could be accomplished by geographically targeting building electrification in places where the gas system can be pruned with stretches of pipeline decommissioned. While this study makes no suggestions about where the gas system should be decommissioned, it does suggest there should be geographically-based prioritization so that as gas consumption declines, the revenue requirements also shrink. An orderly planned transition from gas would have the effects of stabilizing the industry and protecting low-income and gas-dependent consumers.

A planned contraction also allows for workforce planning. Certainty about ongoing workforce needs to maintain a safe and reliable system can guide workforce planning to retain the skilled workers needed even as the industry is in decline, while minimizing the number of layoffs and transition assistance needs. With good planning, the workforce can slowly shrink through worker retirement and natural attrition without losing the skilled and experienced workers necessary to manage a smaller gas system.

The assumption of geographic prioritization is as important for quality job creation as it is for minimizing job loss. Aggregating building electrification in particular regions creates the economies of scale critical for project labor agreements (PLAs), community benefits agreements (CBAs), or other workforce standards that support a diverse, skilled, and trained electrification workforce.

METHODOLOGICAL OVERVIEW

We used the IMPLAN calculation process[17] to estimate the employment impacts of electrification. IMPLAN is a regional economic analysis software application designed to estimate the impact of a given economic activity within a specific geographic area through a built-in input-output model. Studies that rely on IMPLAN are limited by the researcher's assumptions and inputs. Prior to running IMPLAN, the following estimations were made in order to determine the inputs upon which employment impacts would be based:

1. **Number and Types of Buildings in California** and rate of growth. The building segments covered include 1) single- and small multi-family residential, 2) large multi-family residential, 3) small and medium commercial (private-sector), as well as 4) large commercial and municipalities, universities, schools, and hospitals (MUSH) of all sizes. The residential information was estimated from U.S. Census data and the California Department of Finance. The commercial data was derived from the California Commercial End Use Survey (CEUS) and the U.S. Energy Information Administration's (EIA) Commercial Buildings Energy Consumption Survey. Details and calculations are provided in Appendix B. Building Market Analysis (Supplemental Information).

2. **Current Building Gas Use.** To estimate the scale of building electrification activity, we gathered data on gas availability and consumption across different end uses and building types. This information was estimated from data available in CEUS and the U.S. EIA. Calculations are provided in Appendix C. Gas Use in Buildings (Supplemental Information).

3. **Electrification Investment Cost.** To estimate the costs of electrification retrofits of existing buildings, we gathered information from published literature, construction cost estimators, and industry professionals to determine the technology and work required to replace gas appliances in buildings as well as other building modifications necessary to complete electrification work. Several recent studies indicate that all-electric new residential construction is less expensive than gas-dependent construction due, in part, to the avoided cost of natural gas piping associated with the service and meter connection. We estimated this associated reduction in labor demand from this cost savings in the residential sector. In the commercial sector, we note that more work would shift from plumbing to electrical work. The sources and details are provided in Appendix D. Cost Estimates.

4. **Change in Electricity and Gas Demand.** To determine the change in utility employment, we estimated the increased sales of electricity due to electrification based on high-efficiency and low-efficiency equipment replacement scenarios. We also estimated the reduction in gas sales. The sources and details are provided in Appendix E. Change in Electricity and Gas Demand.

5. **New Electricity Capacity Requirements.** To determine the employment needs for new electricity generation and transmission to meet increased demand, we explored the seasonality of gas demand and distributed increased electricity demand accordingly. Because the grid is designed for peak summer demand, increased peak demand could require more grid infrastructure investments. While this is an area requiring more rigorous analysis, we found that the challenge with electrification is not that the overall peak increases dramatically, but rather that winter demand increases dramatically as heating loads shift from gas to electricity. Accounting for low winter capacity factors for wind and solar in California, we estimated the generation capacity required to meet new winter demand from buildings.

A detailed graphic on the scope and steps taken to derive the estimates in this study is provided in Appendix A. Study Scope and Steps. Underlying assumptions and caveats can be found in Appendix F. Assumptions and Caveats.

LITERATURE REVIEW

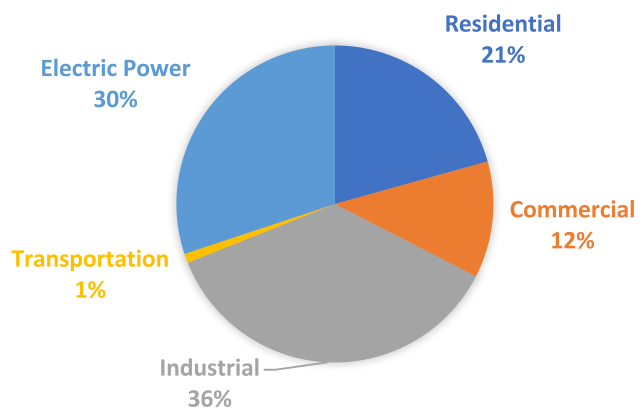
To date, no studies on the employment impacts of building electrification have been completed, and, at the time this research was conducted, no statewide assessment of building electrification market potential and upfront investment costs had been conducted.[iv] The majority of existing literature on building electrification has focused on lifecycle cost assessments and case studies to assess or inform electric or net-zero energy building upgrades at the building scale. Several studies have explored electrification scenarios by modeling technology adoption and the related grid impacts at the state and national levels, but do not provide associated cost estimates. See Appendix G. Literature Review for a brief review of these studies.

iv E3 has since published, Residential Building Electrification in California, a paper estimating the market potential and costs of electrification in California with more granularity than is presented here. Future research should examine the sensitivity of E3's costs assumptions on the same employment outcomes studied here. For the E3 report, visit: https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf .

FINDINGS

Natural gas use in California is roughly evenly split between three uses: power generation, industrial processes, and direct use in buildings. The share of gas used by industry is increasing, and the share of gas used for electricity generation is decreasing. The decrease on the power side can be attributed to reduced electricity demand from efficiency improvements and displaced gas generation by carbon-free alternatives required by the Renewables Portfolio Standard (RPS).

Figure 3. California Natural Gas Use by Sector, 2018[18]



On the building side, gas use is split between residential and commercial buildings, with the residential sector using almost twice the gas of the commercial sector. Residential gas use in California is declining faster than overall gas use in buildings. Residential use has declined 14 percent since 2010, and overall gas use in buildings has declined nine percent in that same period.[19]

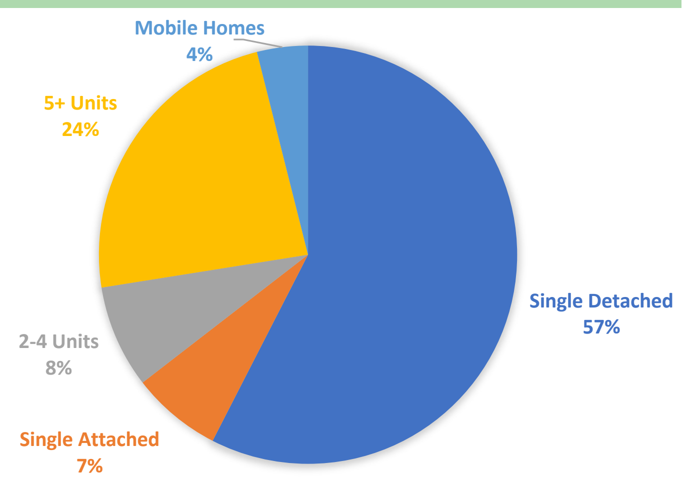
RESIDENTIAL MARKET

Number and Types of Buildings in California

California has approximately 14.2 million homes.[20] Accounting for new construction, this study estimates that by 2025, California will have 15–15.4 million homes,[v] and 12.2–13 million of them will use gas.[21] The range depends on the pace of the phase out of gas in new construction and the growth of residential construction. The share of multi-family homes is increasing; today, about half of new home construction are multi-family structures.[22]

This study assumes that after 2025, all new residential construction will be all-electric. Depending on the rate of residential development and the phase out of gas, this study assumes that 2.5–5.3 million new homes will be built all-electric by 2045. See Appendix B. Building Market Analysis (Supplemental Information) for more detail.

Figure 4. Distribution of California Housing Units by Structure



Source: 2019 California Department of Finance[23]

Gas Use in Homes

Eighty-nine percent of residential gas is used in single-family and small multi-family units; 11 percent is used in large (5+) multi-family units.[24,25] Gas use in buildings varies significantly by unit structure and ownership. Figure 5 and Figure 6 illustrate these differences. Figure 5 shows gas appliance saturation in the single-family detached and large multi-family segments using gas. Eighty-six percent of single-family homes use gas for heating and hot water; while only 62 percent of large multi-family use gas for heating and only 39 percent for water heating. The lower saturation of

v The California Department of Finance estimates there were 14.2 million homes in 2019. They reported in their Finance Bulletin that California is adding 110,000–120,000 units annually evenly split between single- and multi-family homes. California needs to add 3.5 million homes by 2025 (~600,000/year) to close the housing gap. For more information, see: https://www.mckinsey.com/featured-insights/urbanization/closing-californias-housing-gap .

HOW DIFFERENT MARKET SEGMENTS INFLUENCE EMPLOYMENT OUTCOMES

Contractors involved in construction activity in the residential and small commercial market segments differ from contractors serving large commercial, large multi-family, and institutional markets. The single-family residential and small commercial market is highly competitive and price-driven. Barriers to entry are low, but firm turnover is high. As the 2011 CEC draft staff report , *Achieving Energy Savings in California Buildings*[26], notes (p.21), "Contractors who work in the residential sector have historically worked under a low-bid contractor model, where the lowest bidder is typically awarded the contract." According to the January 2019 report, *Rebuilding California: The Golden State's Housing Workforce Reckoning*[27], residential construction workers earn 33% less per year than non-residential construction workers; and non-residential contractors' contributions to fringe benefits are triple those of residential contractors.

Firms serving the large commercial, large multi-family residential, and institutional market segments are more able to gain a competitive advantage on the basis of qualifications, skill, and experience. The *2011 California Workforce Education and Needs Assessment for Energy Efficiency, Distributed Generation, and Demand Response*[28] documents differences in worker compensation, training, and certifications between these two market segments.

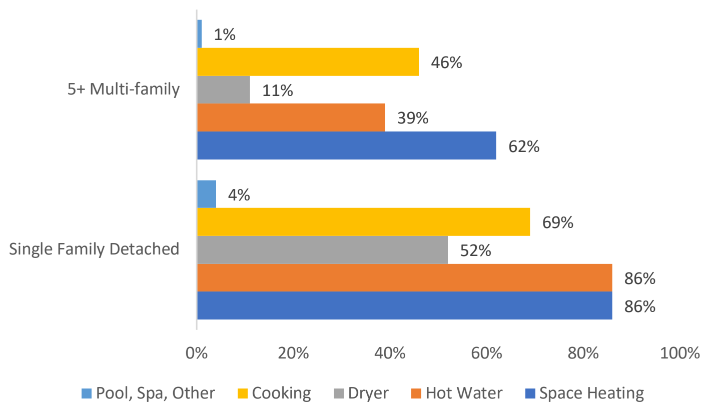
Given these differences, not all construction jobs created from building electrification will be of equal quality. According to this assessment, the work in large commercial, large multi-family, public market segment is likely to lead to higher-paying jobs and support a skilled and trained workforce, but 80 percent of the gas use in buildings is in the residential and small commercial market segment, where pay is low and earnings are volatile.[29]

Low job quality can lead to labor market shortages. As the *Rebuilding California* report notes, the residential construction industry lacks the wage competitiveness and career training pipeline to attract and retain workers. Without closing the pay and training gap between the residential and non-residential construction workforce, it could be difficult to attract the skilled workers needed to serve the residential and small commercial market. Training for the large commercial and MUSH market segment is well-established with joint labor-management apprenticeship programs, so even though the building systems are more complex, higher wages and benefits linked to a formal training system reduce the likelihood of a labor shortage.

gas appliances in the multi-family segment, coupled with the fact that only one-quarter of homes in California are in 5+ unit buildings, makes large multi-family buildings a small share of the total residential electrification market.

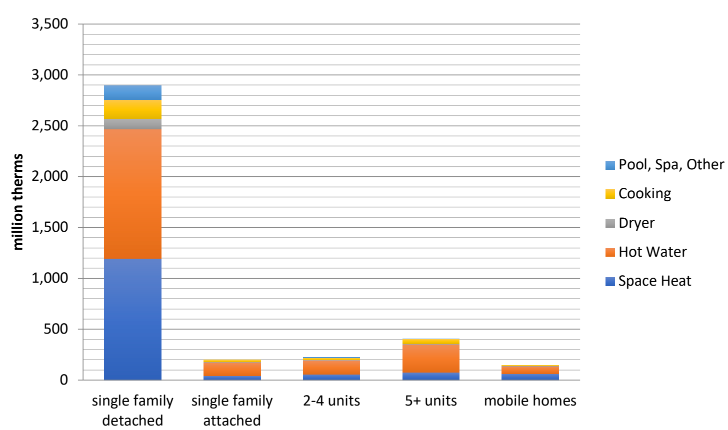
Figure 6 shows this distribution by building structure in the quantity of gas consumed. Single-family residential water heating is the end use of greatest gas consumption in the residential sector. Together single-family residential space and water heating make up two-thirds of residential gas use. Water heating in homes accounts for more than half of residential gas use. Altogether residential gas consumption totaled 4,393 million therms in 2018. Table 1 shows residential gas appliance saturation by building structure.

Figure 5. Percent of Single- and 5+ Unit Multi-family Homes Using Gas for Different End Uses (2009 Data)



Source: 2009 California Residential Appliance Saturation Study

Figure 6. Total Natural Gas Use by Residential Building Type in California (Million Therms, 2017 Estimates)



Source: Author's estimates based on 2009 California Residential Appliance Saturation Study, 2017 American Community Survey, and CEC Gas Consumption by Entity data

EQUITY CONSIDERATION:

Nine out of 10 units in multi-family buildings are occupied by renters; whereas, only one in four single-family houses are occupied by renters (see Figure 7). According to the U.S. Census, renter-occupied units are more likely to use electricity for heating, whereas owner-occupied units are more likely to use natural gas. Despite their lower overall gas use, multi-family housing — and rental housing in general — should not be overlooked in the push for building electrification. There is likely significant potential to upgrade inefficient costly to operate electric appliances with newer more efficient models, thus reducing energy expenses and reducing total system electricity demand. An additional challenge is that because renters are seldom the decision makers about appliances or the fuels they use, they are not able to make investments in equipment that would save them money long-term. The October 2019 report "Equitable Building Electrification" produced in partnership between the Greenlining Institute and California Energy Efficiency for All coalition, highlights these concerns and potential solutions.

Figure 7. California Housing Units By Type And Renter/ Owner Occupancy (Source: Us Census)

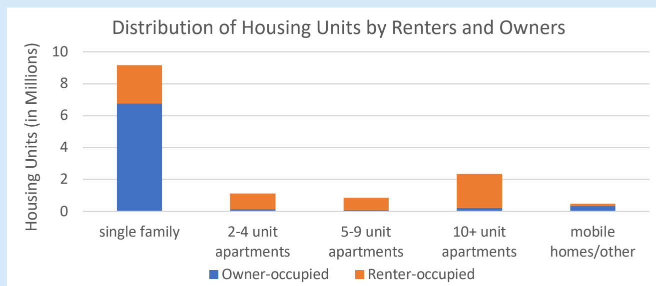


Table 1. Percent of Homes with Gas by End Use

Gas End Use	Single-family Detached	Single-family Attached	2-4 Units Multi-family	Mobile Home	5+ Units Multi-family
Space Heating (Primary)	85%	80%	70%	56%	61%
Space Heating (Auxiliary)	1%	1%	1%	-	1%
Space Heating	86%	81%	71%	56%	62%
Conventional Gas Water	86%	77%	62%	54%	39%
Dryer	52%	31%	20%	29%	11%
Range/Oven	69%	61%	57%	52%	46%
Pool Heat	6%	-	1%	-	1%
Spa Heat	7%	1%	-	-	-
Miscellaneous	13%	10%	7%	6%	3%

Source: 2009 California Residential Appliance Saturation Study

HOW TO USE MARKET ANALYSIS TO DESIGN AN ELECTRIFICATION POLICY OR PROGRAM THAT IS ALIGNED WITH WORKFORCE DEVELOPMENT

Market analysis is useful for designing electrification policies and programs that align with workforce development efforts because electrifying different end uses correspond to different workforce skills and training requirements.

For example, if a utility or community choice aggregator want to accelerate the adoption of electric heat pump water heaters, they might reach out to the local plumber apprenticeship and training programs to look at how the required skills and knowledge could be incorporated into the training curriculum. They might then tie incentives to pre-qualified contractors who agree to use workers from those training programs.

Thoughtfully designed electrification policy can simultaneously grow both the demand for trained workers and the supply of trained workers. Policy makers can strengthen the ties between training providers and employers by establishing contractor qualifications, explicitly requiring skill standards, or encouraging other formal partnerships.

Another reason that market analysis is useful for workforce development alignment is that it can be used to estimate the number of jobs that might be created by a program or policy. Calibrating training with the potential job availability is critical, so that there are enough, but not too many, workers to meet demand. If too many workers are trained for jobs available, excessive competition for work can drive down wages and force the most highly skilled workers to seek other opportunities.

Table 2 shows the estimated total number of housing units with access to gas.

Table 2. Residential Market Potential for Electrification (Million Housing Units)

End Use	Single-family and 2-4 unit Multi-family		5+ Multi-family	
	Low	High	Low	High
Space Heating	8.34	8.61	2.30	2.38
Water Heating	8.06	8.32	1.45	1.50
Dryer	3.87	3.99	0.41	0.42
Cooking	6.81	7.03	1.71	1.76
Pool	0.20	0.21	0.04	0.04
Spa	0.24	0.25	-	-
Gas Disconnection	9.57	10.22	2.64	2.82
Energy Efficiency	9.57	10.22	2.64	2.82
Service/Panel Upgrade	0.89	1.87	0.11	0.23

Source: Author's estimates based on percentages reported by 2009 California Residential Appliance Saturation Study, 2017 American Community Survey, U.S. EIA, and California Air Resources Board

Investment Estimates

There is a very wide range of electric options for the residential end uses currently served by gas. Detailed descriptions of these technologies can be found in the 2018 Synapse Energy Economics, Inc. report commissioned by the Natural Resources Defense Council titled, *Decarbonization of Heating Energy Use in California Buildings*.[30] For the purposes of this study, we assume residential electrification will take place with the best available technology, which is summarized in Table 3.[31]

Table 3. Residential Electrification Technology Assumptions

Electric Technology	End Use	Home Type
Ducted Heat Pump[32,33]	Space heating and cooling	Single-family
Ductless Heat Pumps	Space heating and cooling	Mobile homes, Multi-family
Heat Pump Water Heater	Water heating	All
Induction Stove, Convection Oven	Cooking	All
Energy Efficient Electric or Heat Pump Dryer	Clothes drying	All
Solar or Heat Pump Heater	Pool heater	All
Electric Resistance Heater	Spa/hot tub	All
Air sealing, Insulation, and Water Efficiency Measures	Heating, cooling, and water heating	All

This study estimates construction and capital investment costs for electrifying each end use currently served by gas. In addition to these estimates, we assume that all homes converting to all-electric will require some building modifications and efficiency improvements in order to right-size equipment and capitalize on the high-efficiency of electric replacement technologies. We estimated these costs as well as gas disconnection costs in all homes. We also estimated the number of homes in need of panel upgrades based on the age of existing homes and retirement and renovation rates.[34] California adopted comprehensive building codes for electric panel requirements in 1990, so only considering homes built before 1990 and not yet renovated, we estimate a total of 1–2.1 million homes require electric service panel upgrades to accommodate new electric appliances.[vi] These cost estimates and sources are detailed in Appendix D. Cost Estimates and summarized in Table 4.

Table 4. Residential Electrification Cost Estimates (Per Unit)

	Capital Investments in New Equipment		Non-Capital Construction Cost		Total Costs	
	Low	High	Low	High	Low	High
Building Efficiency Improvements	$0	$0	$4,000	$6,000	$4,000	$6,000
Gas Disconnection	$0	$0	$400	$600	$400	$600
Panel/ Distribution Upgrades	$0	$0	$3,000	$6,000	$3,000	$6,000
Ducted Heat Pump	$2,500	$3,100	$4,500	$6,400	$7,000	$9,500
Ductless Heat Pump	$1,500	$2,500	$3,800	$5,400	$5,300	$7,900
Heat Pump Water Heater	$1,300	$2,000	$800	$1,000	$2,100	$3,000
Induction Stove	$1,000	$2,300	$400	$600	$1,400	$2,900
Efficient Electric or Heat Pump Dryer	$700	$1,400	$300	$400	$1,000	$1,800
Spa	$400	$1,200	$700	$800	$1,100	$2,000
Pool	$2,000	$3,800	$1,500	$4,200	$3,500	$8,000

Taking the residential building gas saturation by end use (Table 1), the residential electrification market potential (Table 2), and the costs for electrifying different end uses (Table 4), we determined the average cost per home is $14,674–20,854, with a wide range depending on the number of measures required. Homes with gas cooking, clothes drying, heating, water heating, and pool heating could cost much more, while those using fewer gas appliances will cost less. Homes in multi-family buildings will generally cost less than single-family homes.

vi Panel upgrades can be avoided with technological advances in heat pumps, such as models that require lower amperage.

A 2018 California Public Utilities Commission (CPUC)-approved residential pilot in the San Joaquin Valley will serve 1,944 low-income households for a total pilot cost of $56 million. The weighted average for approved per household costs for electrification plus efficiency is $28,184.[35] This pilot cost is substantially higher than the high-end estimate in this study because the CPUC estimate assumes that all homes will require panel upgrades and have significant remediation needs (e.g., mold and asbestos removal).[vii,viii]

For the impacts of all-electric new construction, we assumed cost savings of $6000 per single-family home and $1000 per unit in multi-family buildings.[36]

Employment Effects

The employment effects of residential electrification are shown in Table 5 . The IMPLAN inputs behind these figures are shown in Appendix H. IMPLAN Inputs.

Table 5. IMPLAN Direct Construction Employment Effects for Residential Electrification

Sector	Direct Employment Effects (annual average)	
	Low	High
Construction		
Residential Electrification Retrofits	26,000	39,300
New Residential All-Electric Construction	-3,100	-3,600
TOTAL DIRECT	**22,900**	**35,700**

Based on the estimated costs of electrification and the IMPLAN analysis, this study estimates that California would need 22,900–35,700 full-time construction industry workers per year from 2020–2045 to electrify California's homes. Eighteen percent of these would be in large (5+ unit) multi-family buildings.

vii These pilots include a 20% administrative overhead for participating investor-owned utilities and include high contingency costs to bring homes up to code or improve health and safety. In addition, pilot projects are generally more expensive than market- or policy-driven projects.

viii If we assume average remediation costs per home of $5,000, then electrification of California homes would require an additional 13,000 FTE workers per year.

COMMERCIAL ELECTRIFICATION

Number and Types of Buildings in California

Commercial building data is frequently reported by floor space rather than number of buildings or establishments. The analysis is this study assumes that by 2025, California will have commercial buildings covering 8.2–8.6 billion square feet (See Appendix B. Building Market Analysis (Supplemental Information) for more information). Of those buildings, approximately 70 percent are small commercial (under 10,000 square feet) space; 25 percent are medium (over 10,000 but under 50,000 square feet), and just 5 percent are large (over 50,000 square feet). These buildings are divided among many different building uses, as shown in Table 6 . There is limited data on the exact number of commercial buildings; floor space estimates are more readily available. This study estimates the number and square footage of commercial space from the U.S. EIA[ix,37] and the CEC.[38]

Table 6 . Estimated California Commercial Buildings by Type, 2025

Building Type	Floor Space (million SqFt)	
	Low	High
Colleges	345	360
Health	390	407
Large Office	1,107	1,155
School	746	778
Miscellaneous	1,843	1,922
Lodging	453	472
Grocery	242	252
Refrigerated Warehouse	160	167
Warehouse	929	969
Restaurant	250	260
Retail	1,177	1,227
Small Office	606	632
ALL COMMERCIAL	**8,249**	**8,602**

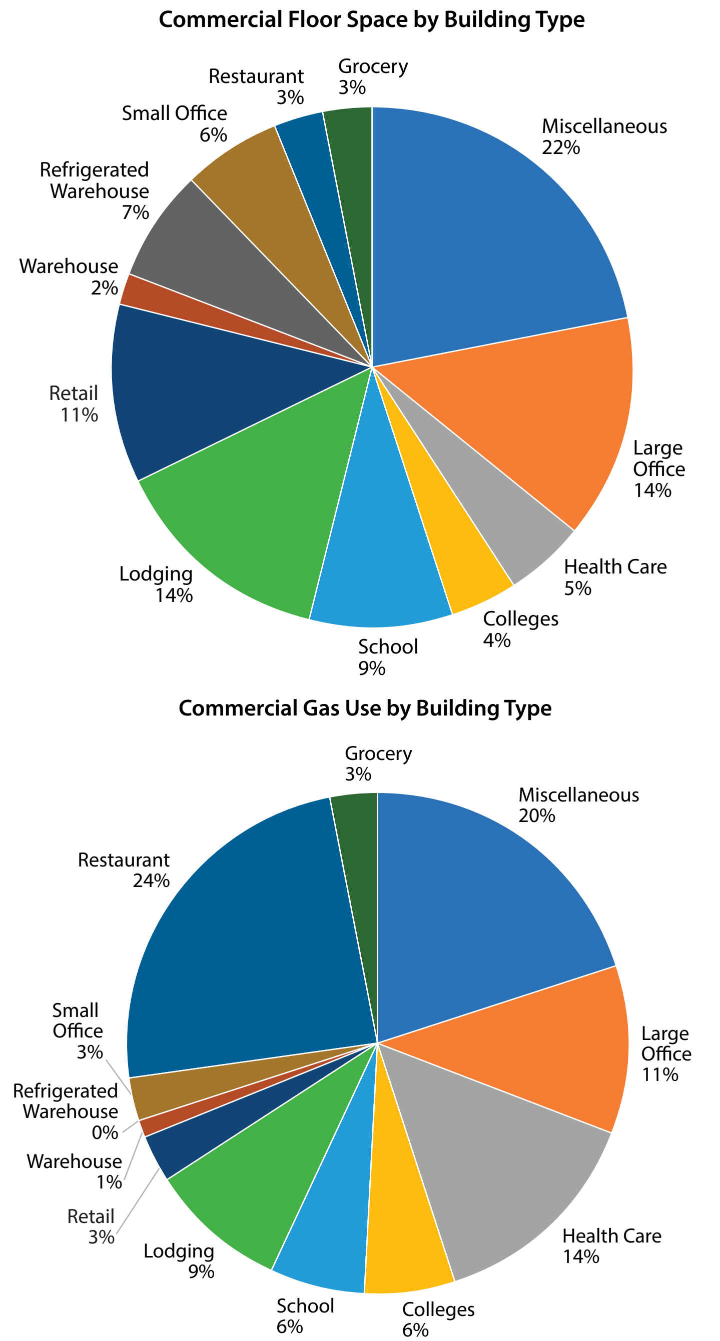
Source: Author's analysis with data from U.S. EIA,[39] CEC,[40] and Itron, Inc.[41]

Given a lack of data, we assume that all new commercial buildings after 2025 will be all-electric and that there is no significant incremental costs or cost savings in the construction of all-electric versus gas plus electric new commercial buildings, and therefore no net employment impact. All-electric new construction could shift employment between trades, specifically reducing demand for plumbers and pipefitters installing gas lines and connections.

Gas Use in Commercial Buildings

Figure 8 shows the share of gas consumed by different building types compared to their share of total commercial building area. Restaurants consume almost ¼ of the gas used in commercial buildings, despite accounting for only three percent of commercial buildings by size, and hospitals consume 14 percent but only account for only five percent of commercial space.

Figure 8. Commercial Gas Use by Market Segment

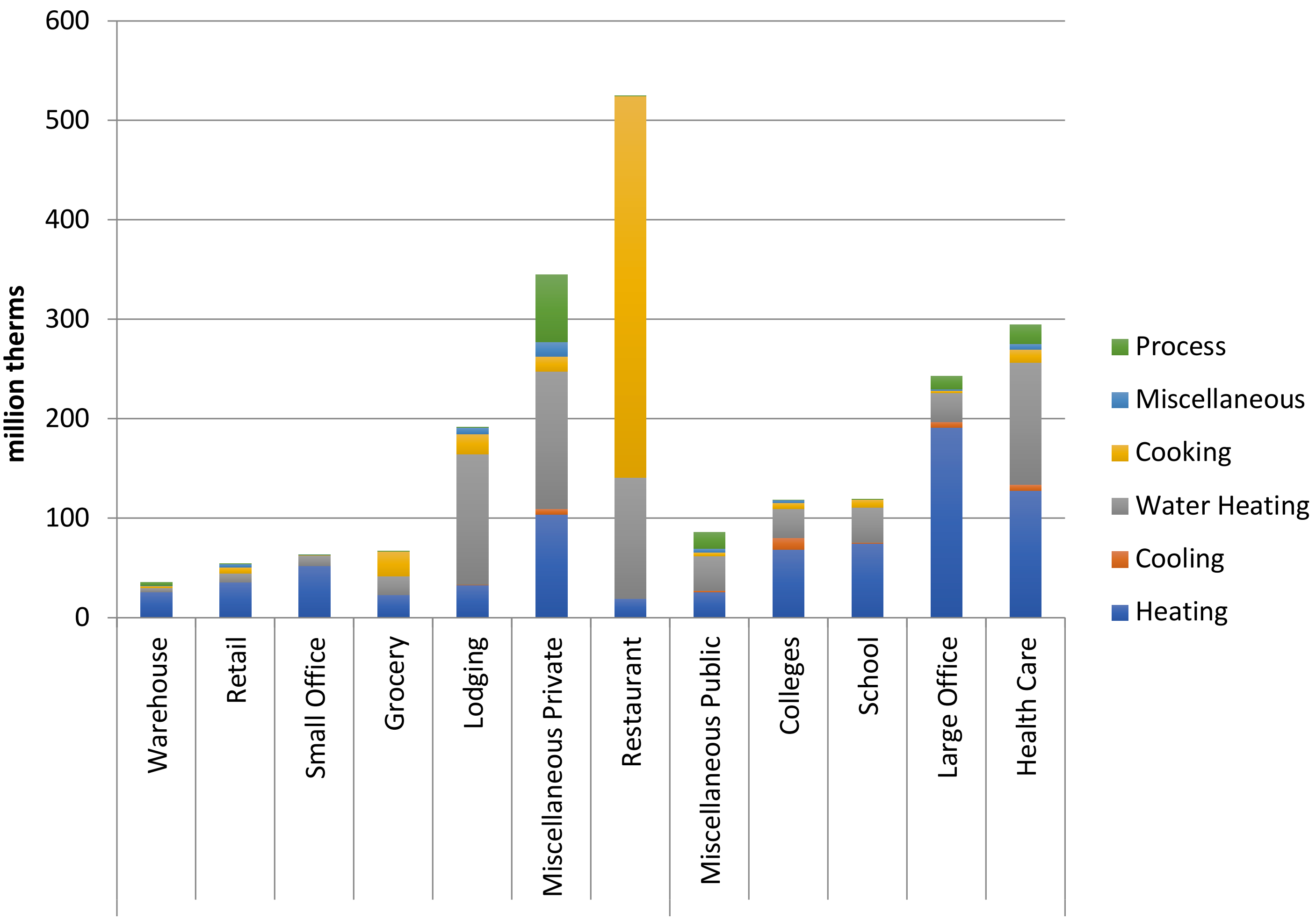


Source: California Commercial End Use Survey[42]

ix CBECS will provide updated 2018 data in mid-2020.

Figure 9 displays gas use by building type and end use. These charts show that in small commercial buildings, cooking and water heating use the most gas, whereas in the large commercial/MUSH segment space heating uses the most gas. This suggests that there may be some specialization among contractors serving the small and large commercial segments. Cooking and water heating specialists will be important in the small commercial sector, while HVAC specialists will be critical in the large commercial sector.

Figure 9. Commercial Annual Gas Use by End Use and Building Type (2018 Estimates)



Source: Author's analysis using California Commercial End Use Survey[43] data projected to 2018 using CEC Demand 2018-2030 Revised Baseline Forecast.[44]

Table 7 and Table 8 show an estimated distribution of California buildings by principal activity. In these tables, buildings are organized by two categories: (1) private small and medium commercial[x] and (2) large commercial/MUSH. We estimate that about 60 percent of the floor area is in the small and medium commercial segment, and 40 percent is in the large commercial/MUSH segment.

This study uses the Itron California Commercial End Use Survey (CUES)[45] to determine the percent building area using gas for each end use.

PRIVATE SMALL AND MEDIUM COMMERCIAL

Table 7. Market Potential For Building Electrification Retrofits, Private Small And Medium Commercial Sector

Gas Use	Percent of Commercial Floor Space Served by Each Gas End Use	Estimated Commercial Building Space Using Gas (million SqFt)	
		Low	High
Water Heating	50.80%	2,490.2	2,665.0
Space Heating	44.10%	2,161.8	2,313.5
Cooking	23.00%	1,127.5	1,206.6
Miscellaneous (Dryers, Pools/ Spas, etc.)	9.50%	465.7	498.4
Process	2.60%	127.5	136.4
Estimated Total Using Gas	**75%**	**3830**	**3994**

Source: 2012 Commercial Buildings Energy Consumption Survey and CUES

LARGE COMMERCIAL/MUSH

Table 8. Market Potential For Building Electrification Retrofits, Large Commercial And MUSH Sectors

Gas Use	Percent of Commercial Floor Space Served by Each Gas End Use	Estimated Commercial Building Space Using Gas (million SqFt)	
		Low	High
Space Heating	71.10%	2384.7	2629.3
Water Heating	65.50%	2196.9	2422.2
Cooking	35.70%	1197.4	1320.2
Miscellaneous (Dryers, Pools/ Spas, etc.)	12.30%	412.5	454.9
Process	4.10%	137.5	151.6
Estimated Total Using Gas	**85%**	**2778**	**3143**
Deep Energy Retrofits		2245	2455
District Energy + End Use Electrification		533	688

Source: 2012 CBECS and CUES

x Some small commercial (e.g., fire stations, libraries, etc.) are classified in the MUSH segment.

DISTRICT ENERGY

Some buildings are supplied heating, cooling, and water heating from district energy systems.[46] District energy systems typically use combined heat and power (CHP) or co-generation systems to produce both electricity and steam or hot water which is moved through a series of underground pipes to radiators in buildings where the heat is released to warm space. Sometimes these systems provide a building's hot water as well. District energy can also be used to move chilled water and providing space cooling for buildings. Although CHP systems are highly efficient, they often use a lot of gas. For example, across the University of California (UC) system, 64 percent of the gas consumption is for CHP plants (see Figure 8), which provide both electricity and heat to campus buildings.[47]

Decarbonized district energy systems[xi] are good options for MUSH facilities reliant on centralized energy systems. A February 2018 report, *University of California Strategies for Decarbonization: Replacing Natural Gas*, looked at various options for reducing natural gas use across UC buildings and identified both distributed (individual building) and centralized (district energy) electrification as viable decarbonization strategies.

Figure 10. UC Gas Use by Centralized District Heating Systems[48]

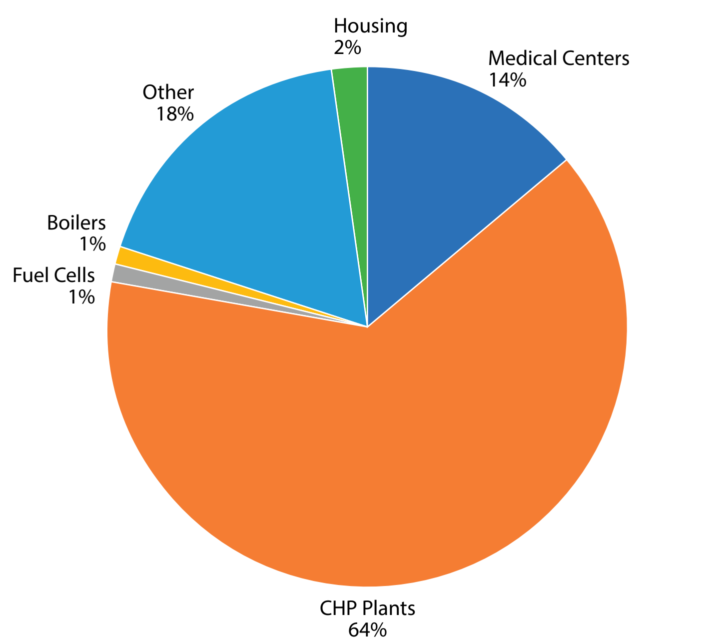


Table 9 shows the estimated buildings on district energy.[xii,49] In addition to buildings already using district energy, there is potential to expand its use. Buildings that are already

xi See *Addendum on District Energy Decarbonization* for more information

xii This study assumes that the percent of total buildings on district energy systems in the Pacific region (which is as granular as the data is available) is the same percent of buildings in California part of an existing building complex are good candidates. Approximately 40 percent of California's non-residential building space is part of a campus or complex of buildings.[50] Table 18 and Table 19 in Appendix B. Building Market Analysis (Supplemental Information) shows the existing buildings with district energy and the distribution of buildings by different complex types. This study estimates that 533–688 million square feet of building space could be decarbonized through centralized solutions. We assume that this is most likely in the MUSH and large commercial segments.

While the upfront cost of decarbonized district energy may be higher than stand-alone building electrification, the life-cycle costs may be lower because of economies of scale, the opportunity to optimize heating and cooling needs across a network of buildings, and the ability to use different and more flexible sources of energy like waste heat from sewer systems, data centers, supermarkets, other buildings,[xiii] or geothermal. Depending on the cost of electricity, particularly in the winter, this approach could be very economical over time. (See Addendum on District Energy System Decarbonization for more information).

Investment Estimates

PRIVATE, SMALL AND MEDIUM COMMERCIAL

Like residential electrification, small commercial electrification can be achieved with equipment replacements and efficiency improvements. The National Renewable Energy Laboratory (NREL) and others report that units of similar size can be used to electrify space heating in the residential and small commercial sector.[51] We estimated the total upfront investment costs based on the technologies required to address the market needs and the costs associated with installing those technologies. Where cost data could be garnered from existing studies or case studies, we used average costs and referenced the sources. Where cost data was unavailable, we extrapolated from the residential cost estimates. The cost assumptions are detailed in Table 9 and Appendix D. Cost Estimates.

Table 9. Cost Assumptions For Small And Medium Commercial Electrification And Efficiency Measures (Per Unit)

End Use	Total Costs	Unit	Equipment Cost Estimates (% of Total)
Building Efficiency	$5,000–8,000	Per Building	
Building Modification	$20,000–35,000	Per Building	
Gas Disconnection	$400–600	Per Building	
Panel Upgrades*	$10,000–24,000	Per Building	
Heat Pump Water Heater*	$1.03	Per Square Foot	25%
Space Heating Heat Pump*	$3.37	Per Square Foot	25%
Commercial Kitchen Electrification[52]	$16–20	Per Square Foot (kitchen area)	40%
Miscellaneous	$1.5–2	Per Square Foot	25%
Process	N/A	N/A	

Source: San Francisco Municipal Facilities De-Carbonization Study[53]

LARGE COMMERCIAL/MUSH

In the large commercial/MUSH market segment, the equipment and building systems are often complex, requiring more customized decarbonization solutions. Space heating and cooling is sometimes provided by boilers, furnaces, or other HVAC equipment within the building, but it's also common for heating and cooling to be provided from a central plant designed to serve the heating and/or cooling needs of a network of buildings. This study assumes that 80 percent of the large-commercial/MUSH sector will be decarbonized with whole building approaches. This assumes that the economics of electrification will be most beneficial to the consumer if the work is done as part of an extensive building over-haul. We assume the other 20 percent will use centralized district energy solutions for space heating and cooling coupled with on-site electrification of other end uses (i.e., kitchen electrification, hot water electrification, etc.).

Stand-alone building electrification in the large commercial/ MUSH sector will likely be part of a more comprehensive whole-building retrofit including deep energy efficiency. To develop an estimate of the investment required for stand-alone building electrification, we reviewed cost data from the literature (see Appendix G. Literature Review) as well as deep energy retrofit case studies[54] in the large commercial/ MUSH sectors. We estimated a cost per square foot for these project types. The cost assumptions are detailed in Table 10 with more detail in Appendix D. Cost Estimates.

xiii Sweden has an emerging market for waste heat from buildings, pitched as a way to "transform cooling costs into a revenue stream from heat recovery." See OpenDistrictHeating.com.

Table 10. Cost Assumptions For Large Commercial/MUSH Electrification And Efficiency Measures (Per Unit)			
	Total Costs	Unit	Equipment Cost Estimates (% of Total)
Deep Energy Retrofits	$28–81	Per Square Foot	25%
District Energy for Heating & Cooling	$5–39	Per Square Foot	15%
Heat Pump Water Heater[55]	$0.43	Per Square Foot	25%
Commercial Kitchen Electrification[56]	$16–20	Per Square Foot (kitchen area)	40%
Miscellaneous	$1.5–2	Per Square Foot	25%
Process	N/A	N/A	N/A

The cost estimates for electrifying district energy systems apply to both new installation of district systems and retrofits of existing systems. This assumes that even if there is a system in place, new construction, including laying new pipes, is needed to decarbonize the system. The investment cost for the heating and cooling systems was based on Stanford University's[57] and Ball State University's recent district energy projects (See Table 29 in Appendix D. Cost Estimates).

Taking the electrification market potential of small and medium buildings (Table 7), and the costs for electrifying different end uses (Table 9), we determine the average cost per small and medium commercial building is $42,000–54,000 (assuming 450,000 small and medium buildings with gas service in California), with a wide range depending on the number of measures required. Restaurants will likely cost more, while office buildings and warehouses will cost less. The average cost per square foot for electrifying small and medium buildings is $11.76–13.61.

For the large commercial/MUSH sector, the average cost per square foot for whole building efficiency plus electrification is $54.21 (with a range of $28–81), and the average cost for district energy heating and cooling plus end-use decarbonization is $12.95–47.46.

Employment Effects

Based on the estimated costs of electrification and the IMPLAN analysis, this study estimates that California would need 16,000–41,300 full-time construction industry workers per year from 2020–2045 to fully electrify all of California's commercial buildings. Eighty-nine percent of these would be in large commercial or MUSH buildings, due to the higher labor demands of the more comprehensive energy retrofits assumed for large buildings.

The building retrofit work will require electrical, HVAC, plumbing, and carpentry workers. The district energy system jobs require skilled workers from a wide range of construction trades. For example, the Stanford University district energy project employed California union labor from 72 different subcontractors, with significant work for pipefitters and insulators, in addition to the aforementioned trades.[58]

Table 11. IMPLAN Direct Construction Employment Effects For Commercial Electrification		
Sector	Direct Employment Effects (annual average 2020– 2045)	
	Low	High
Small and Medium Commercial Electrification	3,300	4,500
Large Commercial/ MUSH Electrification	11,000	30,900
District Energy Decarbonization*	1,700	5,900
TOTAL DIRECT	**16,000**	**41,300**

These are jobs associated with the construction or decarbonization (capital) costs of district energy systems. One employment analysis of CHP showed the operations and maintenance jobs and induced jobs from cost savings were greater than the construction impacts.[59]

In addition to the installation or construction jobs associated with commercial building decarbonization, there are ongoing maintenance and management jobs. Utility-owned and operated district energy systems in California could provide ongoing jobs for the state's current gas utility workers already trained and qualified to work on networks of pressurized pipes.

Due to the higher than typical investments in equipment associated with building electrification relative to standard maintenance and repair construction activity built into IMPLAN, we modeled the employment impacts from equipment purchases with results shown in Table 12 . Based on our assumptions, building electrification could support an average of 3,200–4,900 full time equivalent (FTE) manufacturing jobs per year over that time period. Efforts to develop equipment manufacturing in California could push this figure higher. To see which energy efficient products are currently manufactured in California, visit: http://www.buildingclean.org/.

Table 12. IMPLAN Direct Manufacturing And Related Employment Effects For Building Electrification		
Sector	Direct Employment Effects (annual average 2020–2045)	
	Low	High
Manufacturing	3,200	4,900

DEMAND FOR ELECTRICITY

Market Analysis

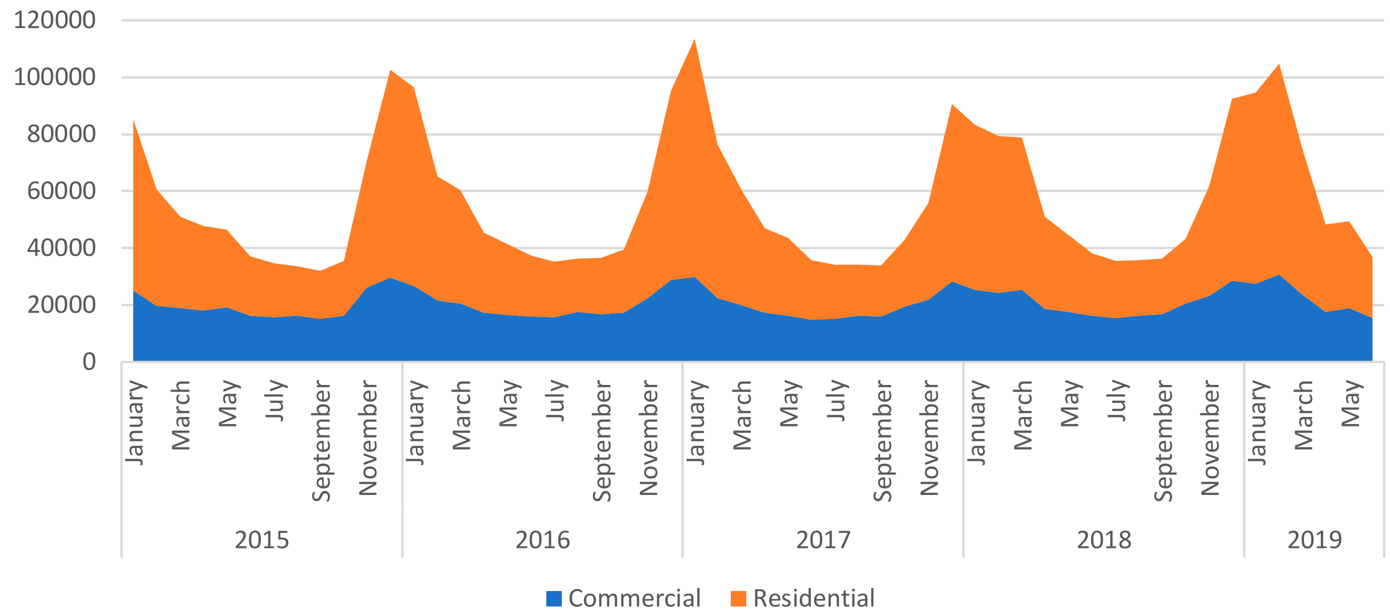
The demand for more electricity under building decarbonization will depend on the efficiency of the buildings, equipment, and systems installed as well as the time of energy use. If all demand growth due to electrification were to occur at off-peak periods and during the winter, new electricity infrastructure could be mostly avoided.[60] This is because the California grid is designed for summer peak load, with spare capacity in the winter. If, however, building electrification increases summer peak demands or creates new winter peaks, the electricity system will need to add both generation and distribution capacity.

Using efficiency factors and technology assumptions described Appendix E. Change in Electricity and Gas Demand, a high-efficiency pathway would add 53–60 GWh annually to California's load, and a low-efficiency electrification pathway using electric appliances with U.S. federal minimum efficiency ratings would add about 75–84 GWh annually, with the range depending on the rate of new building development.[xiv] By 2045, 95 percent electrification of California's residential and commercial buildings equates to a total increase in demand of 26–29 percent.[61] For reference, NREL's *Electrification Futures Study* showed that electrification of buildings and industry in the United States would increase 2050 electricity demand by more than 25 percent.[62]

To determine the timing of this demand, we look at the pattern of residential and commercial gas consumption. Figure 11 shows the building gas demand by month for 2015 to early 2019. Currently, California's natural gas consumption in residential and commercial buildings is skewed to the winter months; half of total gas consumption occurs during the four winter months of November, December, January, and February. Only about 20 percent of total gas is consumed during the summer.[63,64] Replacing gas appliances with electric versions will likely skew new electricity use to winter months when heating needs are highest.

xiv E3 estimates an increased demand from buildings of 52,700 GWh by 2050, but their electrification scenario is less aggressive than the one assumed here (CEC 2018).

Figure 11. California Building Gas Consumption by Month (MMCf)

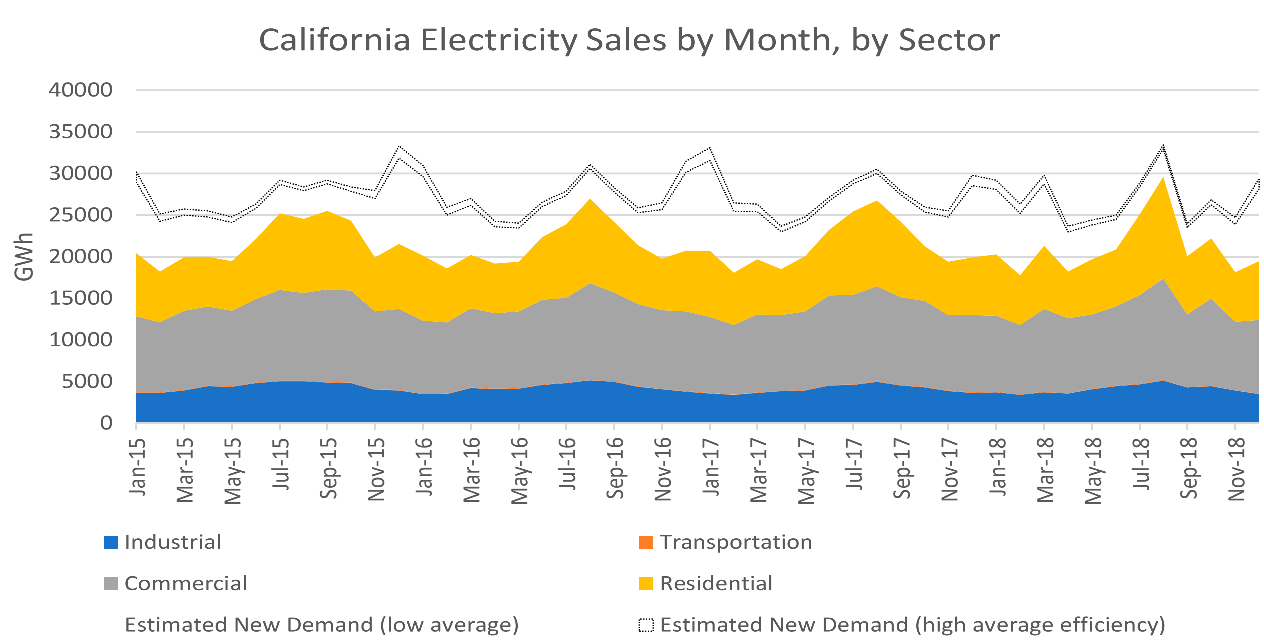


Source: Author's analysis from U.S. EIA data[65]

We used this gas demand pattern to plot a new month-by-month demand for electricity resulting from building electrification. The dotted black lines in Figure 12 illustrate the potential changes to the seasonal pattern of electricity demand due to building electrification. This is backward looking, presenting past energy usage overlaid with the hypothetical electricity demand associated with a 95 percent building electrification scenario in 2045.

This chart illustrates two important considerations. First, building electrification to replace existing gas demand could increase summer peak electricity demand if buildings add air conditioning where they did not have it before — a likely result of installing heat pumps for space heating, which can run in reverse to provide cooling. Second, building electrification will likely increase winter electricity demand significantly — by over 50 percent because heating currently provided by gas would be provided by electricity. This could create new demand peaks in the winter, when California land-based wind and solar (the most common sources of in-state renewable energy) are less productive.

Figure 12. California Electricity Sales By Month with Projected Increase From Building Electrification, by Sector (GWH)

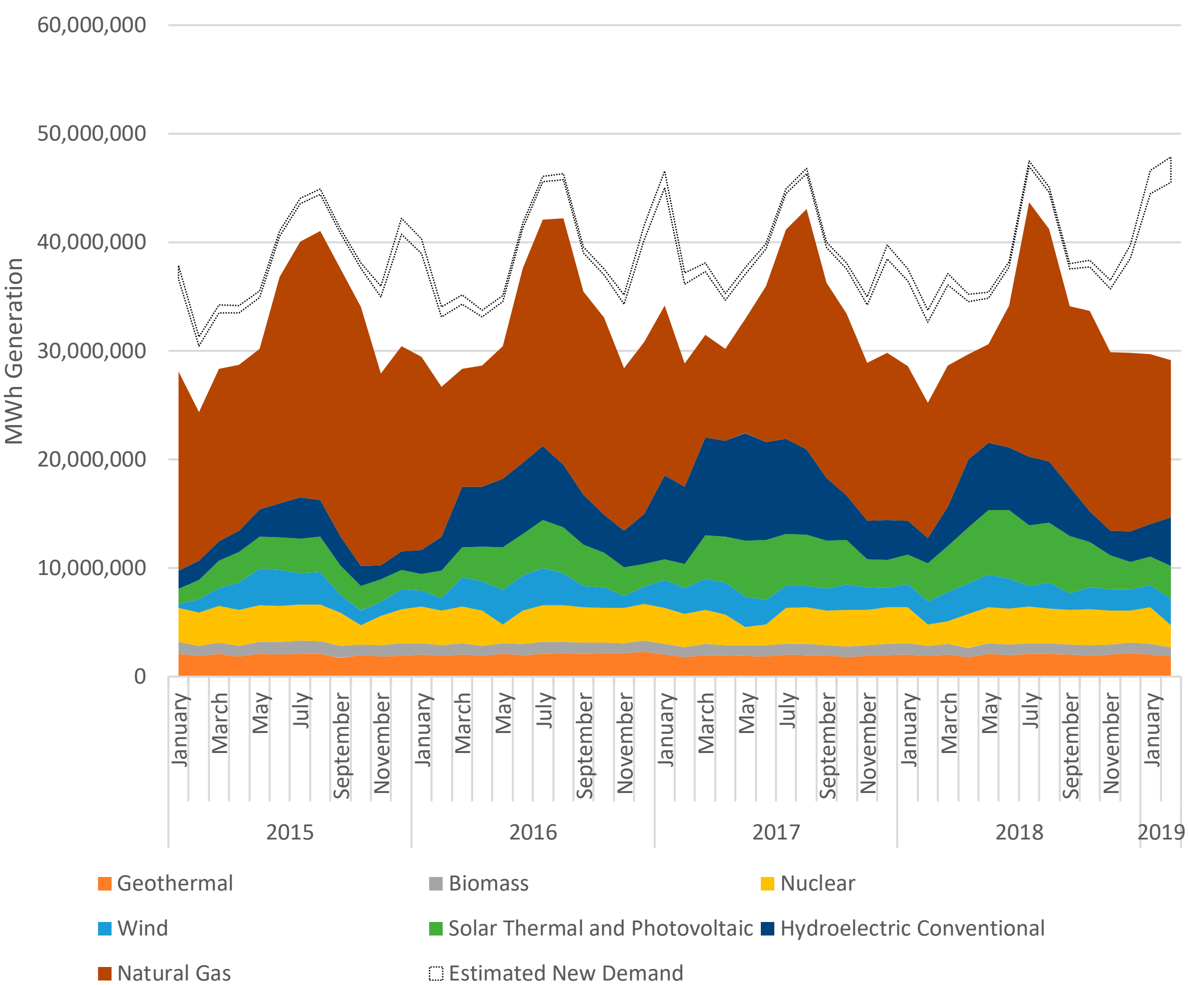


Source: Author's analysis from U.S. EIA data[66]

Figure 13 shows the current electricity generation by month by energy source. Wind and solar together generated 4,400 GWh in December 2018 (7% of total in-state generation), while the same facilities can produce more than twice that amount in the month of June. The dotted black line projects new monthly electricity demand due to building electrification on past electricity generation. The seasonal mismatch between new demand and in-state renewable generation means that it could be challenging to meet new winter electricity demand with in-state land-based wind and solar. Currently natural gas generation is used to satisfy peak demand. As California continues to move away from gas generation, other sources of clean winter energy such as offshore wind,[xv] geothermal, biomass, landfill gas, electricity imports, and/or long-term energy storage will be needed to meet winter electricity needs.

xv The September 2019 report by UC Berkeley and E3, *California Offshore Wind: Workforce Impacts and Grid Integration* makes note of the winter offshore wind potential and concludes that California will need 20 GW of offshore wind to comply with Senate Bill 100.

Figure 13. California Electricity Generation by Source, by Month (TWH)



Source: Author's analysis from U.S. EIA data [67]

Investment Estimate

NEW GENERATION

A capacity factor is a measure of the percent of actual energy output relative to nameplate capacity. Capacity factors vary enormously by source of energy, technology efficiency, and other variables. The higher the capacity factor, the less capacity is needed to produce the same amount of energy. For example, in the winter, a 5 MW geothermal plant (with a capacity factor of 80%) will produce approximately 4 times the electricity as a 5 MW solar plant (with a capacity factor of 20%). We used winter capacity factors of different California renewables to calculate new capacity needed to meet new peak electricity demands.

The new capacity projections used in this study are based on the distribution of power generation by source in the "High Electrification" scenario in the *Deep Decarbonization in a High Renewables Future* report developed by E3 for the

CEC.[68] E3's scenario relies heavily on solar and wind. Their assumptions are based on flexible load shifting and new out-of-state imports to achieve the lowest possible GHG abatement cost.

E3's high electrification scenario includes both transportation and building electrification, whereas this study looks only at buildings. This study also assumes a 95 percent transition from gas to electricity in buildings, which will depend on some early retirement of equipment (a more aggressive scenario than the one modeled by E3). For these reasons, we used E3's generation ratios but calculated our own capacity requirements.

Table 13. New Renewable Capacity Required to Meet Building Electrification-Driven Winter Demand

Energy Source	Solar PV	Wind	Geothermal	Biomass & Landfill Gas	Out-of-state or existing hydro or gas	TOTAL
Assumed Winter (Jan*) Capacity Factor	0.20	0.15**	0.71	0.68	N/A	**N/A**
Percent of Energy Generation* **	49%	34%	7%	0%	10%	**100%**
New Peak Winter (Jan) Demand in 2045 (GWh)	5,320–6,070	3,690–4,210	760–870	--	1,090–1,240	**10,900–12,400**
New CA Capacity Required by 2045 (GW)	35.7–40.8	33.1–37.8	1.4–1.6	--	--	**70.2–80.2**

**Based on the conversion from gas to electric appliances, electricity demand peaks in the month of January, so the capacity is calculated from new January generation requirements. U.S. EIA has average national capacity factors, which is 0.17 for solar and 0.39 for wind.[69] We assumed the average California winter solar capacity factor is higher and the wind lower than the national average.*

*** A useful tool for exploring California wind potential is the* Visualization of Seasonal Variation in California Wind Generation[70]

****Source: High electrification scenario in the* Deep Decarbonization in a High Renewables Future *report developed by E3 for the CEC.*[71]

Employment Effects

CONSTRUCTION

IMPLAN does not account for the different spending patterns between different types of energy infrastructure (e.g., solar, wind, natural gas, etc.). To assess the employment and economic impacts of different energy sources, NREL developed the Jobs and Economic Development Impact (JEDI) models to allow for a more granular analysis of jobs impacts by energy source. JEDI is built on IMPLAN multipliers but accounts for different spending patterns that the industries built into IMPLAN.[72] The most recently available JEDI models[73] were used to estimate employment effects of renewable energy construction, with results referenced against published literature.[74] A summary of the inputs and multipliers is provided in Table 14 .

Table 14. New Generation Capacity to Meet Increased Demand and Employment Multipliers

Renewable Energy	New Capacity by 2045 (MW)	Direct Construction Jobs per MW
Solar PV	35,700–40,800	11.5
Wind	33,100–37,800	0.76
Geothermal	1,400–1,600	10.3
Infrastructure for Grid connectivity	N/A	N/A
TOTAL	**70,2300–80,200**	**N/A**

In addition to the construction of the power plants themselves, there is additional construction needed to build electric transmission lines from the generating station to the point of interconnection with the electricity grid, usually at a substation.[75] These costs are highly variable and dependent on the location of new electricity generating resources relative to existing transmission infrastructure. To estimate these costs, we use the mid-case interconnection cost estimates from the CEC *Estimated Cost of New Utility-Scale Generation in California* report.[76] These estimates are summarized in Table 28 in Appendix D. Cost Estimates.

Table 15. Employment Estimates From New Renewable Construction

Sector	Direct Employment Effects (annual average 2020–2045)	
	Low	High
Construction		
Solar PV	16,400	18,800
Wind	1,000	1,100
Geothermal	600	700
Infrastructure for Grid connectivity	2,300	2,600
TOTAL DIRECT	**20,300**	**23,200**

In total, as shown in Table 15 , this study estimates that meeting new demand for electricity due to electrification of California's buildings would require an average of 20,300–23,200 FTE construction workers building new utility-scale renewables per year from 2020–2045.

ELECTRICITY GENERATION AND DISTRIBUTION

After new power generation capacity is built to meet increased demand for electricity, there will be ongoing jobs associated with electricity generation, transmission, distribution, and customer service. We estimated the increase in labor demand by calculating the value of increased electricity sales and using IMPLAN to estimate the employment associated with the affected industries. This method assumes an increase in the workforce proportional to sales increases. See Table 32 in Electricity Sales in Appendix E. Change in Electricity and Gas Demand for more detail on these calculations.

As described above, electrification of California buildings would increase electricity sales by 67,300 to 76,800 GWh by 2045. Table 16 shows the assumed distribution of electric utility revenue across industries.

Based on this distribution, by 2045, increased electricity sales (associated with 100% building electrification) would support 10,400–12,400 workers in renewable generation, transmission and distribution, and other utility jobs.

Table 16. Estimated Allocation of Increased Electric Utility Revenue by Industry

	Annual Revenue (2045) in $billion (2019 dollars)	
Industry	**Low**	**High**
Generation*	5.90	6.74
Solar	2.89	3.30
Wind	2.01	2.29
Geothermal	0.41	0.47
Out-of-State	0.59	0.67
Distribution and Transmission	6.31	7.21
Other	1.04	1.13
TOTAL**	**$13.22**	**$15.11**

**Estimated Levelized Cost of Energy (LOCE) is assumed to be approximately the same across these resources.[77]*

***May not sum due to rounding*

Table 17. Employment Estimates In Electricity Generation and Distribution

Sector	**Direct Employment Effects (Year 2045)**	
	Low	**High**
Generation		
Solar	3,800	4,900
Wind	900	1,000
Geothermal	500	600
Out-of-State	—	—
Distribution and Transmission	3,600	4,100
Public Purpose Charge and Other	1,500	1,800
TOTAL	**10,400**	**12,400**

DEMAND FOR GAS

Market and Cost Analysis

It's easier to conceptualize how the electricity industry will expand than how the gas industry will contract. What is the trajectory and speed at which building electrification will occur? Will customers gradually switch from gas to electric appliances to avoid increasing costs of gas or because the technology is preferable? Where and how will gas throughput decline? And most importantly, how will the industry respond to decreasing sales? The answers to these questions are not yet known.

Also unknown are the ripple effects of decreased residential and commercial gas use. As Figure 1 shows, residential and commercial customers make up close to 80 percent of Pacific Gas & Electric's (PG&E) gas revenue. With shrinking sales, how will utility revenue requirements be met? The biggest short-term threat to gas employment is not reduced gas sales but the industry destabilization of an unpredictable reduction in sales. If costs and sales are reduced simultaneously, a death spiral could be averted. For workers, unpredictable layoffs are more challenging that intentional contraction of the workforce—one aligned with retirement and attrition rates and offering incentives for workers who remain or relocate to meet changing needs.

EQUITY CONSIDERATION

Low-income households are both less likely to afford to convert to efficient electric appliances and more sensitive to higher prices. How gas revenue requirements will be met while gas sales are shrinking is an important equity question. As Maximilian Auffhammer and Edward Rubin (2018) show in their working paper Natural Gas Price Elasticities and Optimal Cost Recovery Under Consumer Heterogeneity: Evidence from 300 Million Natural Gas Bills, lower-income households "are substantially more elastic to price than higher income households," particularly in the winter.[78] This means that low-income households are more like to respond to higher gas prices by lowering the heat in their homes. Auffhammer and Rubin suggest that for optimal and more progressive cost recovery, extra costs (including carbon taxes) would be better added in the summer.

To estimate the employment effects, this study assumes the following. (1) Gas employment effects in the gas distribution sector will be proportional to the reduction in sales, so a 95 percent reduction in throughput will result in a 75-95 percent reduction in the associated gas distribution workforce. (2) Gas employment effects in the extraction side could have zero effect on in-state extraction employment because California imports 90 percent of the natural gas it consumes. California produces about 200,000 million cubic feet of natural gas[79] and consumes 2,111,000 million cubic feet, of which 32 percent is used in buildings.[80] California could reduce statewide gas use by 90 percent without affecting in-state gas extraction jobs at all. A 95 percent reduction in commercial and residential gas use would represent only a 30 percent reduction in statewide gas use, and, this could be fully achieved by reducing gas imports. This would likely require public policy intervention to support in-state gas extraction jobs.

To estimate employment impacts in the gas industry, we multiplied the current retail prices[xvi] by total residential and commercial building consumption. In 2017, that consumption totaled 623,684–668,365 million cubic feet.[81,82] and the value of the retail sales from that consumption in 2017 totaled $7.07–7.46 billion.[xvii]

California's investor-owned utilities (IOU) sold 96 percent of the gas consumed by residential and commercial customers.[83] Residential sales covered 42 percent of IOU sales and an estimated 55 percent of their revenue requirements: commercial sales covered 20 percent of sales and an estimated 19 percent of revenue requirements.[84,85] We assume that the size of the workforce is a function of the revenue from each sector, meaning that residential sales support 55 percent of the utility workforce and commercial sales support about 19 percent. Because residential gas is more distributed, we assume that maintaining gas service for residential customers is more labor-intensive than for commercial customers. We assume that the distribution of revenue requirements determined by the CPUC for the IOUs (Table 18) is the same as for other (non-regulated) gas providers.

xvi These prices do not account for requested rate increases (or the associated increase in employment) for distribution system maintenance and repair.

xvii The low end of the range represents consumption in commercial buildings only, while the higher end of the range includes all commercial gas use.

Table 18. Distribution of Gas revenue Requirements by Component Category and Estimate of Total Revenue by Component Category (2017 $billion)					
Component	**Average Percent**	**Residential**	**Commercial**	**Total**	**Direct Employment effects (2017)**
Core Procurement	26%	$1.398–1.400	$0.440–0.541	$1.838–1.940	6,600
Transmission, Distribution, and Storage	67%	$3.603–3.607	$1.133–1.393	$4.737–5.000	7,200
Public Purpose Charge	7%	$0.376–0.377	$0.118–0.146	$0.495–0.522	1,500
TOTAL	**100%**	**$5.378–5.383**	**$1.692–2.079**	**$7.070–7.462**	**15,300**

Source of dollar figures: The higher end of the range is provided by U.S. EIA[86] which does not separate commercial building energy use from other commercial energy use. The lower end of the range is from the CEC[87] (converted to million cubic feet), in which we only included commercial buildings. Source of distribution by component: CPUC.[88]

Employment Effects

Given the total employment effects associated with 2017 residential and commercial gas sales (Table 18), we estimate that total percent building electrification would result in a loss of up to 15,100 jobs by 2045. Zero to 6,600 of these jobs would be associated with the extraction of gas; 5400–7200 would be associated with the delivery of gas, while 1500 would be working in gas efficiency or other public purpose programs (which would be made up for with increased electricity public purpose programs). Table 19 provides a summary of these figures.

Table 19. Employment Estimates In Gas Extraction and Distribution		
Sector	**Direct Employment Effects (Year 2045)**	
	Low	**High**
Core Procurement	0	-6,600
Transmission, Distribution, and Storage	-5,400	-7,200
Public Purpose Charge	-1,500	-1,500
100% Building Electrification by 2045	-6,900	-15,300

IMPLAN indicates that there are 25,300 workers in the state employed in the natural gas and crude oil extraction industry[xviii] and 33,500 engaged in natural gas transmission, storage, and distribution. The electrification of buildings could affect up to 0–25 percent of the extraction workforce and 16–20 percent of the transmission and distribution workforce. With a well-planned gas transition, to support current in-state gas production, layoffs could be minimized through retention and relocation support of younger workers as older workers transition to retirement.

xviii IMPLAN aggregates natural gas and oil extraction.

WORKER TRANSITION PLANNING AND JOB QUALITY

The transition away from natural gas in residential and commercial buildings raises several equity concerns relating to the disproportionate burden of this transition on particular groups, namely displaced workers and vulnerable consumers, including low-income households, renters, and gas-dependent businesses.

Worker Transition

The utilities provide “bundled” gas services (i.e., procurement and delivery services) to most residential and commercial customers. Some large commercial and industrial customers, however, purchase “unbundled” services, in which they procure the gas commodity from third-party marketers, while the utilities are paid for the service of delivering the commodity. Other large commercial and industrial customers bypass the utilities’ transmission and distribution systems altogether.[89] As a result of this industry structure, residential and commercial sales account for a high number (74–79%) of the gas utility workers.

Declining sales to residential and commercial customers could increase prices for remaining customers. This could trigger more customers to seek alternatives, including alternative heat sources or even not using heat (a risky alternative deployed by low-income customers), which would raise prices further.

Long-term planning is needed to support an orderly transition away from natural gas and toward a clean energy economy. This planning effort will need to manage a planned contraction (or pruning) of the centralized gas distribution system, while also retaining a skilled and trained workforce to maintain a smaller system. A future for gas utilities and their workers may require shifting away from providing gas through an expensive-to-maintain centralized network to providing energy (not necessarily gas) for customer needs. This could mean a significantly smaller distribution network, non-pipeline deliveries of gas to large isolated customers, delivery of different heating fuels or electricity, or delivery of heating and cooling directly through district energy systems.

Transition planning involves not only retaining skilled workers and addressing the needs of workers displaced from the natural gas industry, but also ensuring that new jobs in building electrification and decarbonization are high-road, good quality jobs.[90] Workers facing displacement because of the decrease in natural gas consumption will need protection of benefits earned during their tenure as well as access to resources to retire or find new employment. For those workers approaching retirement age, public and private funds can provide a bridge to retirement and help to secure pension and healthcare benefits. Younger workers should have access to high-road career-pathways through paid on-the-job training like apprenticeship, and access to quality, unionized work with comparable pay and benefits. While specific transition needs should be negotiated with workers and their unions, the following could be considered:

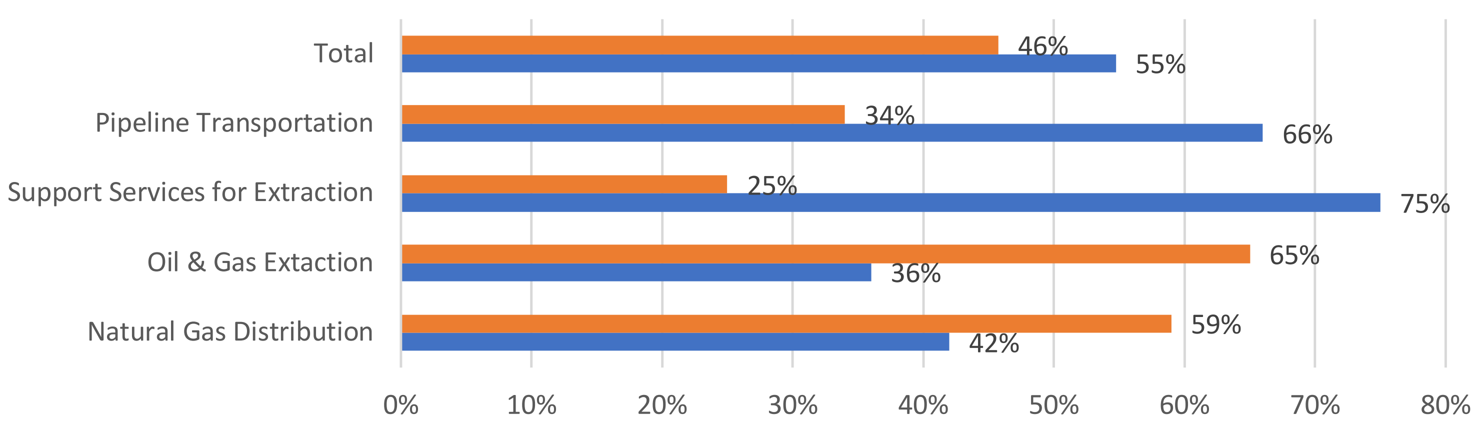
- Retention and relocation bonuses to keep skilled and trained workers employed to maintain safe and reliable service, even as the industry is in decline;
- Pension guarantee for current workers;
- An appropriate "glide path" to retirement for workers who are 60 years and older;
- Retraining resources (extended unemployment or wage replacement, retraining, relocation assistance, and wage insurance); and
- Priority hire in utilities and on publicly-supported energy projects for workers seeking new employment.

The costs of these programs can be minimized if displaced workers are guaranteed re-employment in jobs in the growing low-carbon economy, the electricity industry, or within the public sector.[91] When workers face difficulties finding reemployment, transition assistance can be used as a backstop. As part of gas transition planning, a public or utility fund should be established to plan for the eventual costs of worker transition support.

Industry Occupational Characteristics

Fifty-five percent of overall work in natural gas is blue-collar, construction work and 45 percent is white-collar, office work. Figure 14 shows the distribution by blue- and white-collar workers across the gas industry. The workers performing administrative, marketing, finance, and other types of white-collar work have skills that translate well to other industries and sectors, whereas the blue-collar workers, who rely on skills more specific to natural gas distribution, may need more access to retraining and wage insurance. Women make up about 25 percent of the industry workforce, as do people of color.

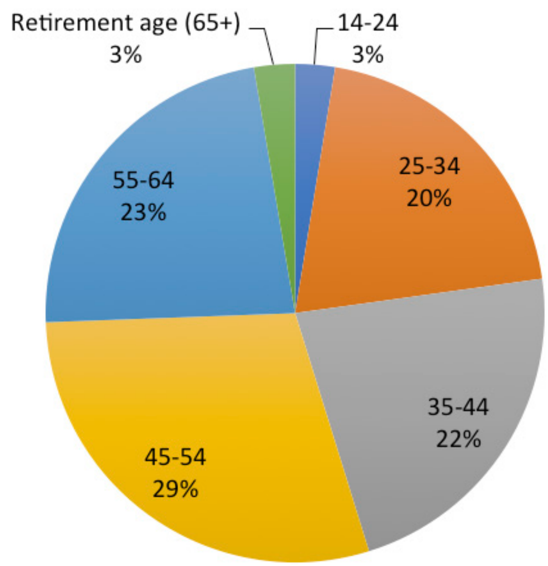
Figure 14. Distribution by Blue- and White-Collar Workers Across Gas Industries



Source: QCEW

Figure 15 shows the current age distribution of the natural gas workforce. This figure showing that 55 percent of the workforce is above the age of 45 and will reach or pass the retirement age of 65 within the next 25 years reiterates that good transition planning can ensure that workforce contraction aligns with retirement.

Figure 15. Current Age Distribution of Natural Gas Workforce



Source: QCEW

Job Quality Implications of Building Decarbonization

Electrifying buildings can involve many traditional building trade occupations, but it will primarily engage HVAC contractors, electricians, and plumbers, corresponding to the C-4, C-20, C-10, and C-36 trades.[92] It is unclear what the net impact will be within individual trades; some trades well-represented in the gas industry could face more job loss than gain, particularly if electrification is pursued solely through a stand-alone building approach without centralized district energy solutions playing a part.

Job quality is not only a concern for workers. The quality of a job is inextricably linked to the quality of the work performed. This is particularly evident when dealing with building systems and complex technologies that use sensors and controls, like HVAC. There are three key ways to improve work quality: 1) Upfront labor standards (licensing or training requirements, wage standards, responsible contractor criteria, etc.), 2) Labor law and building code compliance, and 3) Improved Quality Assurance, Quality Control, Evaluation, or Verification that identifies and holds accountable the source of failure (manufacturer, installer, user error, etc.).

1. **Labor Standards are upfront conditions that employers must meet to legally perform work.** In the case of building electrification and other complex building work, broad occupational credentials and apprenticeship or equivalent training would be appropriate. Successful building electrification requires understanding more than how to install a particular piece of equipment. It requires understanding the building as a system and how to optimize that system with new technology. This understanding would be very difficult to attain through on-the-job training alone. Relevant classroom training is offered through a community college occupational degree program or registered apprenticeship.

   The appropriate skill standards can be required by law or as a condition of qualifying for rebates, permits, or incentives. Vetting and pre-qualifying contractors eligible to receive public or ratepayer incentives for heat pump or other electrification appliances is an excellent way to instill consumer confidence and stimulate market transformation.[93] A California survey of consumers indicated that contractor pre-qualification is the highest ranking area of support that the state can provide consumers.[94] This is particularly true in the residential and small commercial sectors in which consumers lack the expertise to evaluate worker skill and work quality.

   Centralized or aggregated smaller projects can create the economies of scale needed to adopt labor standards through a project labor agreement (PLA) or community workforce agreement (CWA) and drive down per unit costs without weakening labor standards.

2. **Building code and labor law compliance** is critical to supporting quality work and safe jobs in building electrification. A recent study completed for the CPUC showed that the majority (71–92%) of HVAC systems are unpermitted, resulting in "defective installation, safety hazards for homeowners and contractors, higher energy usage, and higher maintenance costs."[95] This points to the need to aggressively address extremely low rates of compliance with California building code and licensing requirements.

To support electrification, there may be a need to clarify licensing requirements for electrification activities. For example, installing a heat pump water heater currently could require a C-20 HVAC contractor, a C-36 plumber to connect with the water system and decommission gas lines, and a C-10 electrician to add new circuits and upgrade electrical panels.[96] Even for a single piece of equipment, the work is complex. Yet, revising licensing criteria is also challenging and can pose safety risks for workers and customers. The goal should be to engage skilled, qualified, and appropriately licensed contractors. Making the licensing criteria too loose can accelerate the "race to the bottom" flooding the labor market with unqualified workers.

Although California has robust permitting and contractor licensure requirements, compliance remains a concern. Existing law states that in order to receive a rebate or incentive offered by a utility for an energy efficiency improvement or for the installation of energy-efficient components, equipment, or appliances in buildings, the recipient is required to certify that the improvement or installation complied with any applicable permitting requirements. Additionally, if a contractor performed the installation or improvement, the contractor needs to hold the appropriate license for the work performed.[97] Enforcement is a challenge.

Senate Bill (SB) 1414 (Wolk), signed into law in 2016, was designed to increase compliance with permitting and inspection requirements for central air conditioning and heat pumps. The law requires a customer or contractor receiving an incentive from an IOU for purchasing or installing heating and cooling equipment to provide a proof of permit closure.[98] These types of measures support not only work quality (making sure equipment is installed for safe and efficient operation), but also job quality, protecting workers from wage theft and other labor law violations common in the underground market of residential construction work.

While compliance enforcement will help support a high-road environment in the residential and small commercial sectors, compliance alone cannot shift the entrenched labor market dynamics in which contractors compete primarily on cost rather than skill.

3. **Quality Assurance/Quality Control** and improved evaluation and verification can identify reasons for failures to achieve modeled outcomes. Sometimes equipment fails due to a manufacturing defect; sometimes it fails due to poor installation or commissioning, and sometimes it fails due to user error. When such failures go unnoticed or that remain unattributed, there is no way to hold the manufacturer or installer accountable. Performance-based incentives — or disincentives for performing poor quality installations — can help weed out low-performing or unskilled contractors and improve work quality. When work quality is not properly evaluated, skilled workers may see no advantage to their participation in a particular line of work.

BENEFITS OF CENTRALIZING OR AGGREGATING ELECTRIFICATION WORK:

Neighborhood- or business district-scale electrification is useful beyond creating the economies of scale to improve job and work quality. Geographic aggregation would also allow for more deliberate "pruning" of the natural gas distribution system where repair and maintenance costs are highest. This approach — a planned contraction of the natural gas distribution system coinciding with targeted investments in neighborhood electrification — would enable both a planned contraction of the natural gas workforce and a high-road path to decarbonization of the residential and small commercial sectors. Criteria for determining appropriate neighborhoods should include the following:

- Age/vintage of the current system as well as incidence of methane leak and other repair needs (those with most repair needs should be targeted first);
- Location within the gas distribution system (communities on distant branches of the distribution system should be targeted before those on main thoroughfare);
- Seasonal gas consumption; and
- Income of the residents (neighborhoods least likely to bear the costs of higher gas prices should be provided early opportunities for electrification).

RECOMMENDATIONS FOR HIGH-ROAD ELECTRIFICATION

California policy makers should aim to expand high-road opportunities that offer family-sustaining wages, benefits, and job security for workers. Because they procure services, climate and energy agencies, utilities, and local governments exert the most influence on the labor market through demand-side strategies.

By establishing (or failing to establish) workforce standards, agencies set the bar for the level of skill and training of workers in the labor market, particularly in emerging industries. Agencies can, with deliberate effort, support high-road workforce development, or they run the risk of inadvertently supporting a low-road environment. Often, concerns about project costs lead to decision makers seeking ways to reduce soft costs—especially for labor.[xix] But reducing labor expenses has high costs for society, for individual workers, and for businesses that train and employ skilled workers.[99]

The ten recommendations in this study fall into three basic categories: **(A)** Engage affected workers and unions; **(B)** Prioritize demand-side strategies; and **(C)** Target investments in supply-side (training) strategies. The demand and supply-side strategies can be implemented at the local level, where building decarbonization work is already underway. Transition planning is best managed at the utility or state level.

A) Engage with Affected Unions to Grow Good Jobs and Minimize Job Loss

1. **Create conditions that attract skilled workers.** Engage local building trades councils and Labor Management Cooperation Committees (LMCCs) to identify where goals align. Building electrification is complex work requiring skilled and trained building professionals across a range of occupations. The building trade unions and their signatory contractors co-invest in the best-in-class training for construction professionals: apprenticeship. Working with apprenticeship coordinators to ensure training curriculum covers electrification work and technology presents a solid path to developing a skilled and trained workforce for this work. Furthermore, ensuring work opportunities for apprenticeship-trained workers ensures those skills and knowledge will be deployed in real-world environments.

2. **Plan an orderly transition.** Engage labor, ratepayer advocates, utilities, and other stakeholders and experts in long-term planning process. The goal is to methodically contract and eventually decommission the natural gas distribution system in California in a way that is safe, economical for remaining customers, and minimizes worker displacement. This should include avoiding new investments in gas system expansion that will not be recoverable.

3. **Develop a fund for gas worker retention and transition assistance.** Worker transition assistance should include bridges to retirement for older workers and wage replacement, retraining, and job placement assistance for younger workers. In addition, as California's natural gas system is condensed, it is paramount to retain a skilled and trained workforce to ensure safety and reliability of the system as it contracts.

B) Prioritize Demand-side Strategies

Demand-side interventions to support high-road employment include: investing in high-road sectors and opportunities (those that require and appropriately compensate a skilled and trained workforce), aggregating smaller projects, and establishing workforce standards for programs and policies. Local jurisdictions should:

xix In their "How-To Guide: Net-Zero Retrofit Technical and Cost Benchmark Studies" the Rocky Mountain Institute, states (p.2), "...high labor rates in San Francisco increase the potential for off-site pre-fabrication to significantly reduce project costs." Statements like this are common in clean energy, climate advocacy, and technical assistance documents and presentations, but driving down costs by reducing labor costs has direct negative consequences for skilled workers in the local construction market and may actually slow market adoption.

4. **Pre-qualify contractors.** Agencies can help to stimulate market transformation and improve consumer confidence by pre-qualifying contractors as eligible to receive public or ratepayer incentives for heat pump or other electrification appliances.[xx] Ideally, this would be coordinated at the statewide level, but individual jurisdictions could also implement a contractor vetting process.

5. **Condition incentives on skill standards or offer incentives (i.e., accelerated permitting, financial remuneration, etc.) for projects that meet certain workforce criteria.** Condition rebates and incentives for electrification on skill standards and/or responsible contractor criteria to attract high-performing contractors, ensure work quality, and prevent wage and labor law violations common in the residential construction market. Heating, ventilation, and air conditioning (HVAC) skill standards should be applied to building decarbonization policies and programs at all levels (i.e., local government and utility programs, Title 24 building code compliance, state policy, etc.)[xxi]

6. **Lead with the large commercial and municipal, university, school, and hospital (MUSH) sector.** The large commercial and MUSH sector draws workers from registered apprenticeship programs and the unionized construction workforce. By prioritizing decarbonization and electrification in this sector, the state can utilize the best-in-class training for skilled construction workers and seed a qualified electrification workforce in California. Through project labor agreements or community workforce agreements, these projects can provide training opportunities for workers facing barriers to employment.

7. **Pursue aggregated community-scale decarbonization.** Targeting projects in regions or neighborhoods planned for new natural gas infrastructure or in need of upgrades is a smart way to "prune" the natural gas distribution system and minimize future stranded assets. Aggregating or bundling small commercial and residential projects can improve the economies of scale, reduce contractor marketing expenses, accelerate market adoption, and enforce skill standards to enhance both the quality of the work performed and the quality of jobs for workers. Geographic pilots should adopt and enforce prevailing wage and targeted hire standards to improve job quality and access for disadvantaged workers.

8. **Invest in decarbonized district energy.** Decarbonization of existing and the expansion of new district energy systems provide a carbon-free pathway to create and sustain good jobs for California's gas workers, plumbers, and pipefitters as well as a new line of business for gas utilities. Like the gas system, district energy systems rely on underground networks of pipes, but instead of moving gas, they move hot water to provide heating and cooling directly to buildings. District energy systems can be powered by a wide array of renewable energy sources, reducing reliance on the electric grid, and their use could be expanded beyond current applications to new residential developments, redevelopment zones, campuses, business parks, and whole neighborhoods. (See Decarbonized District Energy Addendum for more information).

C) Target Investments in Supply-side (Training) Strategies

Most people think about workforce development as a set of training programs and activities, but it is important to recognize that only when training is calibrated to market demand do positive outcomes ensue. Creating stand-alone training programs or over-investing in training, can lead to negative results in the labor market, such as flooding it with more workers than there are jobs, suppressing wages, and diluting the skill of the workforce. Thoughtfully targeted training interventions can avoid these outcomes and more effectively support clean energy goals. Local jurisdictions should:

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xx While many utilities across the country pre-qualify contractors for various programs, California investor-owned utilities (IOUs) and agencies have refrained from undertaking this activity due to concerns of potential legal vulnerability resulting from making contractor recommendations.

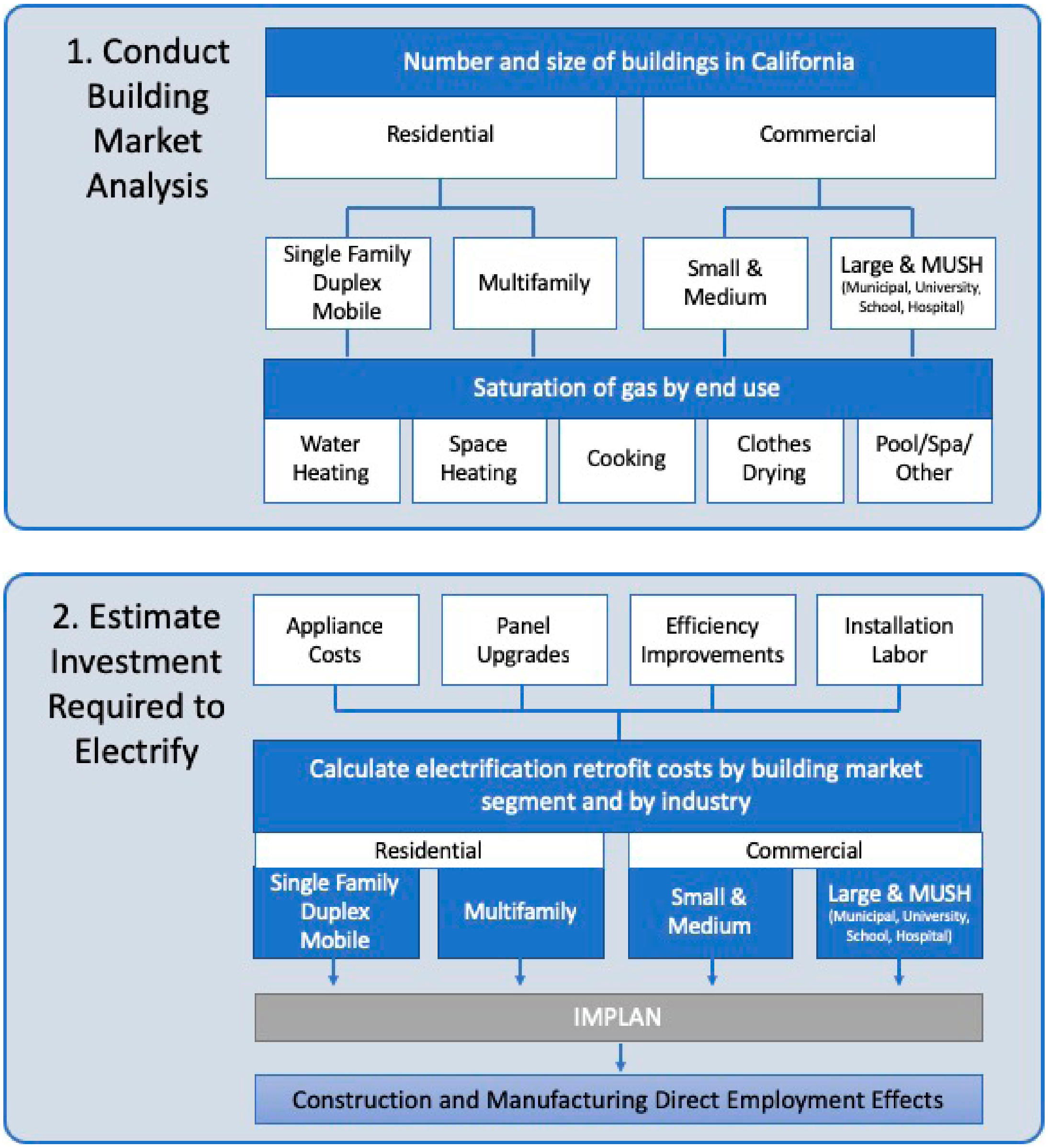
xxi See discussion about comments and recommendations on pages 7–20 in CPUC (2018). *Proposed Decision Addressing Workforce Requirements and Third-Party Contract Terms and Conditions*, dated 10/11/2018. The 2018 standard adopted by the CPUC requires that workers installing HVAC systems have completed or are enrolled in an accredited HVAC apprenticeship in HVAC installation; completed at least five years of work experience and all other requirements in the HVAC craft which has workers classified as journeymen in HVAC installation or a related field at the journey level as defined by the California Department of Industrial Relations, passed a practical and written HVAC system installation competency test, and received credentialed training specific to the installation of the technology being installed; or have at least five years of experience as an experienced worker, not a trainee, and is fully qualified and able to perform in the specific HVAC trade without supervision.

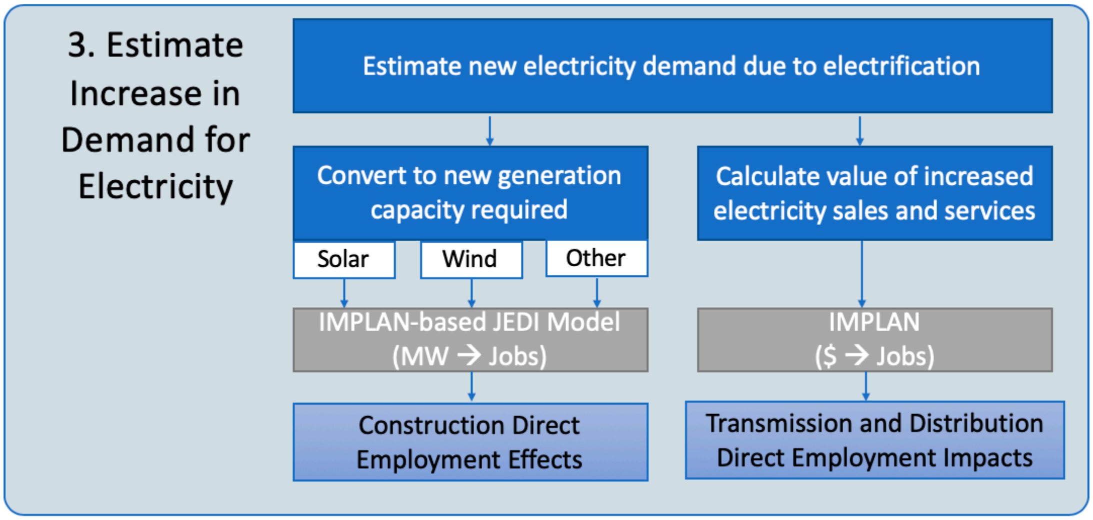
9. **Support the up-skilling of workers through stackable credentials.** Workforce training is needed to support quality work: however, specialized training should be used in addition to (not instead of) broad occupational training. The trades most needed for building decarbonization are electricians, sheet metal and HVAC workers, and plumbers and pipefitters. Building decarbonization training will be most effective if it is targeted to workers with licenses in these trades rather than to general contractors or other market actors. Programs like California Advanced Lighting Control Program (CALCTP), a training for electricians for advanced lighting controls, or Electric Vehicle Infrastucture Training Program (EVITP) for electric vehicle infrastructure, are good examples of the type of stackable credential training that will likely by most effective for building electrification.

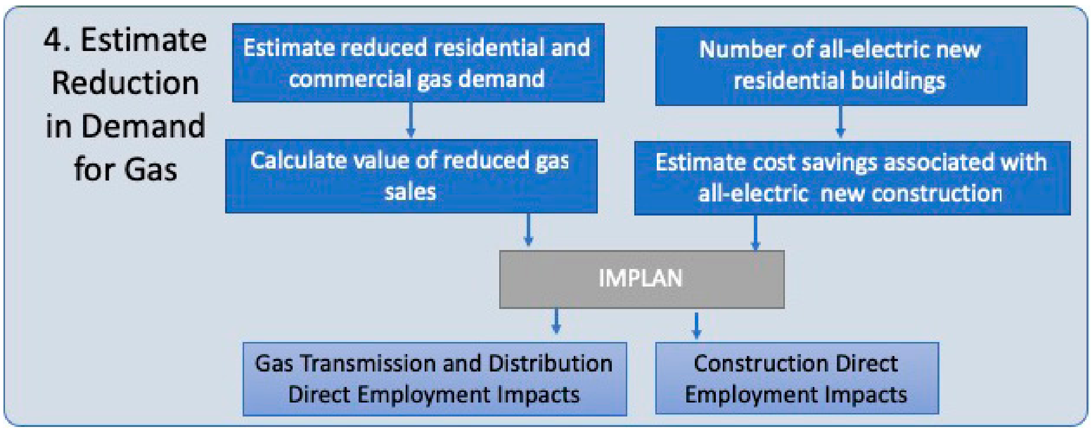
10. **Structure the work to create opportunities for disadvantaged workers.** Support high-road construction careers (HRCCs) for construction and develop high-road training partnerships (HRTPs) for manufacturing and other skills needed for building decarbonization. California's HRCCs and HRTPs work to improve job access for disadvantaged workers and support their career development. Community-based organizations are well-positioned to serve the specific needs of individuals in their communities. When these frontline training organizations have formal agreements with employers, agencies, and apprenticeship programs, better job training and placement outcomes are achieved. Forging stronger partnerships between different facets of the workforce development and support system is key to improving outcomes for disadvantaged workers.

Climate science tells us that we must rapidly and dramatically reduce emissions to maintain a habitable planet.[100] This will require shifting the way we use energy from the direct combustion of fossil fuels to clean and safe electricity. There are pathways to building electrification that can create good jobs for tens of thousands trained and skilled workers in California, while mitigating the impacts for workers negatively impacted. This study lays out the job estimates and opportunities for pursuing a high-road pathway to building electrification. Pursuing a high-road pathway can further demonstrate California's commitment to broadly shared prosperity in a low-carbon future.

APPENDIX A. STUDY SCOPE AND STEPS




3. Estimate Increase in Demand for Electricity
Estimate new electricity demand due to electrification
Convert to new generation capacity required
Solar
Wind
Other
IMPLAN-based JEDI Model (MW → Jobs)
Construction Direct Employment Effects
Calculate value of increased electricity sales and services
IMPLAN ($ → Jobs)
Transmission and Distribution Direct Employment Impacts


4. Estimate Reduction in Demand for Gas
Estimate reduced residential and commercial gas demand
Calculate value of reduced gas sales
Number of all-electric new residential buildings
Estimate cost savings associated with all-electric new construction
IMPLAN
Gas Transmission and Distribution Direct Employment Impacts
Construction Direct Employment Impacts

APPENDIX B. BUILDING MARKET ANALYSIS (SUPPLEMENTAL INFORMATION)

Table 20. Market Potential for Building Electrification Retrofits and All-electric New Construction in Residential Sector

Year	Business-as-usual Development		Accelerated Development	
2045	Retrofits	All-electric new	Retrofits	All-electric new
Rapid gas phase out in new construction	12,218,752	2,943,000	12,610,927	5,265,000
Slow gas phase out in new construction	12,635,752	2,526,000	13,041,311	3,180,000

For residential calculations see tab labeled "Residential Units" in Excel Sheet "Residential Calculations 9-16-19."

Table 21. Estimated Existing Percent, Number, and Space of Buildings Using District Energy in California

	Percent of Buildings	Number of Buildings	Percent of Space	Floor Space (million SqFt)
District Heating for Space Heat	0.5%	2,798	2.9%	233
District Chilled Water for Space Cooling	0.9%	5,036	2.5%	201
District Heating for Hot Water	0.3%	1,679	1.8%	145
TOTAL	**0.9–1.2%**	**5,000–5,600**	**2.9–4.8%**	**233–380**

Table 22. Estimated Existing California Commercial Buildings Part of a Campus or Complex

Part of Campus or Complex	Percent of Commercial Buildings	Number of Buildings	Percent of Commercial Space	Floor Space (million SqFt)
Primary or secondary school	9%	53,000	5%	440
College or university	2%	9,000	3%	249
Health care complex	1%	3000	3%	222
Government complex	2%	9000	2%	153
Total MUSH Complex*	13%	74,000	12%	1064
Office complex	3%	18,000	5%	425
Retail complex	6%	33,000	6%	488
Storage complex	7%	37,000	5%	415
Religious campus or complex	5%	29,000	2%	209
Other	9-11%	51,000–62,000	9%	705–928
Total Private Complex*	30–32%	168,000–179,000	26%	2,242
TOTAL buildings part of a campus or complex*	**43–45% (of total commercial buildings)**	**242,000–253,000**	**38–40% (of total commercial space)**	**3,234–3,457**

**May not sum due to rounding*

For additional commercial calculations, see tab "2025 Commercial" in "Commercial Calculations 9-16-19."

APPENDIX C. GAS USE IN BUILDINGS (SUPPLEMENTAL INFORMATION)

Table 23. Residence Type- Gas Access — All Homes (Average), in Million Units

End Use	Single-family Detached	Townhouse	2-4 Units (Multi- family)	Mobile Home	5+ Units (Multi- family)	All Residential Units
Space Heating	7.47	1.57	0.82	0.32	2.34	10.82
Hot Water	7.47	1.12	0.71	0.31	1.47	9.66
Dryer	4.52	0.31	0.23	0.16	0.42	4.35
Range/Oven	5.99	0.62	0.66	0.30	1.74	8.66
Pool						
Spa	0.61	0.01	0.00	0.00	0.00	0.24
Gas Disconnections	7.85	0.86	0.86	0.33	2.73	12.63
EE	8.27	0.86	0.86	0.33	2.73	12.63
Panel Upgrade	1.15	0.08	0.09	0.06	0.17	1.55

For calculations, see tab labeled “2016 Residential Gas End Use” in Excel Sheet “Residential Calculations 9-16-19.”

Table 24. Market Potential for District Energy Decarbonization, Large Commercial and MUSH Sector

	Existing conditions (million SqFt)	District Energy Decarbonization Potential (million SqFt)	District Energy Expansion Potential (million SqFt) (10%)	Total District Energy Potential (million SqFt)
Part of Campus or Complex	3,234–3,457			533–688
Existing District Energy (million SqFt)	233–380	233–380		
Building Complexes without District Energy	3001–3077		300–308	

APPENDIX D. COST ESTIMATES

Residential

The bottom-up cost analysis for residential electrification started with data provided on the websites Homewyse.com, ImproveNet.com, RemodelingExpense.com, and Fixr.com, which described the work involved and installation time estimates for a wide range of residential construction and installation activities. These costs are shown in Table 25.

Table 25. Equipment Costs Based on Residential Repair Cost Estimators

End Use	Technology	Purchase Cost	Materials & Supplies	Installation	Total Cost per Unit	Assumptions	Sources (August 2019)
Space Heating/ Cooling	Energy Efficient Heat Pump	$2658–3102	$234–276	$4253–6147	$7135–9524	Assume 24.7 hours of licensed contractor labor, value grade quality appliance with major fit position change[xxii]	https://www.homewyse.com/costs/cost_of_heat_pump_systems.html
	Ductless Heat Pump	$1475–1722	$257–314	$4253–6147	$5986–8182	Assume 24.7 hours of licensed contractor labor, value grade quality appliance with major fit position change[26]	https://www.homewyse.com/costs/cost_of_ductless_heat_pump_systems.html
	Mini-Split	$1400–1634	$230–261	$3547–5177	$5177–7072	Assume 23.9 hours of licensed contractor labor, value grade quality appliance with major fit position change[xxiii]	https://www.homewyse.com/costs/cost_of_mini_split_air_conditioning_systems.html
Water Heating (Single Unit)	Heat Pump Water Heater (50 gallons)	$1,163–1307	$196–244	$1348–1852	$2706–3404	11.1 hours of licensed contractor labor, value grade quality appliance with major fit position change[xxiv]	https://www.homewyse.com/costs/cost_of_heat_pump_water_heaters.html
(Shared)	Commercial Heat Pump Water Heater	$47,100			$2706–3404	Requires insulated supply and return ductwork, supply and return water piping and a properly sized storage tanks, installation of condensate drain. Ensure power supply matches specifications.	https://www.energy.gov/sites/prod/files/2016/07/f33/The%20Future%20of%20AC%20Report%20-%20Executive%20Summary_0.pdf[101]
Dryer	Efficient Electric or Heat Pump Dryer	$991–2172	$40–42	$243–412	$1274–2626	2.7 hours of licensed contractor labor, value grade quality appliance with major fit position change[xxv]	https://www.homewyse.com/costs/cost_of_electric_dryers.html
Range/ Oven	Induction Stove	$1032– 2261	$74	$299–508	$1,405–2843	3.4 hours of licensed contractor labor, value grade quality appliance with major fit position change[xxvi]	https://www.homewyse.com/costs/cost_of_electric_cooktops.html
Pool	Solar Flat Plate Collector	$2000–3800			$3500–8000		https://solarexpert.com/solar-education/solar-faqs/solar-pool/; https://thesunbank.com/products/sunbank-solar-pool-heater-kit/?gclid=EAIaIQobChMI54_e9pri5AIVlMJkCh1xsAQdEAYYAiABEgLXrPD_BwE
Spa Heating	Efficient Electric Spa Heater	$430–1207	$-	$696–844	$1126–2051	9.2 hours of basic labor, basic quality appliance[xxvii]	https://www.home-water-heater.com/spa-heaters.html; https://www.homewyse.com/services/cost_to_replace_pool_heater.html

These costs and assumptions were vetted with electrification industry contractors and professionals and revised accordingly.

xxii Remove HVAC equipment: Disconnect power, connections, and fittings. Disconnect mounting hardware and remove unit from premises. Add new heat pump to replace central air furnace: Install dedicated 240V 20A circuit. Place and level mounting pad. Mount and secure condenser to pad. Install heat exchanger in existing supply plenum. Connect, insulate lines between condenser and heat exchanger. Connect existing thermostat. Connect condenser to power. Charge condenser with up to 12 lbs of R410a refrigerant. Power unit. Verify proper cycling and temperature control. Includes planning, equipment and material acquisition, area preparation and protection, setup, and cleanup.

xxiii Install new single zone split AC system: Install dedicated 240V 20A circuit. Place and level mounting pad. Mount and secure condenser to pad. Install mounting plate. Fabricate pass through. Connect air handler lines and mount unit. Connect, insulate, and enclose lines between condenser air handler — up to 20 ft. Connect control panel. Connect condenser to power source. Charge condenser with up to 12 lbs of R410a refrigerant. Power unit. Verify proper cycling and temperature control.

xxiv Remove and dispose of existing water heater: Install new tank style electric water heater. Install dedicated 240V 40A electrical circuit. Place, align, and secure unit. Connect inlet and outlet water to existing plumbing — up to 5 ft runs. Power unit and verify proper operation.

xxv Remove existing dryer: Connect new dryer to existing utility and vent connections behind appliance. Level and place dryer and verify operation. Includes planning, equipment and material acquisition, area preparation and protection, setup and cleanup.

xxvi Disconnect and remove existing oven: Detach from adjacent surfaces and components. Break into haulable pieces. Remove from home and dispose of legally. Measure, place, and secure mounting hardware. Connect appliance to existing utility connections behind appliance. Secure appliance to mounting hardware and verify operation. Includes planning, equipment and material acquisition, area preparation and protection, setup, and cleanup.

xxvii Disconnect and remove existing heater. Mount and secure new unit. Attach inlet and outlet connectors to existing plumbing. Connect power and verify operation. Includes planning, equipment and material acquisition, area preparation and protection, setup and cleanup.

Commercial

Table 26. Cost Estimates for Private Small and Medium Commercial

Gas Use	Percent of Commercial Floor Space Served by Each Gas End Use	Estimated Commercial Building Space Using Gas		Unit	Cost		Source
		Low	High		Low	High	
Water Heating	50.8%	2,490.2	2,665.0	(million SqFt)		$1.03	Arup North America Ltd. (2016). San Francisco Municipal Facilities De-Carbonization Study. Prepared for the City of San Francisco Department of Environment. San Francisco, CA.
Space Heating	44.1%	2,161.8	2,313.5	(million SqFt)		$3.37	Arup North America Ltd. (2016). San Francisco Municipal Facilities De-Carbonization Study. Prepared for the City of San Francisco Department of Environment. San Francisco, CA.
Cooking	23.0%	112.7	120.7	(million SqFt)	$16	$20	To estimate kitchen electrification construction costs, we estimated it will cost 15–25% of the cost of a new kitchen, estimated at $15,000–100,000 per small kitchen. This estimate does not include equipment costs. Electrical work for new restaurants are estimated at 11.4% of the total construction costs. This study assumes retrofits are slightly more expensive because of the need to remove and dispose of gas equipment. See https://blog.sweeten.com/commercial-reno/commercial-101/cost-breakdown-restaurant-renovation-cost/
Miscellaneous (Dryers, Pools/ Spas, etc.)	9.5%	465.7	498.4	(million SqFt)	$1.50		Arup North America Ltd. (2016). San Francisco Municipal Facilities De-Carbonization Study. Prepared for the City of San Francisco Department of Environment. San Francisco, CA
Process	2.6%	127.5	136.4	(million SqFt)	N/A	N/A	Arup North America Ltd. (2016). San Francisco Municipal Facilities De-Carbonization Study. Prepared for the City of San Francisco Department of Environment. San Francisco, CA
Energy Efficiency	85%		370,000	Buildings	$5000	$8000	Extrapolated from residential
Building Modification	20%		74,000	Buildings	$20,000	$35,000	See TRC Energy Services. (2016). *Palo Alto Electrification Final Report.* Submitted to City of Palo Alto Development Services. Oakland, CA.
Gas Disconnection	20%		74,000	Buildings	$400	$600	Extrapolated from residential
Panel Upgrades	20%		74,000	Buildings	$10,000	$24,000	Extrapolated from residential

Table 27. Cost Estimates for Large Commercial/MUSH

Stand-alone Buildings	Million SqFt		Cost		Source
	Low	High	Low	High	
Deep Energy Retrofits	2318	2455	$28	$82	See Table 29
Centralized Systems for Building Complexes					
Carbon-Free District Energy for Heating & Cooling	533	688	$15	$39	See Table 30
Heat Pump Water Heater	533	688	$0.40	$0.47	Arup North America Ltd. (2016). San Francisco Municipal Facilities De-Carbonization Study. Prepared for the City of San Francisco Department of Environment. San Francisco, CA.
Commercial Kitchen Electrification	35	45	$16	$20	To estimate kitchen electrification construction costs, we estimated it will cost 15–25% of the cost of a new kitchen, estimated at $15,000–100,000 per small kitchen. This estimate does not include equipment costs. Electrical work for new restaurants are estimated at 11.4% of the total construction costs. This study assumes retrofits are slightly more expensive because of the need to remove and dispose of gas equipment. See https://blog.sweeten.com/commercial-reno/commercial-101/cost-breakdown-restaurant-renovation-cost/
Miscellaneous	106.6	137.6	$1.50	$2.00	NA

Table 28. Water and Space Heat Pump Cases

	Index	size (SqFt)	Heat Pump Hot Water Heater	$/SqFt	Heat Pump Installed Cost	$/SqFt
SMALL	Small Office	14,219	$2,561.00	$0.18	33817	$2.38
SMALL	Medium Office	52,200	$2,322.00	$0.04	44973	$0.86
SMALL	Pool	23,851	$138,545.00	$5.81	390.29	$0.02
SMALL	Fire Station	11,420	$2,643.00	$0.23	95809	$8.39
SMALL	Corporation Yard	67,500	$28,218.00	$0.42	394401	$5.84
LARGE	Museum	185,000	$141,746.00	$0.77	32606	$0.18
LARGE	Jail/Correctional	210,000	$97,258.00	$0.46	93675	$0.45
LARGE	Gas Station, Vehicle Repair	101,510	$16,159.00	$0.16	529550	$5.22
LARGE	Performance Hall	229,500	$54,848.00	$0.24	49085	$0.21
TOTAL SMALL	**ALL SMALL**	**169,190**	**174,289**	**$1.03**	**569,390**	**$3.37**
TOTAL LARGE	**ALL LARGE**	**726,010**	**310,011**	**$0.43**	**704,916**	**$0.97**

Source: Arup North America Ltd. (2016). San Francisco Municipal Facilities De-Carbonization Study. Prepared for the City of San Francisco Department of Environment. San Francisco, CA.

Table 29. Deep Energy Retrofit Case Studies

Case Study Name	$/SqFt		Source
	total	energy-related	
3	$56.17	$28.09	International Energy Agency (IEA). (2017) Deep Energy Retrofit- Case Studies. https://iea-annex61.org/files/results/Annex_61_SubTask_A_CaseStudies_2017-12-18.pdf
7	$127.67	$81.71	Ibid.
9	$122.56	$56.17	Ibid.
10	$81.71	$71.49	Ibid.
11	$91.92	$48.51	Ibid.
Empire State Building, NY	$203.70	$39.26	Rocky Mountain Institute. (2017) RetroFit an RMI Initiative. Project Case Study: Empire State Building. https://rmi.org/wp-content/uploads/2017/04/Buildings_Retrofit_EmpireStateBuilding_CaseStudy_2009.pdf
Beardmore, Idaho	$105.50		New Buildings Institute. (2015). A Case for Deep Savings. https://newbuildings.org/wp-content/uploads/2015/11/DeepSavings_11CaseStudies1.pdf
Lovejoy, Oregon	$115.00		Ibid.
The Christman Building	$138.00		Ibid.
AVERAGE	**$115.80**	**$54.21**	

Table 30. District Energy Case Studies

District Energy Systems	Total Cost	Cost per Square Foot (of affected indoor space)	Source
Stanford Energy Systems Innovation (SESI) Project (12 million SqFt of building space affected)	$468 million	$39	Stanford University http://sustainable.stanford.edu/sites/default/files/documents/Stanford_SESI_General_Information_Brochure.pdf
Ball State University Geothermal system (5.5 million SqFt of building space affected))	$83 million	$15	Ball State University https://www.bsu.edu/about/geothermal
City of Vancouver (6.5 million SqFt of building space affected)	$30.5 million	$5	City of Vancouver http://web.mit.edu/colab/gedi/pdf/Financing%20District%20Energy/DES_report.pdf

Table 31. Employment Estimates of Renewable Energy Connectivity to Transmission Grid

Renewable Energy	$/kW (mid-Case)	Total ($billion)	Estimated Job-Years	Average Annual Jobs	Source
Solar PV (20 MW)*	400	$3.57–4.08	58,000–66,000	2,300–2,600	CEC. (2019). Estimated Cost of New Utility-Scale Generation in California: 2018 Update — Staff Report, May 2019. https://ww2.energy.ca.gov/2019publications/CEC-200-2019-005/CEC-200-2019-005.pdf
Solar PV and Thermal (100 MW)	84	$2.25–2.57			
Wind (100 MW)	84	$2.78–3.18			
Geothermal (30 MW)	266	$0.37–0.43			
TOTAL		**$8.97–10.26**			

For these estimates, ¼ new solar was assumed to be 20 MW thin-film and ¾ is assumed to be 100 MW single axis.

Gas to Electric Energy Use Calculations and Assumptions

Appliance conversions from gas to electric are based on the conversion of current gas used in California for various appliances to those same appliances powered by electricity. Appliance gas use comes from the 2006 California Commercial End-Use Survey[102] and the 2009 California Residential Appliance Saturation Study.[103] For each gas end-use in these studies we determine how much gas was actually converted to heat based on the burn efficiency of the appliances. We then apply a low and high coefficient of performance (COP) to determine the therms of gas used in a low- and high-efficiency scenario.

The low-efficiency scenario is the least efficient Energy Star appliance or U.S. federal minimum rating. The high-efficiency scenario is the most efficient Energy Star appliance. Burn efficiencies and COPs for residential appliances came from electrification expert Sean Armstrong, Managing Principal, Redwood Energy. Burn efficiencies and COPs for commercial appliances came from electrification experts Sean Armstrong and Michael Winkler, Partner and Energy Analyst, Redwood Energy.

We convert therms used by a gas appliance to kWh that would be needed with an electric appliance using a standard conversion factor (1 therm = 29.3 kWh) recommended by electrification experts Sean Armstrong and Michael Winkler.

NOTES FOR SPECIFIC APPLIANCES:

Range/oven: We assume an electric resistance stove for the low estimate and an induction stove for the high estimate. According to RESNET, induction likely uses 18 percent less energy.

Dryers: Efficiencies based on 2010 ACEEE study on Energy Efficiency in Buildings[104].

Process: Gas process loads are often industrial, like melting glass, or industrial cooking vats of tomato sauce, etc. We assume a direct conversion of site energy, with no efficiency savings between high and low efficiency. This assumes 100 percent electric resistance, although there could be some savings from more efficient equipment.

Miscellaneous: We assume site conversion to resistance as the conservative low-efficiency scenario, and modest efficiency gains (10%) from new equipment as the high-efficiency scenario.

Table 32. Additional Electrical Load Due to Electrification

	Additional annual demand due to electrification (in kWh)	
	High efficiency per unit average	Low efficiency per unit average
Residential	2,296	3,418
Commercial	1,960,832	2,600,328

Table 33. Electricity Demand form Conversion from Gas to Electricity (kWh/Year in 2045)

LOW Building Development			
2045 CA Buildings	Low Efficiency	High Efficiency	Average Electrification
Residential[105]	51,828,090,347	34,816,270,842	43,322,180,594
Commercial[106]	27,303,439,404	20,588,739,505	23,946,089,454
Total	**79,131,529,750**	**55,405,010,347**	**67,268,270,049**
HIGH Building Development			
2045 CA Buildings	Low Efficiency Average	High Efficiency	Average Electrification
Residential	61,106,075,313	41,048,891,710	51,077,483,511
Commercial	29,383,701,453	22,157,405,372	25,770,553,413
TOTAL	**90,489,776,766**	**63,206,297,082**	**76,848,036,924**

Electricity Sales

Table 34. Additional Electricity Sales Due to Building Electrification by 2045

Sector	2045	$/kWh*	Sales in 2045 (2019 dollars)
Residential	43,300–51,100 GWh	$0.1996	$8.65–10.20 billion
Commercial	22,900–25,800 GWh	$0.1908	$4.57–4.92 billion
TOTAL	**67,300–76,800 GWh**		**$13.22–15.11 billion**

**Source: U.S. EIA 2019, July 2019 prices*[107]

Table 35. Rate Components for Electricity, cents/kWh (2017)

Rate Component	SCE	PG&E	SDG&E	Average	Average Percent
Generation	6.68	7.94	9.57	8.06	45%
Distribution	5.36	5.74	8.19	6.43	36%
Transmission	1.21	2.37	3.01	2.20	12%
Public Purpose Charge	0.73	0.73	1.13	0.86	5%
Nuclear Decommissioning	0.00	0.15	0.05	0.07	0%
DWR and other Bond Charges	0.50	0.50	0.47	0.49	3%
TOTAL	**14.48**	**17.42**	**22.32**	**18.07**	**100%**

Source: CPUC[108]

Gas Sales

Table 36. Residential and Commercial Gas Sales in 2017

Sector	2017 (million cubic feet)	$/thousand cubic feet (2017 dollars)*	Sales in 2017
Residential	430,584–431,005	$12.49	$5.378–5.383 billion
Commercial	193,100–237,360	$8.76	$1.692–2.079 billion
Total	623,684–668,365		$7.070–7.462 billion

Source: The high end of the range is provided by U.S. EIA[109] which doesn't separate commercial buildings. The low end of the range is from the CEC[110] (converted to million cubic feet), in which we only included commercial buildings.

Table 37. Revenue Requirements for Gas (2017) ($)

Component	SoCal Gas	PG&E	SDG&E	Total	Average Percent
Core Procurement	1,154,731	1,158,601	151,850	$2,465,182	26%
Transmission, Distribution, and Storage	2,693,301	3,184,277	397,819	$6,275,397	67%
Public Purpose Charge	343,321	267,938	36,001	$647,260	7%
Total	4,191,353	4,610,816	585,670	$9,387,839	100%

Source: CPUC[111]

APPENDIX F. ASSUMPTIONS AND CAVEATS

- The scenario on which this analysis is based assumes an increase in building electrification and corresponding decrease in building gas use from 2020 to 2045, at which point only five percent of current gas consumption in residential and commercial buildings will remain. The positive employment impacts are assumed to be proportional to the increase electricity demand, and the negative impacts are presented as a range so that 95 percent reduction of residential gas use would lead to a 75–95 percent reduction in workforce needs.
- This study estimates the potential decline in employment in the natural gas industry, and specifically in the utility sector and supporting industries. The projections of the potential decline in employment in the natural gas industry are based on the estimated size of the existing workforce in 2019 without projecting an increase or decrease in that workforce due to currently projected changes in demand for natural gas and/or projected maintenance and repair needs. This estimate does not account for the potential extra work involved in plugging, removing, or otherwise decommissioning gas pipelines.
- Jobs associated with the ongoing transmission and distribution of both electricity and gas are determined by the projected value of the increased or decreased sales of each commodity relative to current sales.
- A rough analysis of the seasonality of new electricity demand shows that building electrification will increase winter demand more than summer demand. Since the California grid is built to accommodate summer peaks, new transmission and distribution infrastructure could be minimal. This study does not specifically estimate the cost or jobs associated with upgrading or expanding the existing grid.
- Most of the renewable construction needed to meet new demand is assumed to take place within California using today's technology. The new capacity projections used in this study are based on the distribution of power generation by source in the high electrification scenario in the Deep Decarbonization in a High Renewables Future report developed by E3 for the California Energy Commission (CEC).[112] This scenario relies heavily on wind and solar, which could prove insufficient to meet increased winter electricity demand. This study accounts for low capacity factors of California wind and solar during the winter months, thus the study reflects significant overbuild to account for winter inefficiencies.
- While the infrastructure required to connect new renewable generation facilities to the grid is highly variable depending on the location of renewable generation facilities relative to current transmission infrastructure. This study does not attempt to calculate the costs associated with these needs. Instead, it estimates that for every 10 jobs building renewable generation capacity, and additional seven would be needed for connecting new renewables to the grid. This assumption is based on interviews with industry experts.
- This study estimates the total rather than incremental costs of electrifying buildings. If one assumes that electrification will only take place upon burnout of existing equipment, then an incremental cost would provide a more accurate estimate of the new jobs beyond business-as-usual replacement. By estimating total rather than incremental costs, we are capturing some jobs that would be incurred even without electrification. This study assumes that public policy will accelerate building electrification, and it therefore reflects the number of full time equivalent workers required to decarbonize the state's existing buildings.
- We assume that natural gas burning equipment in buildings will be replaced with the best currently available technology. This includes heat pumps broadly defined to include air, water, and ground source heat pumps for space heating, cooling, water heating, and clothes drying; and induction ranges for cooking. We made no assumptions about future technology improvements or cost reductions.
- The manufacturing job potential identified in this study is based on a scenario in which all of the equipment for residential and small commercial electrification is manufactured in-state; therefore, the estimate represents the maximum in-state jobs potential that would be realized only if the state attracts new manufacturing facilities.
- Life-cycle costs and total cost effectiveness were not considered. This means that whether the overall economic impact of electrification is positive or negative was not explored. If building electrification results in improved efficiency, consumers will have more money to allocate to other goods and services, creating additional jobs not projected in this study.
- The jobs estimated (and cost figures on which they are based) are order of magnitude estimates only. The imprecision of job estimates arises from uncertainty about the number and size of buildings in California and the estimates of electrification costs. There are few case studies with information on upfront costs of full building electrification, or the work involved. Costs were projected from the few case studies that exist, as well as projecting costs from other related non-electrification construction projects.[xxviii]

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xxviii Since the underlying cost estimates for this study were developed, E3 has published, Residential Building Electrification in Caliofrnia, a paper estimating the market potential and costs of electrification in California. See https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf. In this study, the authors have not reconciled the different approaches or estimates but notes these are within the same general range.

APPENDIX G. LITERATURE REVIEW

The National Renewable Energy Laboratory (NREL) recently released the first installment of the *Electrification Futures Study*, which explores adoption rates and price scenarios for electric technologies in the building and transportation sectors.[113] Future installments of this study will explore the environmental, demand, and economic impacts of widespread electrification in the United States. A 2017 study by Oak Ridge National Laboratory and CSRA, Inc. discussed the market share for various electric technologies including heat pumps and projected household penetration.[114]

Several building, city, and statewide sector-specific electrification studies have also been completed. A 2016 study conducted by Lawrence Berkeley National Laboratory and the University of California (UC) Berkeley Energy and Resources Group and Goldman School of Public Policy assessed existing and future hot water heat pump technology adoption scenarios in the residential sector in California. Although their modeling demonstrated that reaching the 40 percent reduction in emissions attributed to hot water would not be possible by 2030 without a 25 percent decrease in hot water demand, they did demonstrate that it was possible to reduce emissions from natural gas consumption from water heating end uses by 80 percent by 2050.[115]

Another Sierra Club-sponsored study assessing the lowest cost reduction of space and water heating emissions with heat pump technology was completed in 2017 by Imran Sheikh. His research found that heat pump technology would need to be widely adopted in new construction by 2020 for an 80 percent reduction in emissions from residential hot water and space heating end uses by 2050.[116]

The City of Palo Alto has also completed several electrification studies, including a 2015 study on residential electrification opportunities, which explores the lifetime cost of ownership for electric appliances in single-family homes.[117] A city staff report in 2014 estimated the costs associated with electric panel upgrades.[118] In 2016, the city released another study looking at the cost and feasibility of electrifying residential and commercial buildings.[119]

The City of San Francisco also completed a decarbonization study in 2013, which assessed opportunities to electrify municipal buildings. As part of this study, nearly 300 buildings across the state were surveyed, and cost estimates for installation and labor were calculated by square footage and weighted based on energy use intensity.[120]

While heat pump technologies were overwhelming the electrification technology of choice for space and water heating in most of the literature, many studies covered additional or complementary technologies. For example, both the Cities of Palo Alto and San Francisco explored solar hot water heaters to address concerns with heat pump water heaters, such as high upfront costs and their inability to meet hot water demand in some cases.[121] A 2011 NREL study found that solar water heaters have the potential to meet more than 70 percent of California's hot water demand, although high installation costs and lack of attractive financing may inhibit widespread adoption.[122]

A 2017 *UC Carbon Neutral Buildings Cost Study* assessed the energy and costs of new all-electric academic and residential buildings and concluded that costs were on par with conventional construction.[123] The UC study also explored electrification scenarios with geothermal and co-generation technology. Several other studies have shown that while geothermal heat pumps have higher upfront costs, they operated more efficiently, resulting in lower lifetime costs than air-sourced heat pumps. Thus, geothermal is a viable option for facilities with large heat demands and longer building leases.[124] The same is true for other, more advanced heat pump technologies, including variable refrigerant flow technology, which outperforms resistance and air-sourced heat pump technology in terms of efficiency, but often have higher installation costs.

Several reports and action plans also call for electrification as a necessary pathway to decarbonization. Southern California Edison recently released a blueprint that explores three pathways to meet California's 2030 and 2050 greenhouse gas (GHG) emissions reduction goals. The preferred scenario in their study, the "Clean Power and Electrification Pathway," calls for electrifying 30 percent of space and water heating end uses with heat pump technology and ensuring 80 percent of energy delivered is carbon free.[125]

The 2012 paper in the journal *Science*, *The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity*, assessed the impact of technology, costs, infrastructure, and governance on California's ability to meet its 2050 GHG emissions reduction goals. In their model, it is assumed that 81 percent of all buildings in California must be completely electrified in order to meet the state's 2050 goals.[126] In that study, electrification of both buildings and transportation contributed 16 percent to the 2050 GHG emissions reduction goals. The authors concluded that a combination of energy efficiency (28%), energy decarbonization (27%), and electrification (16%), along with other policies, would be necessary to meet the 2050 goals.[127]

APPENDIX H. IMPLAN INPUTS

Spending Category	Sector	Impacted IMPLAN Industry	Modeled Funds By Industry ($billion, 2019 dollars)	Spending Timeline By Industry	Revenue (Total/ Marginal)	Local Purchase Rate By Industry
Building Electrification Construction ($Total)	Single-family residential retrofits	63–Maintenance and repair of residential structures	$125.4–189.5	2020-2045 (evenly split by year)	N/A	(100%)
	Multi-family residential retrofits				N/A	(100%)
	Small and medium commercial retrofits	62–Maintenance and repair construction of nonresidential structures	$15.0–20.6	2020-2045 (evenly split by year)	N/A	(100%)
	Large commercial/ MUSH whole building renovations	62–Maintenance and repair construction of nonresidential structures	$47.3–137.6	2020-2045 (evenly split by year)	N/A	(100%)
	District energy systems	54–Construction of new power and communication structures	$6.8–22.8	2020-2045 (evenly split by year)	N/A	(100%)
	Large Commercial/ MUSH end-use decarbonization	62–Maintenance and repair construction of nonresidential structures	$3.1–4.2	2020-2045 (evenly split by year)	N/A	(100%)
Building Electrification Labor Cost-Savings (-$Total)	Single-family new construction	59–Construction of new single-family residential structures	-$6.96 – -8.37	2020-2045 (evenly split by year)	N/A	(100%)
	Multi-family new construction	60–Construction of new multi-family residential structures	-$7.47 – -8.57	2020-2045 (evenly split by year)	N/A	(100%)
Electric Equipment Manufacturing ($Total)	Heat pump water heater	3276–Heating equipment (except warm air furnaces)	$14.5–21.8	2020-2045 (evenly split by year)	Total	(100%)
	HVAC heat pump	3277–Air conditioning, refrigeration, and warm air heating equipment	$35.0–40.8	2020-2045 (evenly split by year)	Total	(100%)
	Induction stove	3328–Household cooking appliance	$9.9–22.1	2020-2045 (evenly split by year)	Total	(100%)
	Efficient Electric or Heat Pump Dryer	3330–Household laundry equipment	$3.0–6.2	2020-2045 (evenly split by year)	Total	(100%)
	Misc.	3276–Heating equipment (except warm air furnaces)	$1.9–3.1	2020-2045 (evenly split by year)	Total	(100%)
	District Energy Heat Pump	3277–Air conditioning, refrigeration, and warm air heating equipment	$1.2–4.0	2020-2045 (evenly split by year)	Total	(100%)

Spending Category	Sector	Impacted IMPLAN Industry	Modeled Funds By Industry ($billion, 2019 dollars)	Spending Timeline By Industry	Revenue (Total/ Marginal)	Local Purchase Rate By Industry
Renewable Energy Construction ($Total)	Solar PV	JEDI photovoltaic scenario model	35,700–40,800 MW	2020-2045 (evenly split by year)	N/A	(100%)
	Wind	JEDI land-based wind model	33,100–37,800 MW	2020-2045 (evenly split by year)	N/A	(100%)
	Geothermal	JEDI geothermal model	1,400–1,600 MW	2020-2045 (evenly split by year)	N/A	(100%)
	Transmission grid connectivity	54–Construction of new power and communication structures	$8.97–10.26	2020-2045 (evenly split by year)	N/A	(100%)
Electricity ($Total)	Transmission and distribution	49–Electric power transmission and distribution	$5.60–6.40	2045 *	N/A	(100%)
	Solar generation	44–Electric power generation solar	$2.74–3.14	2045*	N/A	(100%)
	Wind generation	45–Electric power generation wind	$1.90–2.18	2045*	N/A	(100%)
	Geothermal generation	46–Electric power generation geothermal	$0.39–0.45	2045*	N/A	(100%)
	Public purpose programs (PPP), bonds, other	525–Local government electric utilities	$0.99–1.13	2045*	N/A	(100%)
Gas (-$Total)	Gas transmission, distribution, and storage	50–Natural gas distribution	-$4.74 – -5.00	2017**	N/A	(100%)
	Gas procurement	20–Extraction of gas and crude petroleum	-$1.84 – -1.94	2017**	N/A	(100%)[xxix]
	Public purpose charge	526–Other local government enterprise	-$0.50 – -0.52	2017**	N/A	(100%)

**Electricity generation and distribution jobs are based on annual (not cumulative) sales of electricity. We modeled the number of additional annual jobs to support fully electric buildings, assuming the 95 percent goal is reached in 2045. If by 2030, California has achieved half of this goal, these inputs (and the corresponding outputs) would be half of this total.*

***To estimate job loss, we modeled the number of jobs required to support current (2017) sales of gas for use in buildings, without projecting future sales under a business-as-usual (no electrification) scenario.*

xxix IMPLAN aggregates gas and crude oil extraction. California imports 90% of the natural gas and 70% of the crude oil it consumes. The "Regional Production Coefficient" of this aggregated industry is 10.89%, while for natural gas, U.S. EIA data indicates it's 9.91%, so we modified the outputs accordingly.

ENDNOTES

1 IMPLAN indicates there are 33,500 jobs in natural gas transmission, storage, and distribution in California. The electrification of buildings could affect 16–20% of the transmission and distribution workforce. With a well-planned gas transition, layoffs could be minimized through retention and relocation support for younger workers as older workers transition to retirement.

2 IMPLAN indicates there are 25,300 California workers employed in the natural gas and oil extraction industry. The electrification of buildings could affect 0–25% of the extraction workforce. With a well-planned gas transition, layoffs could be minimized through retention and relocation support for younger workers as older workers transition to retirement.

3 These estimates do not reflect other potential gains or losses of jobs due to other variables, such as the potential increase in gas employment due to pipe replacement and leak repairs even as throughput declines.

4 Building electrification is not restricted to stand-along building retrofits. Some campuses, business parks, and even residential neighborhoods are decarbonizing buildings through a district model, which involves installing centralized energy facilities with a closed loop system of pipes and heat exchangers. Water is heated in the central plant and piped to individual buildings. Heat exchangers allow hot water to be moved to provide space heating or cooling depending on individual building needs. This is highly efficient when buildings with complementary energy heating and cooling loads are located in close proximity.

5 In addition to construction-phase jobs, district energy systems are large enough to require dedicated professional year-round workers, which are not estimated in this study. In Norway, about 25 workers are employed per 1,000 GWh of energy produced for heating. The operations and maintenance jobs and induced jobs from cost savings associated with these systems can be greater than the construction impacts.

6 Zabin, C. and K. Chapple. (2011). California Workforce Education & Training Needs Assessment for Energy Efficiency, Distributed Generation, and Demand Response. University of California (UC) Berkeley Donald Vial Center on Employment in the Green Economy. http://laborcenter.berkeley.edu/california-workforce-education-and-training-needs-assessment-for-energy-efficiency-distributed-generation-and-demand-response/

7 In their "How-To Guide: Net-Zero Retrofit Technical and Cost Benchmark Studies" the Rocky Mountain Institute, states (p.2), "…high labor rates in San Francisco increase the potential for off-site pre-fabrication to significantly reduce project costs." Statements like this are common in clean energy, climate advocacy, and technical assistance documents and presentations, but driving down costs by reducing labor costs has direct negative consequences for skilled workers in the local construction market and may actually slow market adoption.

8 Jacobs, K, I. E. Perry, and J. MacGillvary. (2015). *The High Public Cost of Low Wages.* UC Berkeley Labor Center. April 13, 2015. http://laborcenter.berkeley.edu/the-high-public-cost-of-low-wages/; Mahalia, N. (2008). *Prevailing wages and government contracting costs: A review of the research.* Economic Policy Institute. July 3, 2008. https://www.epi.org/publication/bp215/

9 While many utilities across the country pre-qualify contractors for various programs, California investor-owned utilities (IOUs) and agencies have refrained from undertaking this activity due to concerns of potential legal vulnerability resulting from making contractor recommendations.

10 See discussion about comments and recommendations on pages 7–20 in CPUC (2018). Proposed Decision Addressing Workforce Requirements and Third-Party Contract Terms and Conditions, dated 10/11/2018. The 2018 standard adopted by the CPUC requires that workers installing HVAC systems have completed or are enrolled in an accredited HVAC apprenticeship in HVAC installation; completed at least five years of work experience and all other requirements in the HVAC craft which has workers classified as journeymen in HVAC installation or a related field at the journey level as defined by the California Department of Industrial Relations, passed a practical and written HVAC system installation competency test, and received credentialed training specific to the installation of the technology being installed; or have at least five years of experience as an experienced worker, not a trainee, and is fully qualified and able to perform in the specific HVAC trade without supervision.

11 Williams, James H., Andrew DeBenedictis, Rebecca Ghanadan, Amber Mahone, Jack Moore, William R. Morrow III, Snuller Price, and Margaret S. Torn. (2011). "The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity." Supporting Online Materials. *Science*. http://science.sciencemag.org/content/suppl/2011/11/23/science.1208365.DC1

12 Nelson, Dr. James, Ana Mileva, Josiah Johnston, Daniel Kammen, Dr. Max Wei, Dr. Jeffery Greenblatt. (2013). *Scenarios for Deep Carbon Emission Reductions from Electricity by 2025 in Western North America Using the Switch Electric Power Sector Planning Model*. California's Carbon Challenge Phase II, Volume II. Prepared for California Energy Commission (CEC) by University of California, Berkeley. Berkeley, CA. http://www.energy.ca.gov/2014publications/CEC-500-2014-109/CEC-500-2014-109.pdf

13 Mahone, A., J. Kahn-Lang, V. Li, N. Ryan, Z. Subin, D. Allen, G. DeMoor, S. Price. (2018). "Deep Decarbonization in a High Renewables Future: Updated Results from the California PATHWAYS Model." CEC. June 2018. https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf

14 CEC. (2019). Gas Consumption by Entity. Accessed September 5, 2019. http://www.ecdms.energy.ca.gov/gasbyutil.aspx

15 Gridworks (2019). *California's Gas System in Transition: Equitable, Affordable, Decarbonized, and Smaller.* https://gridworks.org/wp-content/uploads/2019/09/CA_Gas_System_in_Transition.pdf

16 Pacific Gas and Electric Company. (2019). "Overview of PG&E's Natural Gas Delivery System." PowerPoint presentation May 9, 2019.

17 IMPLAN Group, LLC. IMPLAN 2017, California. Huntersville, NC. IMPLAN.com.

18 U.S. EIA. (2019). *Natural Gas Consumption by End Use.* U.S. Department of Energy. Washington, DC. Accessed April 19, 2019. http://www.eia.gov/dnav/ng/ng_cons_sum_dcu_sca_m.htm.

19 CEC. (2019). Gas Consumption by Entity. Accessed September 5, 2019. http://www.ecdms.energy.ca.gov/gasbyutil.aspx

20 California Department of Finance (2019). E-5 Population and Housing Estimates for Cities, Counties, and the State, 2011–2019 with 2010 Census Benchmark.

21 Data sourced from 2009 Residential Appliance Saturation Study. (2010) Reference Table 2-21 (right) or page 15 of https://webtools.dnvgl.com/rass2009/Uploads/2009_RASS_Volume%202_FINAL_101310.pdf, for data & details. Residential building counts were obtained from U.S. Census Bureau, 2017 American Community Survey 1-Year Estimates. The 2009 Residential Appliance Saturation Study found that of the 24,464 individually metered households in the study, 3,755 had no gas service.

22 California Department of Finance. (2019). E-5 Population and Housing Estimates for Cities, Counties, and the State, 2011–2019 with 2010 Census Benchmark.

23 Ibid.

24 See pp. 10-14. KEMA, Inc. (2010). 2009 *California Residential Appliance Saturation Study.* CEC. Publication number: CEC-200-2010-004-ES. http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-ES.PDF

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