Equitable Electrification Analysis for Existing Buildings in Richmond, CA

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Notice

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List of Acronyms

BIL	Bipartisan Infrastructure Law
BLS	U.S. Bureau of Labor Statistics
CEC	California Energy Commission
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EUSS	End-use savings shapes
FPL	federal poverty level
GBND	City of Richmond Green-Blue New Deal and Just Transitions
GHG	greenhouse gas emissions
IRA	Inflation Reduction Act
IIJA	Infrastructure Investment and Jobs Act
LEAP	Local Energy Action Program
MCE	Marin Clean Energy
NREL	National Renewable Energy Laboratory
OEHHA	California Office of Environmental Health Hazard Assessment
PG&E	Pacific Gas & Electric
PV	photovoltaic
RTU	rooftop unit
TA	technical assistance

Executive Summary

In 2022, the U.S. Department of Energy (DOE) announced that City of Richmond was selected for support through the Communities Local Energy Action Program (Communities LEAP), a pilot technical assistance (TA) program intended to "facilitate sustained community-wide economic and environmental benefits" to low-income and energy-burdened communities experiencing environmental justice or related impacts (DOE, n.d.). The Communities LEAP program is being managed by the National Renewable Energy Laboratory (NREL), in coordination with a variety of subject matter experts.

Over a 12-month period beginning in July 2022, NREL coordinated with a coalition of City staff and community organizations to develop and conduct a city-wide building energy use analysis and develop and assess the impacts of various approaches to electrifying and improving energy efficiency of all existing residential and commercial buildings within the city limits. Building on data available through NREL's ResStock™ and ComStock™ analysis tools, the authors looked at potential modeled impacts of building envelope and electrification upgrades on five indicators identified by the community coalition: building energy consumption, greenhouse gas (GHG) emissions, utility bill charges and cost-effectiveness, employment impacts, and health and safety impacts. This report summarizes the findings of that research and analysis.

Project Limitations

It is important to note the assumptions and limitations to the data and analysis found in this report, which are discussed more in the body of the paper. The central limitation is that this report did not look at actual energy consumption, greenhouse gas emissions, or utility bill data for the City. Instead, it used tools that model potential energy consumption patterns. Although the models are highly vetted and the baseline building stock data cross-checked with city and county assessor data, every model makes specific assumptions and therefore has its uncertainties and limitations.

In addition, not all building types were included in the analysis due to a lack of data available. The analysis includes more than 95% of residential housing units, about 85% of commercial and institutional building floor area, and about 39% of industrial building floor area. More details on this methodology are provided in the body of the paper. And finally, although the energy and emissions modeling presented in this analysis is very detailed, the cost, employment, and health analyses were more high level due to project time and budget limitations. More detail on the project methodology is provided in the report.

In general, this TA was not designed or intended to address every possible implementation approach or anticipate how variables like utility rate structures or broader economic systems may evolve over time. Instead, the findings shared in this report are intended to build an understanding of the potential impacts of existing building electrification and energy efficiency, and to support the Richmond Community Coalition and Richmond City Council in making informed decisions on policies and programs related to existing building electrification and energy efficiency in Richmond.

Summary of Analysis Results

Through the ResStock and ComStock tools, researchers at NREL were able to analyze modeled energy consumption for all single-family and multifamily residential buildings in Richmond, and approximately half of non-residential buildings, referred to in this report as "commercial buildings." On a city-wide annual basis, natural gas makes up an estimated 46% of energy consumption[1] and

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[1] All references to "energy consumption" in this report are for site energy consumption. See https://energystar-mesa.force.com/PortfolioManager/s/article/What-are-Site-Energy-and-Source-Energy-1600088530247 for more details.

almost 80% of GHG emissions for the buildings modeled, although this looks different for different types of buildings. Residential buildings consume about 70% of the energy and are responsible for 81% of associated GHG emissions for the buildings modeled, while the commercial buildings modeled are responsible for the remaining 30% of energy consumption and 19% of emissions. The difference in energy consumption versus emissions is largely a reflection of how energy is used in residential versus commercial buildings: In residential buildings, space and water heating, which are dominated by natural gas use, make up more than half of all energy consumption. However, in commercial buildings, space and water heating are responsible for less than a quarter of energy consumption, which is instead dominated by other equipment (e.g., computers, printers, specialty appliances, etc.), refrigeration, pumps and fans, which are almost entirely electric.

As a result of the different energy use patterns described above, building envelope improvements modeled in this analysis could reduce overall energy consumption in these buildings by an estimated 17%, though they would likely have a bigger impact on energy consumption and emissions for residential buildings compared to commercial buildings. Higher-efficiency electrification upgrades could reduce total energy consumption by an estimated 43% overall for these buildings. The impact could be significant for both residential and commercial, thought it would still be more sizable for residential buildings (53% reduction versus 20% for commercial). Details for the impacts on residential and commercial buildings are discussed separately below, followed by a summary of equity considerations. All figures are from NREL's ResStock or ComStock data unless otherwise noted.

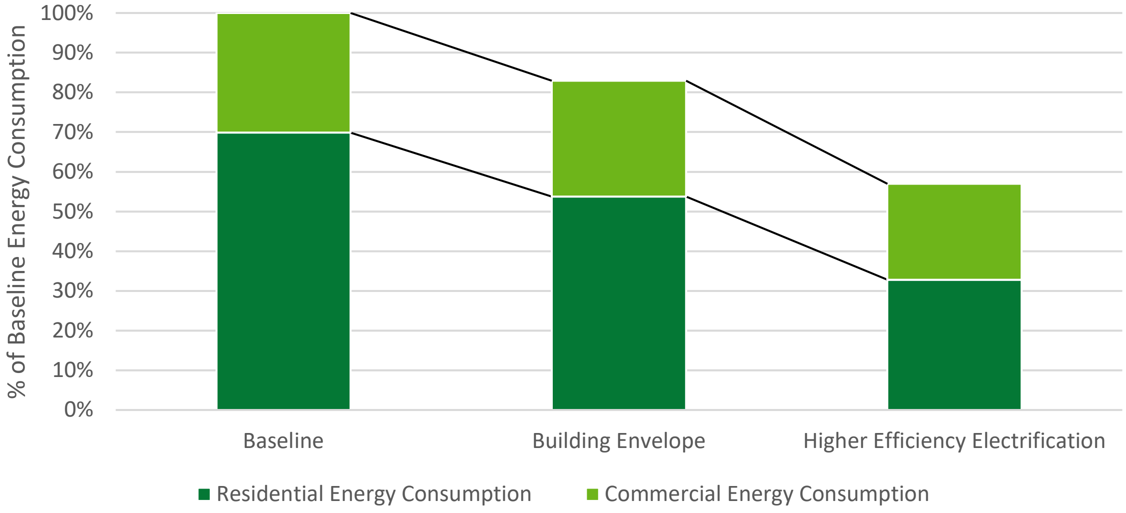

Figure 1. Modeled upgrade scenario impacts on city-wide energy consumption by building sector

Residential Buildings

As is illustrated in Figure 2 below, natural gas represents an estimated 56% of residential energy consumption in Richmond but is responsible for 84% of associated GHG emissions, and only 24% of current residential utility bills.

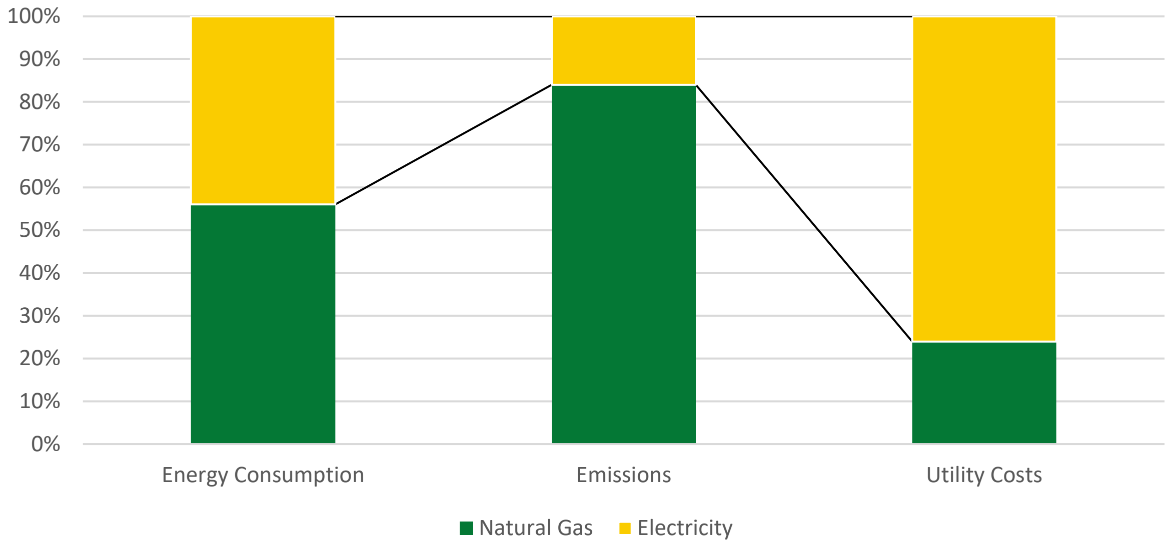

Figure 2. Modeled annual residential energy consumption, emissions, and utility cost share by fuel type

Space and water heating are the largest consumers of energy in Richmond (56% combined), and 87% of that energy is natural gas. Single-family homes and older homes consume more energy per unit and use more natural gas per unit compared to other housing types. The residents of these homes are also more likely to be owners, and more likely to be higher income.

In looking at the impacts of energy efficiency and electrification for existing buildings, we used the ResStock tool to analyze four potential upgrade scenarios:

1. **Envelope**: bringing insulation, air and duct sealing to levels consistent with the current energy code
2. **Electrification – Lower Efficiency**: replacement of major gas-powered appliances (space and water heating, cooking range and clothes dryer) with a lower- efficiency[2] electric alternative
3. **Electrification – Higher Efficiency**: replacement of major gas-powered appliances (space and water heating, cooking range and clothes dryer) with a higher-efficiency electric alternative
4. **Envelope + Electrification**: Combining #1 and #3.

Based on the modelling analysis, all four upgrades modeled could be expected to result in city-wide decreases in total energy consumption and GHG emissions, and most would result in overall utility bill decreases. However, pursuing lower-efficiency electrification upgrades alone could result in slight city-wide increase in utility bill charges, as illustrated in Figure 3 below. These impacts would not be experienced uniformly however. For example, single- family housing units, older housing units, owners, and higher-income households would be more likely to see higher bill savings and thus higher return-on-investment for envelope and upgrades, since they are higher consumers of energy overall.

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[2] The term "lower-efficiency electrification" is used here and throughout the report to describe the assumed/modeled efficiency levels for these scenarios relative to the "higher-efficiency electrification" scenarios.

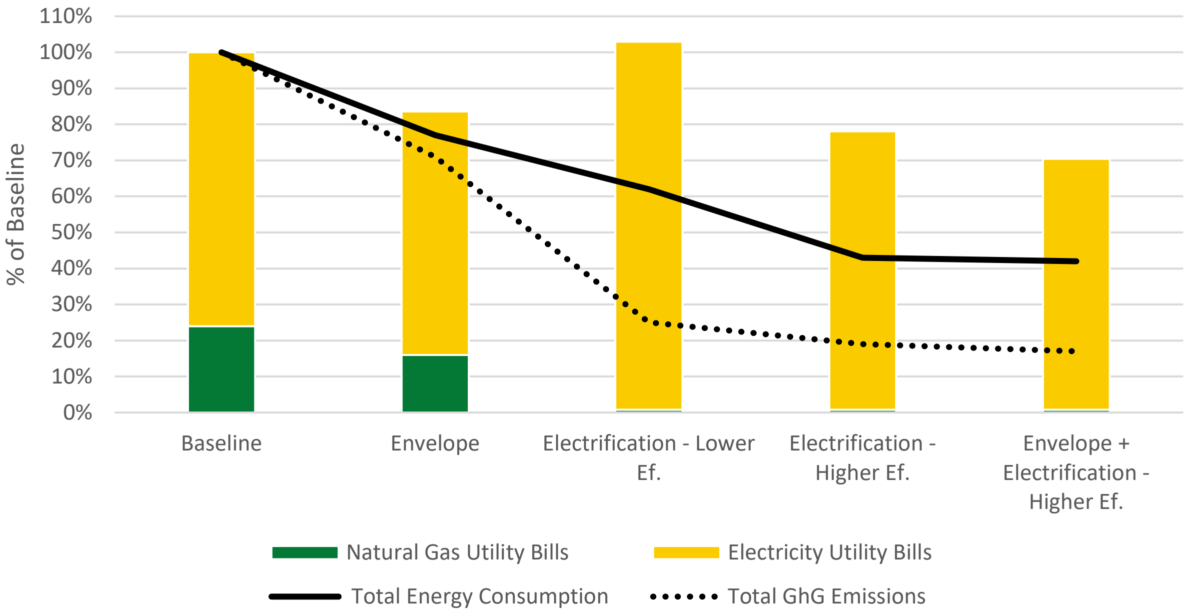

Figure 3. Modeled impact of upgrade scenarios on city-wide annual residential utility bills by fuel type

The analysis also looked at cost-effectiveness in terms of the savings-to-investment ratio over the lifetime of measures. At a city-wide scale, based on the modeled results, only envelope measures have a positive return-on-investment over the lifetime of the measures without considering potential rebates. Higher-efficiency electrification + envelope measures become cost- effective when currently available rebates are applied, and higher-efficiency electrification alone comes close to being cost-effective when rebates are applied.

In terms of employment, pursuing residential envelope and higher-efficiency electrification upgrades combined in Richmond could support up to 7,500 direct and indirect jobs, with two-thirds of those more likely to be local jobs (city/county/region), and half of them likely to be new jobs (a net increase). This would include occupations such as heating, ventilation, and air conditioning (HVAC) technicians, plumbers, electricians, and general residential construction and remodeling. The occupations more likely to be new/net jobs are the insulators and electricians, while HVAC technician and plumbing jobs are more likely to be existing jobs installing new technologies, rather than jobs that would not otherwise exist. Average annual wages for residential workers in these industries is $75,480. This is lower than the average wage for all occupations in Contra Costa County ($80,687), however it is 16% higher than the state average for the same occupations.

Commercial Buildings

Natural gas currently represents an estimated 23% of total annual energy consumption for the commercial buildings modeled, and of the related GHG emissions. As shown in Figure 4, equipment and refrigeration are the uses that consume the most energy in Richmond's commercial buildings (44%), of which one-third (about 15% of city-wide total) is natural gas. Space heating is the use that is most reliant on natural gas (natural gas makes up 70% of energy used for space heating).

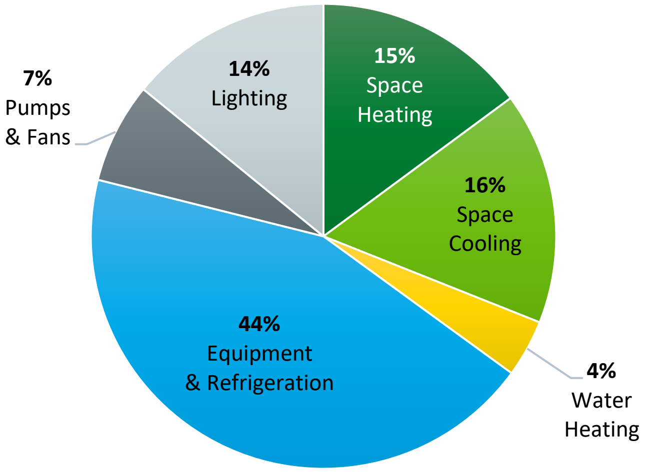

Figure 4. Modeled city-wide annual commercial energy consumption by end use

Mercantile uses are the most common commercial building in Richmond, representing 59% of buildings but only 29% of floor area modeled. Of the non-residential buildings analyzed for this report, they are responsible for an estimated 46% of city-wide commercial building energy consumption and 52% of commercial building GHG emissions. Warehouse and storage buildings have the largest portion of city-wide commercial building floor area modeled (32%) but are responsible for an estimated 20% of energy consumption and 17% of emissions. However, the highest energy consumers per square foot by far are food service establishments, which represent only 1% of the city's commercial floor area. These buildings consume an estimated five times more energy per square foot than the second largest consumer, mercantile buildings, and 11 times more than the average for all other building types. Even more striking is the per-square-foot emissions, which is seven times higher than mercantile buildings, and 19 times more than the average for all other building types. The lowest energy consumers and emitters per square foot are lodging and healthcare uses. The largest commercial buildings in the city—those larger than 100,000 square feet—are responsible for an estimated 62% of city-wide energy consumption and 64% of emissions for commercial buildings, even though they only represent 29% of total floor area and 5% of total commercial buildings.

In looking at the impacts of energy efficiency and electrification for existing buildings, the ComStock tool was used to analyze two potential upgrade scenarios.

1. **Envelope**: bringing roof and wall insulation to levels consistent with the current energy code
2. **Electrification**: replacement of any gas-fired boilers, or gas-fired or electric resistance rooftop units (RTUs) with higher-efficiency heat pump RTUs.

Pursuing envelope upgrades alone could reduce energy consumption for the modeled commercial buildings by about 3%, and associated GHG emissions by 5% compared to baseline. Pursuing higher-efficiency electrification (with no envelope changes) could reduce total commercial energy consumption by an estimated 20% and associated GHG emissions by 28%. Envelope upgrades may have a higher impact overall for warehouse and storage space, where space conditioning is the primary energy use, reducing modeled energy consumption by an estimated 9% and emissions by 18%, while the impact on food service would be minimal. Higher-efficiency electrification would likely have the most significant impact on warehouse and storage space, reducing energy consumption by up to 42%, followed by healthcare (22%), and education facilities (19%).

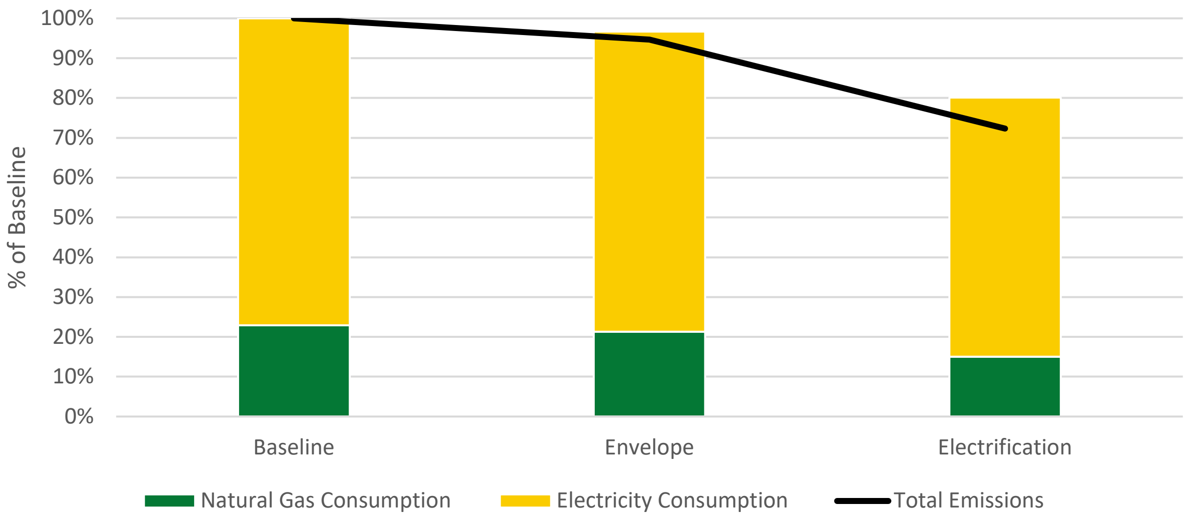

Figure 5. Modeled upgrade scenario impacts on city-wide commercial building energy consumption

Because so much of commercial building energy consumption is currently electricity-based, the higher-efficiency electrification upgrades modeled in this analysis would overall have an estimated positive energy savings (based on time of use), and at an aggregate level are not predicted to result in increasing the demands on the electric grid at any time during the day, though individual building impacts may vary.

The average annual wage for the types of jobs supported by the commercial building upgrades is $97,116. This is higher than the average wage for similar residential building occupations, the state average for the same occupations, and the county average wage for all occupations.

Equity Considerations

According to the baseline ResStock analysis, the lowest-income households in Richmond (those earning less than 200% of the federal poverty limit (FPL) make up about 19% of all households, but they are responsible for only 15% of city-wide energy consumption and 16% of city-wide utility bill costs. However, lower-income households spend a much larger portion of their incomes on energy, which is known as energy burden. The average energy burden for households earning less than 100% FPL is 15%, compared to about 1% for moderate- and higher-income households (above 400% FPL). This means that Richmond's lowest-income households are much more sensitive and vulnerable to even small variations in the dollar amount or percentage change in annual utility bills.

Looking at the impacts of modeled residential upgrades for Richmond, lower-income households, renters, and households living in multifamily buildings would be expected to see less savings as a result of envelope and electrification upgrades, both in absolute dollars and percent savings, compared to higher-income households, owners, and those living in single-family buildings. And because of this, there is less chance of a positive return-on-investment for the upfront costs, particularly of electrification upgrades. An added element for renter households is that they are more likely to pay for their own electricity while their landlord is more likely to pay for natural gas use. Since the price of electricity in Richmond is higher than natural gas (in terms of dollars per equivalent unit of energy, in this case kilowatt hours), these households could be more sensitive than single-family residents to electricity utility bill increases that may result from certain electrification improvements. This is particularly true in the case of lower-efficiency electrification upgrades, which our analysis showed could result in increased utility bills if not paired with envelope improvements.

In general, the high upfront cost of both envelope and electrification measures may be a barrier to low- and moderate-income owner households, and to small-scale landlords (those that own single-family and small multifamily rental properties). Even when items are cost-effective over the lifetime of the measures, a 15–30 year payback may not be feasible for many households, and the cost to finance these measures could reduce the savings they generate.

Another equity consideration is the characteristics of the neighborhood in which buildings are located. NREL compared the location of the city's non-residential buildings to whether they are located in state-designated disadvantaged census tracts as defined by California State Bill 535 and found that 59% of all non-residential buildings and 51% of all non-residential floor area is located in disadvantaged census tracts. The share is higher in uses including industrial buildings, healthcare buildings, public assembly buildings, and government-owned buildings. While there is no clear alignment between location of commercial buildings and energy consumption patterns, it may be helpful for the city to consider the above when crafting policies or programs in the future.

In terms of employment impacts, average annual wages for all Contra County workers engaged in industries relevant to the residential and commercial upgrades described in this report was $88,612 according to the U.S. Bureau of Labor Statistics (BLS). This is higher than the county average for all industries ($80,687), and similar to what is calculated by the Massachusetts Institute of Technology (MIT) as a "living wage" for a working adult in a household with Richmond's average of 3 people: $88,234 (MIT, 2023). According to the data shared in this report, wages for Contra Costa County jobs related to electrification upgrades (HVAC, plumbing and electrical contractors) are 14% higher than those for envelope improvements. In addition, wages for workers in the commercial sector are 28% higher than the residential sector.

Finally, the literature review found that building electrification has the potential to improve indoor air quality and associated health impacts for both Richmond residents and Richmond workers, by reducing or removing pollutants that result from incomplete combustion in natural gas appliances (Mannan et al., 2021, Zhu et al., 2020). Envelope improvements, when completed by a trained professional, have been shown to increase indoor air quality, which can impact the health of Richmond residents and workers. However, poorly or incompletely installed envelope measures could result in an increase in indoor pollutants, especially if natural gas appliances are still present in the home (Mannan and Al-Ghamdi, 2021, EPA, 2022). This would most impact residents and workers in buildings with more indoor natural gas combustion.

Introduction and Project Context

In 2021, DOE announced Communities LEAP, a pilot TA program intended to “facilitate sustained community-wide economic and environmental benefits” to low-income and energy-burdened communities experiencing environmental justice or related impacts (DOE, n.d.). The Communities LEAP program is being managed by NREL, in coordination with a variety of subject matter experts.

One of the 22 Communities LEAP pilot program awardees is Richmond, California. Richmond is a city of approximately 116,000 residents, located on the northeastern-most end of the San Francisco Bay. Richmond is considered “disadvantaged” by state and federal measures, based on indicators such as high poverty levels, energy burden, unemployment, lower enrollment in higher education, and health factors including rates of asthma and cardiovascular disease (OEHHA, n.d.). The city’s top employer is currently a Chevron oil refinery, which is also a major financial contributor to many of the city’s existing sustainability programs.

Figure 6. City of Richmond, California. Source: Richmond General Plan 2030

Based on City goals and objectives related to reducing energy consumption and GHG emissions, and transitioning to clean electricity, a Richmond-based Community Coalition applied to Communities LEAP for TA related to electrification and energy efficiency improvements for existing buildings within the city limits. The Coalition included representatives from the City of Richmond Environmental and Health Initiatives Division and Community Development Department, as well as the Richmond Community Foundation.

Over a 12-month period beginning in July 2022, NREL worked with the Coalition to conduct a city-wide building energy use analysis and develop and assess the feasibility and impact of various approaches to electrifying and improving energy efficiency of all existing residential and commercial buildings within the city limits. This report summarizes the findings of that research and analysis, though it does not include recommendations. It is instead intended to help the Richmond Community Coalition and Richmond City Council make informed decisions for policies and programs related to existing building electrification and energy efficiency in Richmond.

This report is the first of two that will be provided to Richmond as part of the Communities LEAP program. The second report will provide high-level strategies for implementation of existing buildings energy efficiency and electrification based on community-identified priorities.

Project Framework

Based on the community and regional context and priorities described in the following sections, NREL worked with the Richmond Community Coalition to develop a project framework that would provide high-quality data and analysis to support community decision-making related to how best to approach electrification of the city's existing building stock.

For this report, the NREL team separated the analysis into two main sections: one focused on residential buildings and the other focused on commercial buildings. Each section begins with a baseline analysis illustrating current energy consumption patterns in the city. We then provide an analysis of the potential impacts of building electrification and envelope upgrades on five key indicators:

1. **Energy consumption** of HVAC systems and certain appliances used in buildings.
2. **GHG emissions** associated with energy consumption described above.
3. **Utility bill charges and cost-effectiveness** associated with residential energy consumption patterns described above.
4. **Employment indicators,** including estimated number, type and quality of jobs associated with building electrification and other energy improvements described above.
5. **Health and safety indicators** for Richmond residents and workers related to building electrification and other energy improvements described above.

For the purposes of this analysis, the five indicators above are not listed in order of priority and were not weighted based on relative importance. They simply provided a framework to guide the analysis of building energy consumption in Richmond.

Overview of Building Electrification and Energy Efficiency

"Electrification" is a term that refers to the adoption of technologies powered by electricity in place of natural gas or other fossil fuels (Zhou, 2021). The most common examples of electrification refer to vehicle technology (use of electric vehicles rather than traditional gas or diesel engines) and building energy consumption. In buildings, electrification refers mostly to appliances, equipment, and machinery such as:

- Space heating (electric air-source or geothermal heat pumps or mini-splits instead of natural gas forced-air furnaces, boilers, or rooftop units).
- Water heating (electric tankless or heat-pump water heaters instead of natural gas tank water heaters).
- Cooking ranges.
- Clothes dryers.

Within Richmond's 2016 Climate Action Plan, building electrification is framed as a way to reduce the GHG emissions that are associated with the production, transmission, and use of energy in buildings. Because carbon makes up 79% of GHG in the U.S., the concept is sometimes also referred to as "decarbonization." [3] However, the concept of decarbonization is distinct from electrification; depending on how electricity in a particular location is generated, a move towards electrification could either increase or decrease carbon emissions. For example, if a utility generates most or all of its electricity from the burning of coal, then a shift towards electrification instead of natural gas in buildings might increase GHG emissions. Conversely, if a utility generates a large portion of its electricity from clean or renewable sources such as solar photovoltaics (PV) or wind energy, then a shift towards electrification might be more likely to reduce GHG emission associated with building energy use.

The concepts of electrification and decarbonization are also closely related to energy efficiency, which includes both the efficiency of specific appliances and improvements to the envelope of a building. Upgrading any of the appliances or electronics in a home to more energy-efficient ones that use less energy to deliver the same level of service could reduce carbon emissions (whether they are electric or gas-powered) because they would reduce overall energy consumption. Because space heating and cooling are often the most energy-intensive uses in buildings, another way to reduce energy consumption is to make improvements to the envelope of the building: Increasing insulation levels, sealing gaps and cracks in the exterior of the building and in ductwork, and replacing leaky windows are examples of energy conservation measures (ECMs). This in turn reduces the energy needed to heat or cool that home, which could therefore reduce carbon emissions without electrification measures.

Finally, it is important to note that the concepts of electrification and decarbonization refer to technology and building improvements, and do not in themselves address any cost differentials that may come with electrification or ECMs. Any improvement to the energy efficiency of appliances or the envelope of a building should result in reduced energy consumption and therefore reduce monthly utility bills. However, these savings may or may not pay for the cost of the measures over time. In addition, our residential analysis showed that electrification with lower-efficiency electric appliances could in fact increase city-wide utility bills.

The Richmond Community Coalition that applied for and helped guide this Communities LEAP analysis was clear that it was interested in understanding pathways to what is often referred to as "beneficial electrification." Beneficial electrification refers to electrification strategies or approaches that benefit both the environment (through reducing GHG emissions) and the end- users of energy (by saving money and improving health in a way that is equitable) (Beneficial Electrification League, n.d.). Beneficial electrification therefore includes the switching of gas-powered appliances for ones powered by electricity *plus* elements such as appliance energy efficiency, building envelope improvements, building energy management systems, and the adoption of clean and/or renewable energy technologies such as solar PV.

This concept of beneficial electrification, in coordination with the Richmond regulatory context described below, helped set the framework for our approach to analysis for Richmond.

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[3] While GHGs are naturally occurring, human activity increases the presence of these gases in the atmosphere. This can trap heat and lead to climate change, which has numerous potential health, environmental, and social impacts. According to the U.S. Environmental Protection Agency (EPA), more than half of U.S. carbon dioxide emissions come from residential, commercial and industrial sectors, and from electric power generation (EPA, 2022 "Overview of Greenhouse Gases").

Regulatory Context

The Richmond Community Coalition's Communities LEAP TA request was prompted by a variety of policies and activities at the local, regional, state, and federal level, which are summarized below. This context helped inform the Richmond Communities LEAP project framework.

Local Policies & Activities

- 2012 General Plan: In 2012, Richmond's City Council adopted their General Plan, which is intended to guide investments and decision-making for the city through 2030. Although energy is woven throughout this document, one key section of the General Plan relevant to this effort is Element 8 – Energy and Climate Change, which includes the following goals:
    - Goal EC1: Leadership in Managing Climate Change.
    - Goal EC3: Sustainable and Efficient Energy Systems.
    - Goal EC5: Community Revitalization and Economic Development.
- 2014 Health in all Policies: In 2014, Richmond's City Council passed an ordinance that requires/empowers the city to identify and when possible address individual and community health impacts of city policies, projects, and programs.
- 2016 Climate Action Plan: In 2016, Richmond's City Council adopted the Climate Action Plan to help guide how the city could pursue GHG emissions and prepare for impacts of climate change. The sections most relevant to this analysis are:
    - Objective 1: Energy Efficient Buildings and Facilities
        - Strategy EE1: Leverage Existing Programs and Rebates to Improve Efficiency of Existing Buildings (improve the energy efficiency of all existing buildings by 50% by 2030).
    - Objective 2: Increase Use and Generation of Renewable Energy
        - Strategy RE3: Promote Switching from Natural Gas to Clean Electricity (replace 54% of existing natural gas water heaters in homes each year with electric models. Electrify 17% of commercial natural gas use by 2030).
- 2018 Richmond Advanced Energy Community Report: This effort by several state and local organizations reviewed and compiled several financial, policy, and program models for zero-net energy buildings in Richmond, with the goals of reducing GhG emissions and improving health.
- 2021 Green Blue New Deal (GBND): In 2021, Richmond's City Council voted to develop a Green-Blue New Deal and Just Transition to 21st-century jobs. The planning process associated with this decision began in the summer of 2022 and will be completed by the end of 2023. Because this project shares similar goals with Richmond's Communities LEAP request, we worked to align its scope and approach with the GBND effort.
- 2021 Ban on New Natural Gas Hookups: In November of 2021, Richmond's City Council voted to ban natural gas hookups for new building developments in the city.
- Transparent Richmond: Transparent Richmond is an online tool the City uses to share key data and progress with Richmond community members and stakeholders. Where possible, we worked to ensure the analysis is informed by and consistent with data available through Transparent Richmond.

Regional Policies & Activities

- NOx emissions Phase Out for Space and Water Heating: In March 2023, the Bay Area Air Quality Management District voted on rules that would eliminate nitrogen oxide (Nox) emissions from all new space and water heaters starting in 2027. The rules apply to both residential and commercial buildings. Electric appliances are currently the only options that meet this requirement.

State Policies and Activities

- CA State Bill 350, The Clean Energy Pollution Reduction Act: In 2015, the California Energy Commission passed SB 350 with the goals of increasing renewable electricity procurement to 50% by 2030, and double statewide energy efficiency savings for both natural gas and electricity by 2030.
- CA Energy Code Update: The 2022 California Energy Code adopted by the California Energy Commission encourages the use of electric heat pumps for space and water heating in new and renovated buildings.
- Natural Gas Appliance Ban: In 2022, the California Air Resources Board voted to ban the sale of all natural gas-fired space and water-heating appliances by 2030.

Federal Policies and Activities

- Infrastructure Investment and Jobs Act (IIJA): In 2021, Congress passed the IIJA, sometimes also referred to as the Bipartisan Infrastructure Law or BIL. The IIJA included historic investments in energy efficiency for buildings ($6.2 billion) and clean energy infrastructure ($5.8 billion). Much of this funding will be funneled through state energy offices, who will develop and implement programs to allocate those funds within their state.
- Inflation Reduction Act (IRA): In 2022, Congress passed the IRA, which also includes historic investments in clean energy ($185 billion), residential energy efficiency and electrification ($14 billion), and resilient and healthy communities ($12 billion). Of particular interest to this project are residential rebates for low- to moderate-income households for energy efficiency and electrification upgrades.

We will provide the community coalition members with additional detail on potential funding resources throughout the TA process and in the final implementation report.

Project Methodology

Our analysis for this report is based foundationally on data from the ResStock™ and Comstock™ analysis tools. These are open-source tools supported by DOE and developed and managed by NREL which offer details about various characteristics of the U.S. building stock, including energy consumption, with the ability to drill down to state, country, and local geographic levels (NREL, n.d.).

ResStock and ComStock use a combination of public and private data sources that describe the residential and commercial building stocks in the U.S. in terms of age, building type, construction type, appliance types and age, energy consumption and more. They use this data along with high-efficiency sampling algorithms and high-performance computing to generate energy consumption models for a representative subset of buildings for an identified geography (Wilson et al., 2022).

Finally, the end-use savings shape (EUSS) functionality of ResStock and Comstock allows users to model how specific envelope and electrification upgrades might impact the energy consumption for the overall building stock in a specified geographic location. This is similar in process to what energy auditors use when they evaluate individual homes or buildings for energy efficiency or conservation measures; but rather than using actual individual building data, ResStock and ComStock model the energy impacts of pre-determined upgrades on a representative sample of buildings in an area, and aggregate the results to the entire building stock.

We used the data generated by these tools as the basis for all five areas of analyses found in this report:

1. **Energy consumption**: Data from ResStock and ComStock, presented in kilowatt hours (kWh) for both electricity and natural gas for easier comparison.
2. **GHG emissions:** Data from ResStock and ComStock was adjusted based on annual average emissions details from local utilities Pacific Gas and Electric (PG&E) and Marin Clean Energy (MCE). Presented in metric tons of carbon dioxide equivalent (MT CO_2e).
3. **Utility bill charges and cost-effectiveness**: Local utility rate estimates for 2023 were applied to ResStock energy consumption data. Cost data from local contractors and published sources was used to estimate the costs and calculate return-on-investment for residential building upgrades.
4. **Employment outcomes**: High-level state-level energy efficiency jobs multipliers published by NREL (Truitt et al., 2022) were applied to the residential cost estimates developed for #3 above to provide a rough estimate of potential job impacts related to investments in modeled upgrades. Job characteristics from the BLS provided for both residential and commercial work.
5. **Health and safety outcomes:** A literature review was conducted to understand the impacts of building envelope and electrification upgrades on indoor air quality and individual health and safety.

For the items above, we provided information on the potential impacts for city overall, as well as analysis based on building type, vintage, and in the case of residential buildings, also income and tenure (renters versus owners). All figures presented in this report are from NREL's ResStock or ComStock data unless otherwise noted.

A more detailed description of the analysis methodology is provided in Appendix A.

Project Assumptions and Limitations

It is important to reiterate upfront that this analysis did not use *actual* energy consumption, GHG emissions, or utility bill data for the City. Instead, it used the ResStock and ComStock tools that *model* potential energy consumption patterns. Although the models are highly vetted and the baseline building stock data cross-checked with county assessor data, every model makes specific assumptions and therefore has its limitations. Some key limitations are outlined below.

Building Stock

For ease of analysis and interpretation, we aggregated certain building type categories together as described in the analysis and in Appendix A. However, the ResStock and ComStock tools themselves exclude certain categories of buildings, due to lack of consistent data available. The types of buildings *excluded* by these tools are:

- Residential
    - Dormitories (not applicable in Richmond).
    - Prisons (not applicable in Richmond).
- Commercial and Institutional (referred to in this report at "Commercial")
    - Assisted-care facilities and other congregate housing (less than 1% of units in Richmond).
    - Colleges (not applicable in Richmond).
    - Laboratories.
    - Grocery stores.
    - Entertainment venues.
    - Recreation centers.
    - Religious buildings.
    - Vehicle repair shops.
- Industrial
    - All industrial buildings are excluded from the analysis, except for warehouse and storage facilities.

In addition, based on feedback from the community coalition, we chose to exclude certain buildings from the analysis which are not regulated by the City's building/planning departments. This included mobile/manufactured homes, public schools, and government-owned buildings. More detail is provided in the Commercial Building section of this report and in Appendix A.

Upgrade Scenarios

The ResStock and ComStock EUSS tools provide set "packages" of envelope and electrification upgrades that can be applied the building stock. We worked with the Richmond community coalition to identify which of the packages was most appropriate for this project, given the City's goals and interests. As a result, this analysis does not address every possible way the individual buildings could pursue energy efficiency or electrification. Instead, the packages that this report includes are intended to show, in general, the maximum potential impact of these improvements at a city-wide scale; for example, what the impact would be if every existing residential unit electrified every appliance with higher-efficiency alternatives or brought the building's envelope to current energy code requirements.

That being said, the analysis does drill down to the impacts by building type, as well as breaking out energy consumption by end use (meaning which appliances or uses consume what share of energy in the home). This is intended to allow readers of this report to infer some of the nuance that could not be included in the overall analysis.

Cost and Utility Bill Analysis

We worked with community partners to obtain local high-level cost estimates for the upgrades modeled in the analysis. We received several sources for residential cost data, but only two sources for commercial data. As a result, we subcontracted with ICF Incorporated to provide commercial building upgrade cost estimates by building type. These were not used to estimate cost-effectiveness, but to estimate employment impacts as described in the following section. In addition, the analysis of savings-to-investment ratio of modeled residential building upgrades assumed that buildings would pursue electrification upgrades at the time of existing appliance wear-out.

The upgrade costs and utility rate estimates provided in this report are based on the most recent data available at the time analysis began in January 2023 (these sources are described in more detail in Appendix A). However, rates and costs are highly sensitive to changing market and labor conditions and were not projected into the future. Therefore, the cost and utility bill impact analysis should be understood as a point-in-time estimate of the potential fiscal impacts of building electrification, energy efficiency, and envelope measures. Furthermore, the actual costs for any particular building upgrade can vary greatly depending on existing conditions, variations in scope of work, the contractors performing the work, the specific materials/equipment used, etc. They can also be impacted by the availability of rebates, incentives, or tax credits through utilities and local, state, or federal government. Any future use of this data should be reviewed for accuracy.

Employment Estimates

To estimate the employment impacts of the residential and commercial building upgrade scenarios described earlier, We used state-level jobs multipliers for energy efficiency and electrification upgrades that were published by NREL in 2022. Those multipliers do not take all potential local jobs modelling factors into account. Instead, according to the report, the multipliers are intended to “help readers make informed decisions regarding workforce development investments that support clean energy deployments and help identify employment prospects in the clean energy economy.”

Data Age

The ResStock and ComStock tools use a combination of public and private data sources as the foundation for the analysis they provide nation-wide. As a result, the data is not “real-time” information, and in some cases is based on national survey data for which is several years old. Both ResStock and ComStock data models as closely as possible the housing stock and energy consumption for Richmond as it appeared in 2018, and therefore does not capture changes to the building stock over the last 5 years. However, baseline building number and square footage data was matched to current county assessor’s data to account for some differences here.

Residential Building Energy Analysis

This section provides current (baseline) modeled data related to the city's residential building stock and energy consumption patterns. It then describes how this baseline data might be impacted by improvements to residential building envelopes and the electrification of appliances. The section also describes the impacts on employment and health indicators.

Building Stock Baseline Data

Of the estimated 38,499 residential housing units in Richmond, just over two-thirds are single family (attached and detached), and almost one-third are in multifamily buildings. For this analysis, small multifamily buildings are defined as buildings with two to four units, and large multifamily buildings are those with five or more units.

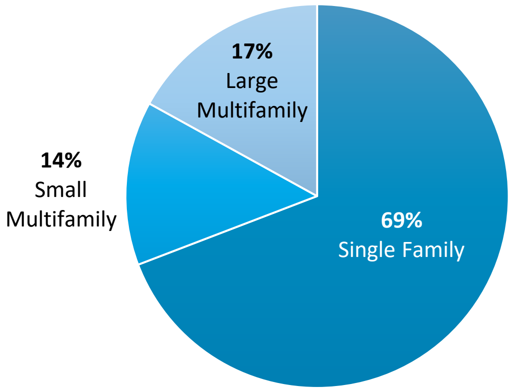


Figure 7. Estimated residential housing stock by building type

Almost three-quarters (71%) of Richmond's housing stock was built before 1980. This is an important date because 1978 was the year California's first energy code was adopted (CEC, 2023), and the year the U.S. Environmental Protection Agency (EPA) first enacted bans on lead-based paint and asbestos in certain building materials (EPA, 2023). This means that homes built before this cutoff are likely to be less energy efficient, and more at risk for health and safety issues. Older homes in Richmond are predominantly single family, while almost half the housing units built since 1980 have been multifamily.

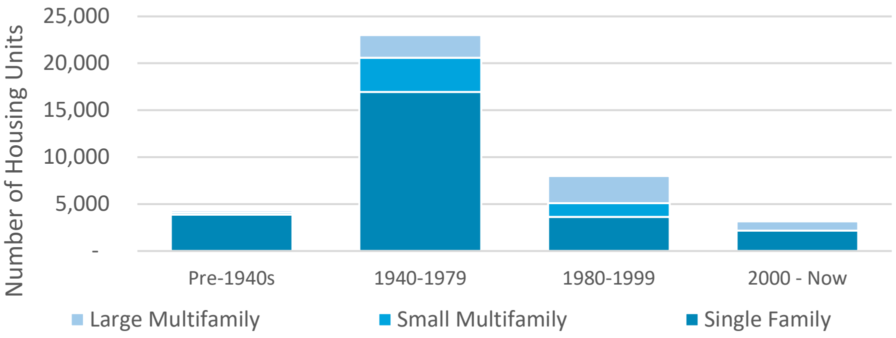


Figure 8. Estimated residential housing stock by vintage

Renters make up about 46% of households in Richmond. As illustrated in Figure 9, the majority of renters (60%) live in multifamily buildings, while 94% of owners live in single-family buildings. Finally, more than half (57%) of low-income households (those earning less than 200% of the FPL live in multifamily buildings, compared to about a quarter of higher-income households, as illustrated in Figure 10.

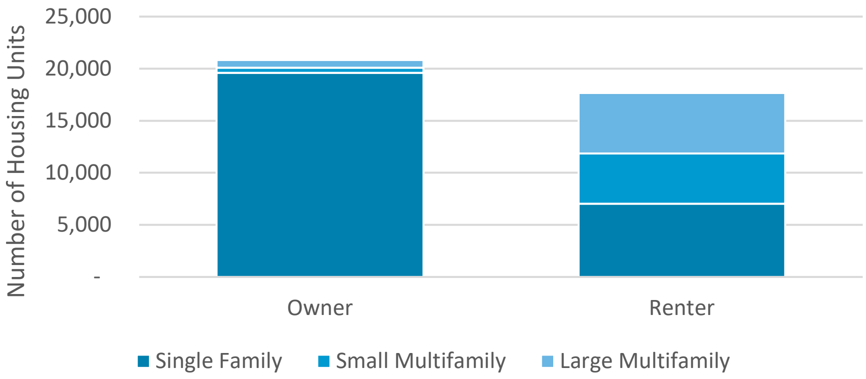


Figure 9. Estimated residential housing stock by federal poverty level

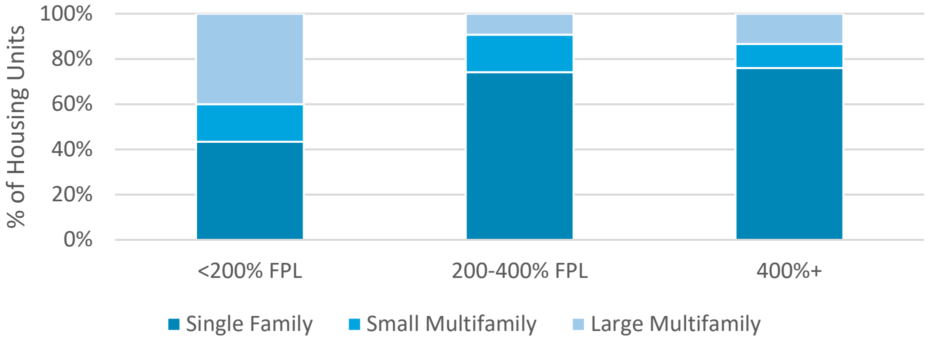


Figure 10. Estimated residential housing stock by building type

More information about how and why these building stock categorizations were used is provided in Appendix A.

Energy Consumption & Associated Greenhouse Gas Emissions

Baseline Data

The ResStock models showed that residential buildings in Richmond currently consume an estimated 688 million kWh of energy each year, for an average of 17,870 kWh per unit. According to ResStock data and data from the California Energy Commission (CEC), this ResStock-modeled average per unit is slightly lower than Contra Costa County, and slightly higher than the state average (CEC, n.d.). As shown in Figure 11, about 56% of energy consumed in Richmond is natural gas, and 44% is electricity for the residential buildings modeled. According to ResStock data, Richmond is slightly more reliant on natural gas compared to both the County and state.

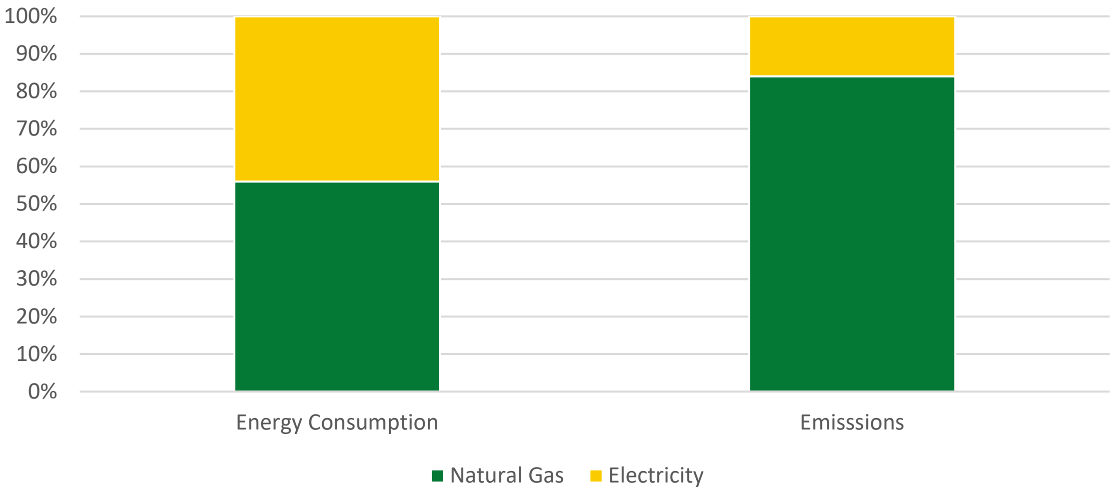
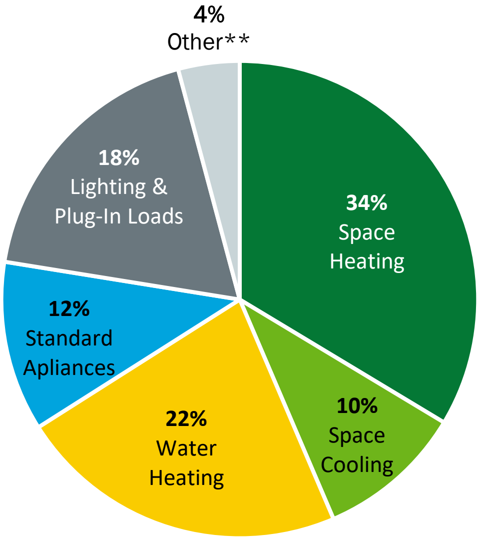


Figure 11. Modeled city-wide residential energy consumption and emissions by fuel type

The generation, transmission, and consumption of energy associated with Richmond's residential buildings is responsible for nearly 91,000 metric tons of carbon dioxide GHG emissions. This is equivalent to 19,572 gasoline-powered passenger vehicles driven for one year (EPA, 2022). And although natural gas represents 56% of residential energy consumption, it is responsible for 83% of GHG emissions associated with residential building energy use.

Space heating is the highest estimated energy consumption end use for Richmond households, responsible for 34% of all residential building energy use in Richmond, and most of that uses natural gas. Water heating represents 22% of all energy use. Clothes dryers and cooking ranges (the other residential appliances that can use either natural gas or electricity) use less energy in general and are more evenly split between natural gas and electricity.



*Cooking range, clothes dryer, dishwasher, refrigerator. **Hot tubs, pools, fireplaces, grills.

Figure 12. Modeled city-wide residential energy consumption by end use

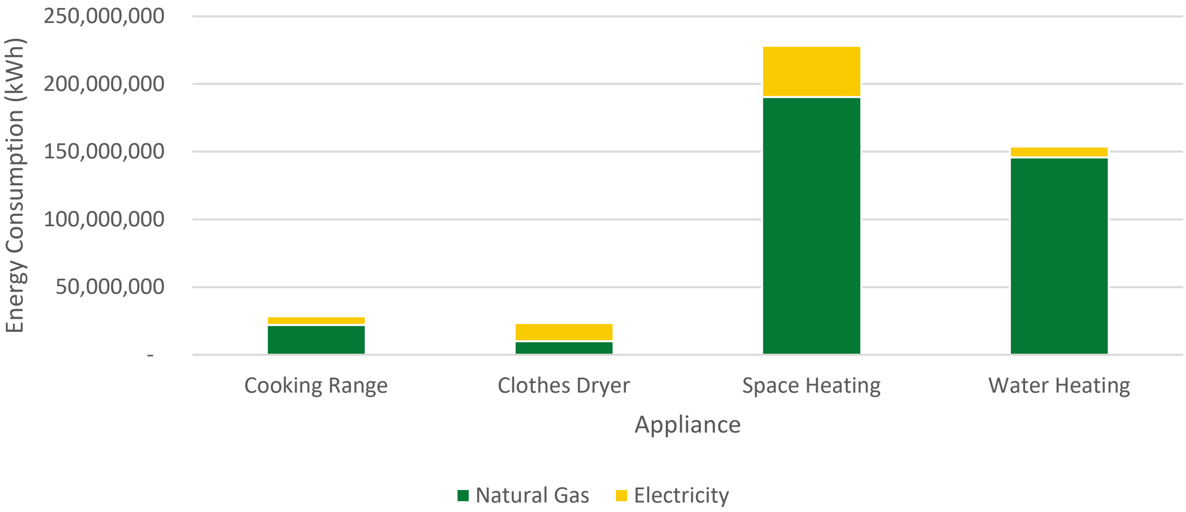


Figure 13. Modeled city-wide residential energy consumption by fuel type for major appliances that could be electrified

Figure 14 shows that on a per unit basis, single family homes are estimated to consume almost twice as much energy as units in small multifamily buildings, and almost three times as much energy as units in large multifamily buildings. Natural gas also represents a higher share of total energy used in single-family homes (58%) versus multifamily buildings (44%). And though single-family housing units make up 69% of Richmond's housing stock, they are responsible for 83% of residential energy use and 85% of associated GHG emissions. Conversely, units in large multifamily buildings make up 17% of the housing stock, but only represent 7% of energy consumption and 6% of GHG emissions (Figure 15).

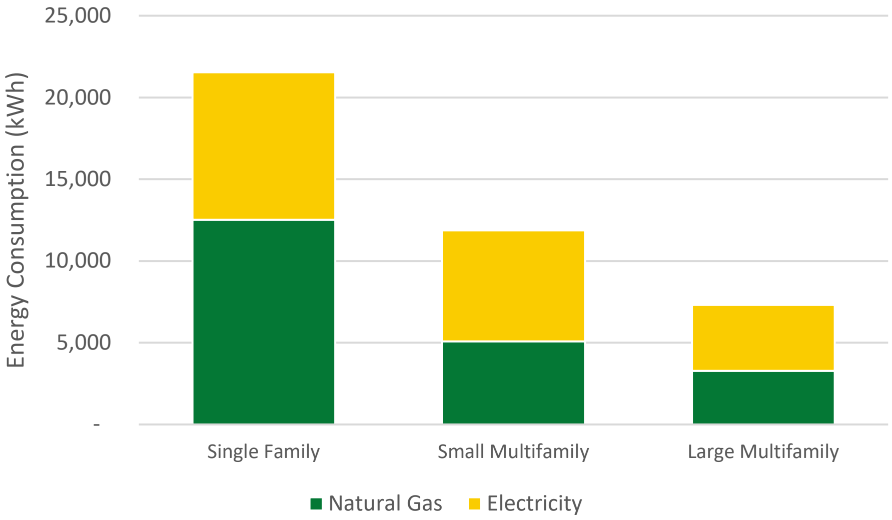


Figure 14. Average annual per unit modeled residential energy consumption by building type

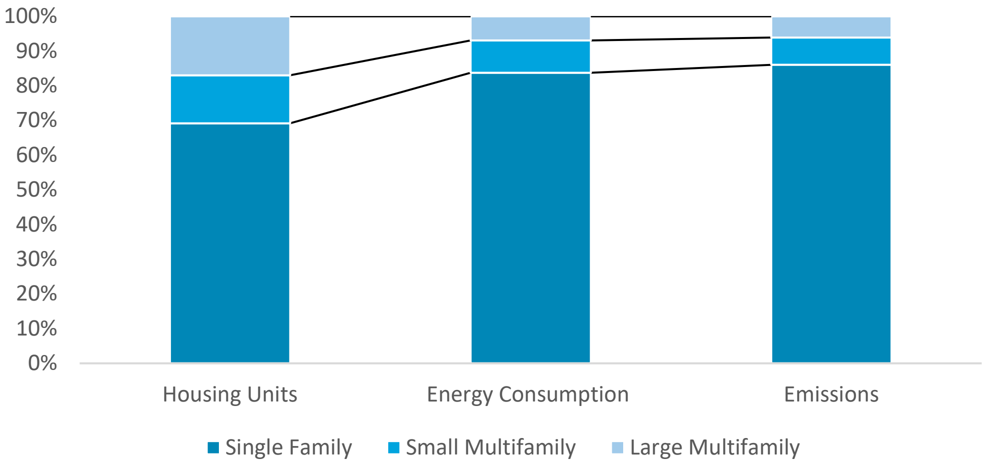


Figure 15. City-wide modeled annual residential energy consumption and emissions by building type

Building age is also related to energy consumption and emissions in Richmond, as shown in Figures 16 and 17. In general, the older a housing unit, the more energy it is likely to use, with a higher share of natural gas, resulting in higher GHG emissions. This is because older homes are more likely to have leakier and less insulated building envelopes, which equates to higher heating and cooling costs. For example, homes built before 1940 make up 11% of Richmond's housing stock, but they are responsible for an estimated 17% of residential energy consumption and 19% of associated GHG emissions. Conversely, homes built since 2000 make up 8% of the city's housing stock but are only responsible for an estimated 7% of energy consumption and 6% of GHG emissions. It should be noted that homes built since 2000 use slightly more energy per unit compared to homes built from 1980–1999 (though less than pre-1980 homes). This is largely due to larger average unit size and greater prevalence of air conditioning.

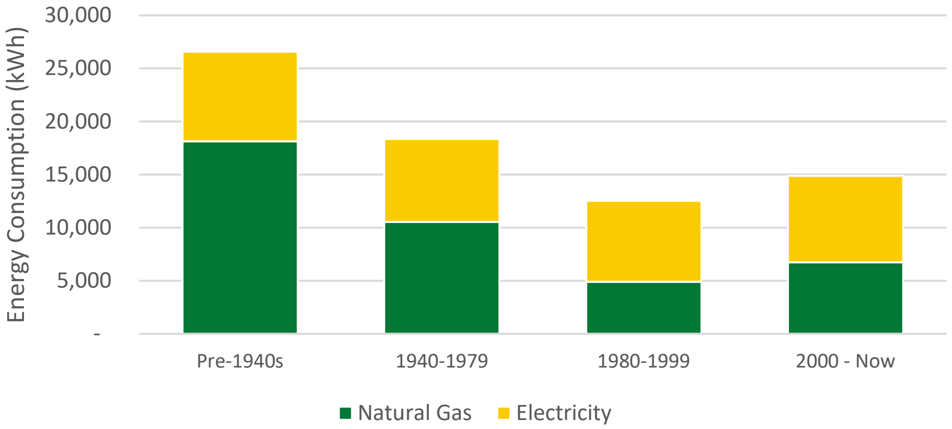


Figure 16. Average annual per unit modeled residential energy consumption by building vintage

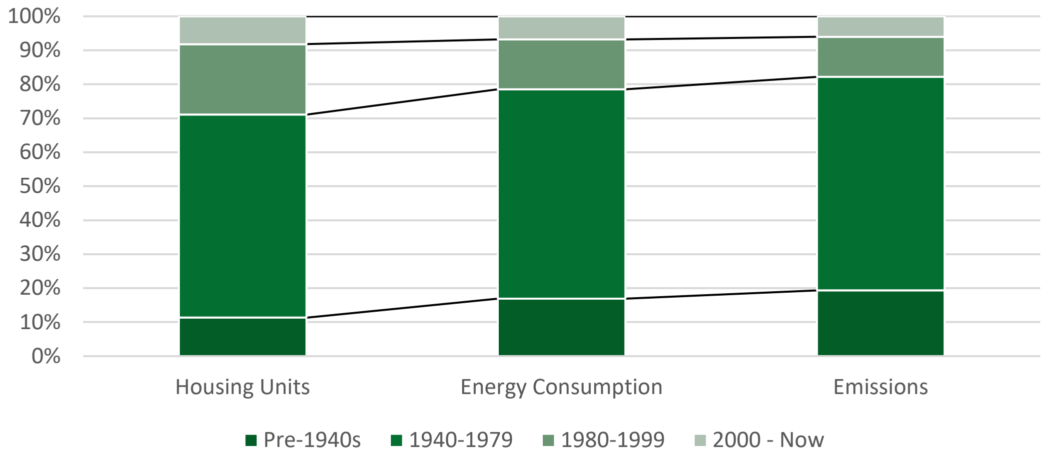


Figure 17. City-wide modeled annual residential energy consumption and emissions by building vintage

Upgrade Analysis

This section investigates how energy consumption and related emissions might change if four potential "packages" of building envelope and electrification upgrades were made city-wide. The four scenarios are summarized below, with more detail on specific insulation, air leakage, and appliance efficiency specifications provided in Appendix B.

Table 1. Residential EUSS Upgrade Scenario Descriptions

Upgrade Scenario	Energy Conservation and Electrification Measures
Building Envelope and Enclosure ("Envelope")	• Attic insulation • Wall insulation • Foundation wall and rim joist insulation • General air sealing • Duct sealing
Electrification of appliances and heating/cooling systems, lower-efficiency approach ("Electrification-Lower Ef.")	• Lower[4]-efficiency air source heat pump and electric resistance backup for space heating • Lower-efficiency heat pump water heater • Electric resistance dryer • Electric range and oven
Electrification of appliances and heating/cooling systems, higher-efficiency approach ("Electrification-Higher Ef.")	• Higher-efficiency air source heat pump and electric resistance backup for space heating • Higher-efficiency heat pump water heater • Ventless heat pump dryer • Induction range and electric oven
Envelope + Electrification - Higher Ef.	See above

As is illustrated in Figure 18 below, our modeling shows that pursuing envelope upgrades alone could reduce total residential energy consumption in Richmond by an estimated 23%, and

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[4] The term "lower-efficiency electrification" is used here and throughout the report to describe the assumed/modeled efficiency levels for these scenarios relative to the "higher-efficiency electrification" scenarios.

associated GHG emissions by 29% compared to baseline. Pursuing higher-efficiency electrification (with no envelope changes) could reduce total residential energy consumption by 53% and associated GHG emissions by 81%. Pursuing both envelope and higher-efficiency electrification together could reduce residential energy consumption by 58% and associated GHG emissions by 83%. Despite overall energy and natural decreases under all scenarios, electricity consumption varies depending on the upgrades. Envelopes have the highest impact on natural gas consumption due to the energy needed for space heating, but there is also a small potential decrease in electricity consumption here, due to the impacts of envelope improvements on space cooling. Lower-efficiency electrification could increase city-wide residential electricity consumption by 35% annually, and even higher-efficiency electrification alone could increase electricity slightly by 2%, which is within the eumargin of error for this analysis. However, pairing envelope with higher-efficiency electrification improvements could potentially decrease electricity consumption by an estimated 8%. This is because of the reduction in energy needed for space conditioning, paired with the improved space cooling efficiency from heat pumps.

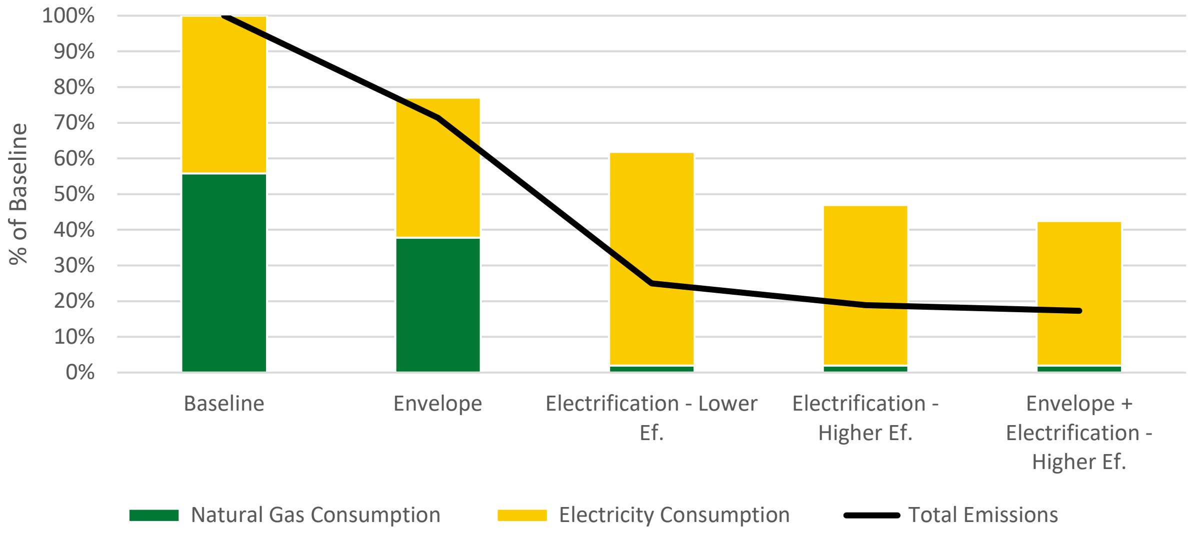
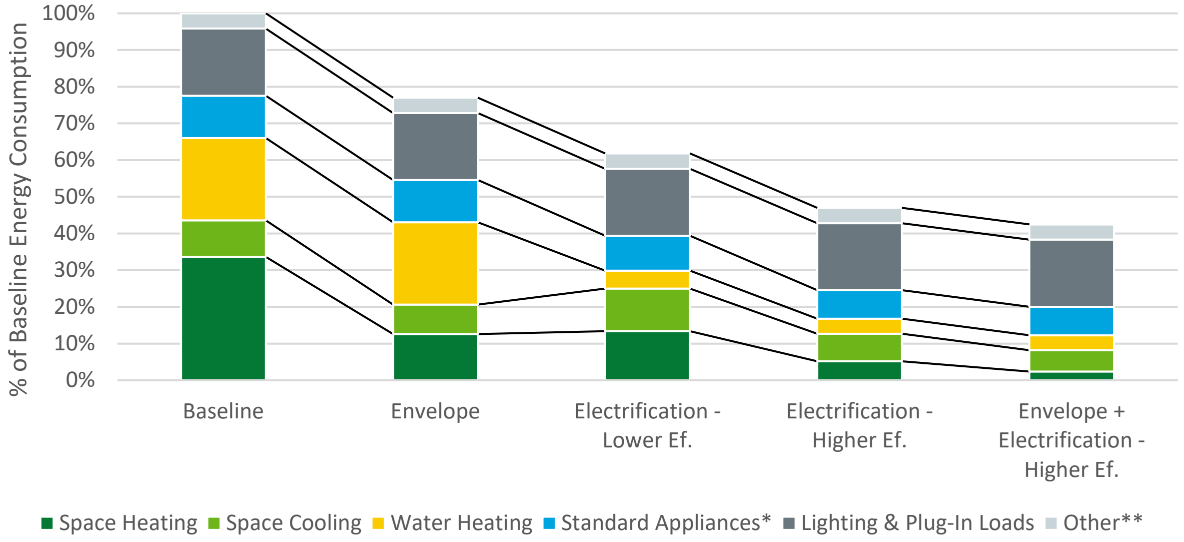


Figure 18. Modeled upgrade scenario impacts on city-wide annual residential energy consumption by fuel type and emissions

The main reason for the relatively small change in overall energy consumption between Electrification and Electrification + Envelope is that when space heating (which is most sensitive to envelope improvements) is electrified using higher-efficiency heat pumps, this dramatically decreases the impact of this factor on overall energy use. For example, Figure 19 illustrates how space heating is currently responsible for an estimated 34% of all residential building energy use in Richmond. This decreases to 11% under the Electrification-higher scenario, and only 6% of all energy use under the Envelope + Electrification scenario. In addition, because heat pumps can both heat and cool a home, there is a portion of homes that currently do not have air conditioning that are assumed in the modeling to use electricity in warm months to cool their homes. This impact is illustrated in the graphic below, where the share of energy used for space cooling actually increases under the lower- efficiency electrification upgrade.



*Cooking range, clothes dryer, dishwasher, refrigerator; **Hot tubs, pools, fireplaces, grills.

Figure 19. Modeled upgrade scenario impacts on city-wide annual residential energy consumption by end use

It is important to note that although the modeling for Richmond showed that combining higher-efficiency electrification with envelope improvements may have a relatively small impact on overall energy use and GHG emissions (relative to higher-efficiency electrification with no envelope improvements), it does have the potential to improve thermal comfort and indoor air quality, which will be discussed more in a later section.

Finally, as is illustrated in Tables 2 and 3 below, these upgrades have different estimated impacts depending on the type of housing unit. For example, the envelope upgrades modeled have a higher impact overall on single-family energy use compared to multifamily buildings, reducing city-wide single-family energy consumption by up to 25% compared to 9%. This is mostly because single-family homes are more likely to be older, less efficient (envelope and appliances) and consume less energy per unit on average to begin with. In addition, all upgrade scenarios will have a higher impact on the energy consumption of older homes, which tend to be less efficient to begin with. For example, homes built before 1940 could see a 33% reduction in energy consumption from envelope upgrades only, compared to only a 5% reduction for homes built since 2000. This difference is less pronounced for the electrification upgrades, with pre-1940s homes seeing a 57% reduction in energy use compared to 46% for homes built since 2000.

Table 2. Upgrade Scenario Modeled Impacts on City-Wide Energy Consumption and GHG Emissions by Building Type

Upgrade Scenario	Building Type	Total Energy Consumption		Total GHG Emissions	
		MWh	% Change	1,000 Metric Tons CO2	% Change
Baseline	Single Family	574	N/A	78.1	N/A
	Small Multifamily	63	N/A	7.1	N/A
	Large Multifamily	48	N/A	5.6	N/A
	Total	685	N/A	90.8	N/A
Envelope	Single Family	429	-25%	53.7	-31%
	Small Multifamily	53	-16%	5.7	-21%
	Large Multifamily	46	-5%	5.2	-7%
	Total	528	-23%	64.5	-29%
Electrification – Lower Efficiency	Single Family	349	-39%	18.6	-76%
	Small Multifamily	42	-33%	2.0	-71%
	Large Multifamily	33	-32%	1.7	-70%
	Total	423	-38%	22.3	-75%
Electrification – Higher Efficiency	Single Family	263	-54%	14.5	-82%
	Small Multifamily	32	-50%	1.5	-78%
	Large Multifamily	27	-43%	1.4	-74%
	Total	322	-53%	17.4	-81%
Envelope + Electrification – Higher Efficiency	Single Family	235	-59%	13.2	-83%
	Small Multifamily	29	-54%	1.4	-80%
	Large Multifamily	27	-45%	1.4	-75%
	Total	291	-58%	16.0	-82%

Table 3. Upgrade Scenario Modeled Impacts on Energy Consumption and GHG Emissions by Building Vintage

Upgrade Scenario	Building Type	Total Energy Consumption		Total GHG Emissions	
		MkWh	% Change	1,000 Metric Tons CO2	% Change
Baseline	Pre-1940s	116	N/A	17.6	N/A
	1940–1979	422	N/A	57.1	N/A
	1980–1999	400	N/A	10.7	N/A
	2000–Present	47	N/A	5.5	N/A
	Total	685	N/A	90.8	N/A
Envelope	Pre-1940s	78	-33%	10.6	-40%
	1940–1979	313	-26%	39.0	-32%
	1980–1999	92	-8%	9.8	-8%
	2000–Present	45	-5%	5.1	-6%
	Total	528	-23%	64.5	-29%
Electrification – Lower Efficiency	Pre-1940s	67	-42%	3.7	-79%
	1940–1979	254	-40%	13.5	-76%
	1980–1999	72	-28%	3.6	-66%
	2000–Present	31	-34%	1.5	-72%
	Total	423	-38%	22.3	-75%
Electrification – Higher Efficiency	Pre-1940s	50	-57%	2.8	-84%
	1940–1979	191	-55%	10.5	-82%
	1980–1999	56	-44%	2.9	-73%
	2000–Present	25	-46%	1.3	-77%
	Total	322	-53%	17.4	-81%
Envelope + Electrification – Higher Efficiency	Pre-1940s	43	-63%	2.5	-86%
	1940–1979	170	-60%	9.5	-83%
	1980–1999	53	-47%	2.7	-74%
	2000–Present	25	-48%	1.2	-78%
	Total	291	-58%	16.0	-82%

Potential Utility Grid Impacts

Figures 20 and 21 below show how city-wide annual residential *electricity* consumption is expected to change in response to the modeled electrification upgrades analyzed in this report. This is important because a key concern in building electrification has to do with the capacity or ability of the electric transmission and distribution grid (operated in Richmond by PG&E) to handle increased electricity demand. The figure below shows average daily modeled changes in electricity consumption by time of day for each of the electrification upgrade scenarios, as compared to the baseline model.

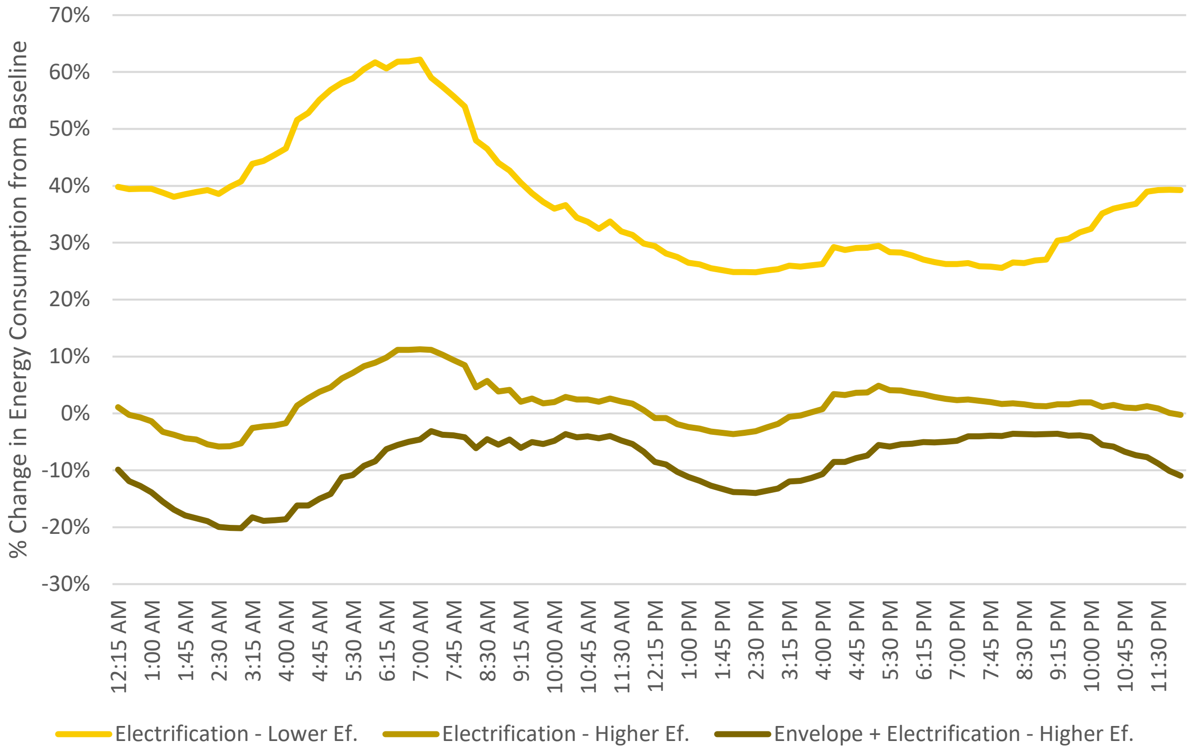


Figure 20. Average estimated daily city-wide residential electricity consumption for modeled building electrification upgrades by time of use

As described earlier, under the lower-efficiency electrification upgrade scenario, city-wide residential electricity consumption is modeled to increase by about 35% annually overall, and could put increased demand on the utility at all times of the day, with the biggest increase between 3 a.m. and 9 a.m. Under the higher-efficiency electrification upgrade scenario, city-wide residential electricity consumption is predicted to stay close to the same (our modeling showed an overall annual increase of less than 2%). However, there are times during the day when city-wide electricity consumption is predicted to increase compared to baseline, and times when it is predicted to decrease. As the chart above illustrates, this increase will be most pronounced between 4 a.m. and 10 a.m., though it is not as high as in the lower-efficiency scenario. Under the envelope + higher-efficiency electrification upgrade scenario, city-wide residential electricity consumption is expected to decrease slightly (by 8% annually) compared to baseline. Our modelling indicates that there would be no time during the day when, on average, this scenario would cause an increase in electricity consumption compared
to baseline.

There are, however, also variations throughout the year based on seasonal changes in temperature. As the graphic below illustrates, under both the lower- and higher-efficiency electrification upgrade scenarios, our modeling shows that the increases in city-wide electricity demand are highest during the winter months, when electricity is being used for space heating. When envelope upgrades are combined with higher-efficiency electrification, there are a few times throughout the year when electricity demand may exceed baseline, but the vast majority of days still show net electricity savings.

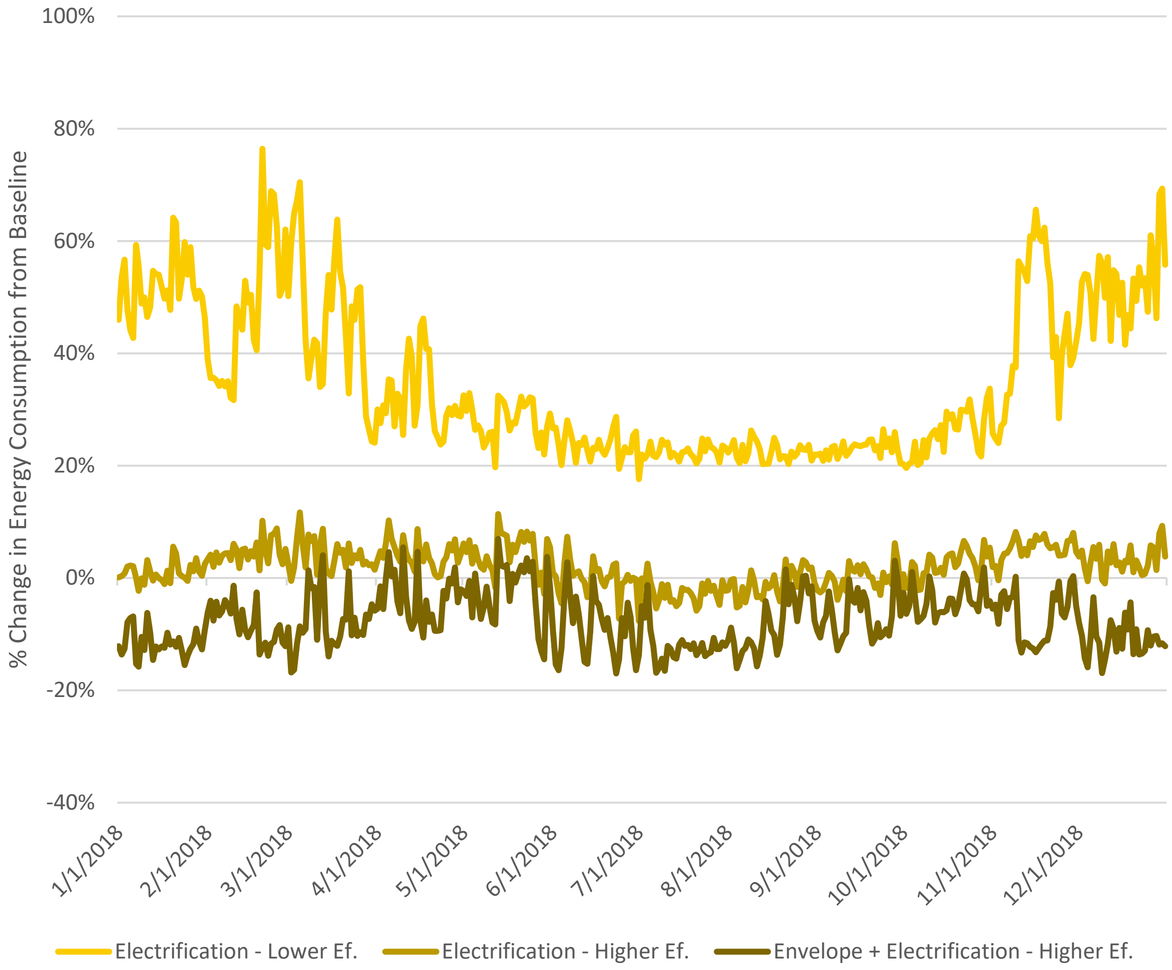


Figure 21. Estimated annual city-wide residential electricity consumption for modeled building electrification upgrades

The implications of this analysis are that the city will need to be strategic in how it approaches residential building electrification so as not to overburden the utility grid. This analysis clearly shows that combining higher-efficiency electrification with envelope measures can help address this. Aligning electrification upgrades with increases in distributed solar PV is another opportunity, though it is not addressed in this analysis and may not fully address the challenge. The city will want to work with PG&E in planning and implementation.

Utility Bill Charges

Baseline Data

Using modeled energy consumption data presented above and PG&E and MCE anticipated rate estimates for 2023, Richmond households are currently expected to pay an average of more than $3,600 per year in gas and electric utility costs, or $350 per month. Because electricity rates are higher than natural gas in Richmond in terms of equivalent units of energy (kWh), about three-quarters of utility bill charges are from electricity consumption even though electricity is responsible for less than half of total site energy consumption. Based on ResStock energy consumption estimates and MCE's rates, Richmond's average annual utility charges per dwelling unit is lower than Contra Costa County, but slightly higher than the state average.

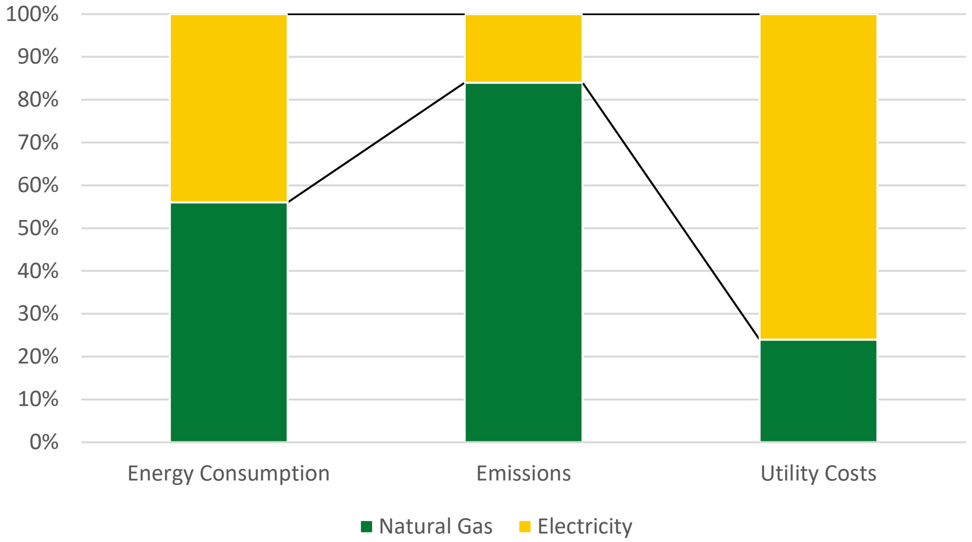


Figure 22. Modeled annual residential energy consumption, emissions, and utility cost share by fuel type

As illustrated in Figures 23 and 24 and Table 4 below, single-family homes, owner-occupied households, older homes, and higher-income households all pay higher utility costs per household, but they also pay a disproportionately higher share of all residential utility costs for the city. For example, single-family households make up 69% of all housing units in Richmond. But they are responsible for 84% of residential energy consumption and pay 81% of residential utility bill costs. Owners, who live almost entirely in single-family homes, make up 54% of households, but consume 63% of residential energy and pay 60% of utility bill costs.

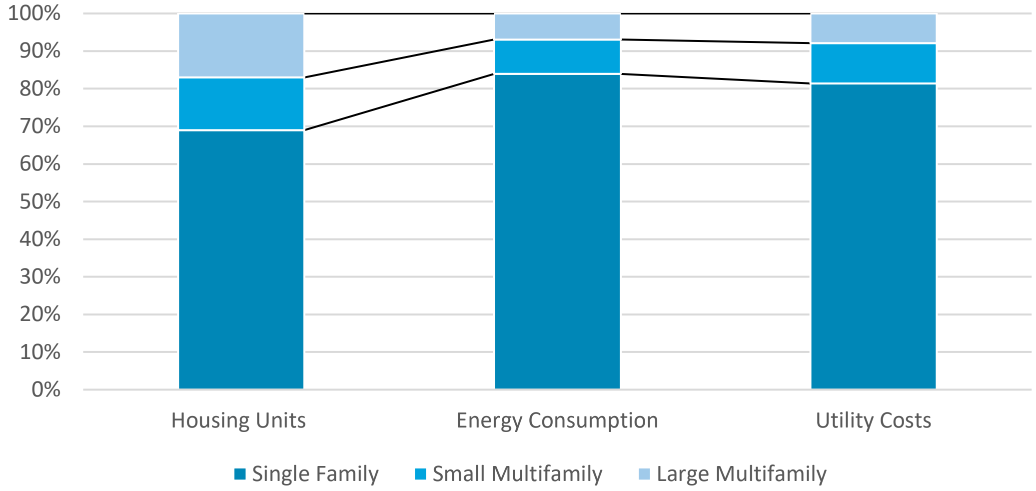


Figure 23. Modeled annual residential energy consumption and utility cost share by building type

Older homes consume more energy and pay higher utility bills compared to newer housing units. For example, homes built before 1940 make up only 11% of housing units but use 17% of residential energy consumption and pay 14% of residential utility bill costs. The energy consumption share for older homes is higher than their utility cost share, because most of the additional energy consumption in older homes is natural gas for heating, which is less expensive than electricity per unit of site energy in Richmond.

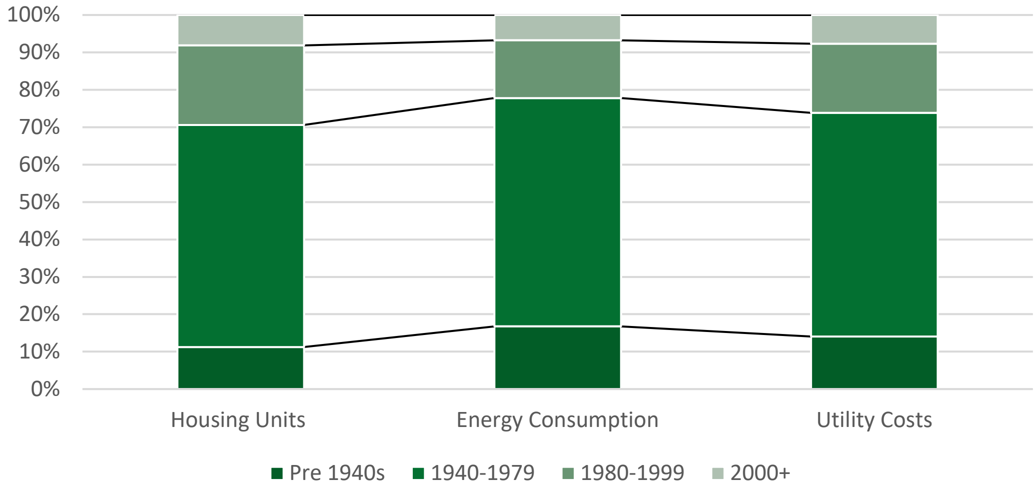


Figure 24. Modeled annual residential energy consumption and utility cost share by building vintage

Finally, households earning less than 200% of the FPL make up about 19% of Richmond residential units, but they are responsible for 15% of residential energy consumption and 16% of residential utility bill costs.

Table 4. Modeled Baseline Utility Bill Costs Per Household*

		Monthly Utility Bill Costs	Annual Utility Bill Costs
Total Average		**$302**	**$3,629**
Building Type	Single Family	$357	$4,283
	Small Multifamily	$237	$2,841
	Large Multifamily	$143	$1,716
Building Vintage	Pre-1940	$380	$3,679
	1940–1979	$307	$3,679
	1980–1999	$264	$3,169
	2000–Present	$289	$3,464
Tenure	Renter	$260	$3,125
	Owner	$342	$4,105
Household Income	Less than 200% FPL	$230	$2,761
	200–400% FPL	$316	$3,789
	More than 400% FPL	$430	$5,156

* These estimates are based on 2023 rates applied to modeled energy consumption. It does not reflect reductions that households may see due to presence of rooftop solar PV, or from enrollment or participation in utility bill reduction or relief programs.

Note on Utility Bill Payments
It is important to note that this analysis does not consider what portion of utility bills renter households are responsible for, especially those renters living in multifamily buildings. This is due to a lack of consistent data. However, findings from the Richmond multifamily affordable housing survey conducted by Shivali Prakash Gowda in alignment with this project found that a majority of these households pay their electricity bills, and approximately half pay their own gas bills (Gowda, 2023). These utility payment estimates also do not reflect discounts, reductions, or other assistance they may receive through any of the following programs available to low-income households in Richmond:

California Alternate Rates for Energy (CARE)

Income level: Less than 200% FPL

Assistance:

30–35% discount on electricity bill

20% discount on natural gas bill

Family Electric Rate Assistance Program (FERA)

Income level: 200–250% FPL

Assistance: 18% discount on electricity bills

Low Income Heating Assistance Program (LIHEAP)

Income level: Less than 250% FPL

Assistance: One-time financial assistance to households struggling to pay utility bills or receiving a 24–48-hour disconnect service from their utility

Upgrade Analysis

Most building envelope and electrification upgrades investigated in this analysis would result in reduced annual utility bill costs for the modeled buildings overall, although the percent decreases are not as high as for energy consumption or GHG emissions. This is because natural gas is currently a higher share of residential energy consumption in Richmond compared to electricity, but it is less expensive compared to electricity per unit of site energy.

Pursuing envelope upgrades alone could reduce total annual residential gas and electric utility bills in Richmond by 16% compared to baseline. Pursuing higher-efficiency electrification (with no envelope changes) could reduce utility bills by 22%, and pursuing both envelope and electrification together could reduce utility bills by 30%. It is important to point out that if households pursued lower-efficiency electrification upgrades, utility bills could actually increase by 3%.

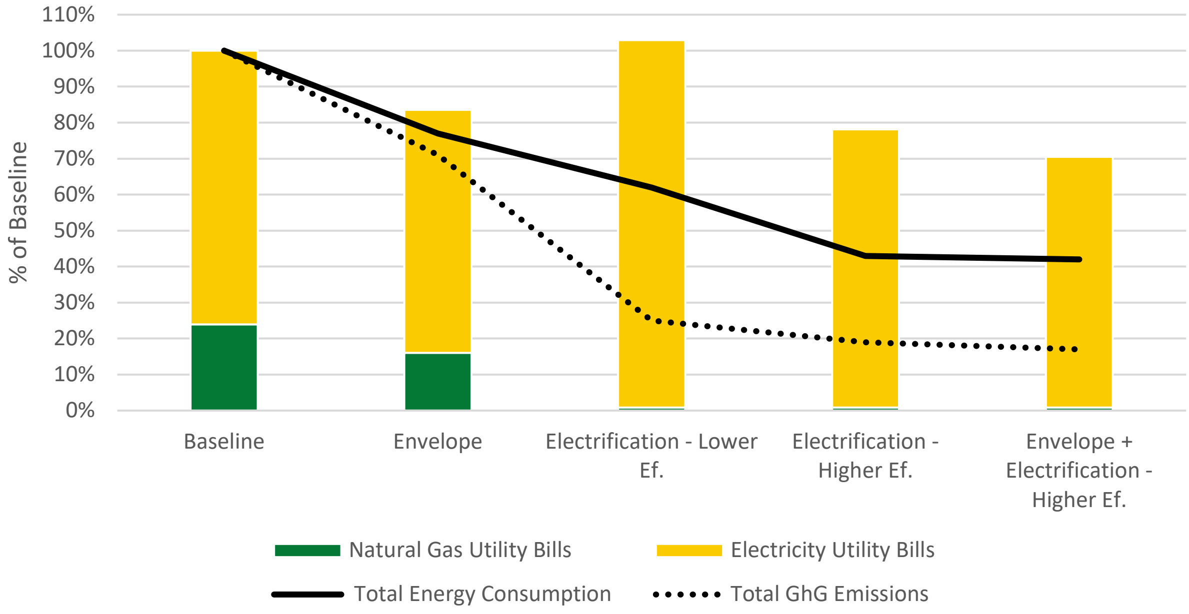


Figure 25. Modeled impact of upgrade scenarios on city-wide annual residential utility bills by fuel type

The impacts described above are a city-wide summary and would not be experienced uniformly across all households as is detailed in the table on the following page. For example, higher-income households could in general expect to see a higher decrease in annual utility bills compared to lower-income householders—both in absolute dollars and in percent decrease in bills. This is mainly because higher-income households are more likely to live in single-family homes, which tend to be older and consume more energy overall compared to lower-income households. As a result, single-family homes also see a higher decrease in overall utility payments, and a higher decrease in terms of percent change. These trends are the same for owners versus renters (since almost all owners in Richmond live in single-family homes). Examples of how these upgrades could affect individual households are provided in Appendix D.

Table 5. Modeled Change in City-wide Annual Utility Bill Costs *

		Upgrade Scenario			
		Envelope	Electrification – Lower Efficiency	Electrification – Higher Efficiency	Envelope + Electrification – Higher Efficiency
Total Average		**-16.4%**	**3.0%**	**-21.9%**	**-29.5%**
Building Type	Single Family	-18.3%	3.9%	-21.9%	-30.3%
	Small Multifamily	-12.0%	-2.3%	-25.8%	-31.7%
	Large Multifamily	-3.1%	0.3%	-15.7%	-18.4%
Building Vintage	Pre-1940	-22.7%	13.1%	-16.2%	-27.8%
	1940–1979	-19/1%	1.9%	-23.5%	-32.1%
	1980–1999	-8.2%	0.4%	-21.8%	-25.8%
	2000–Present	-3.8%	-1.3%	-19.4%	-21.9%
Tenure	Renter	-12.0%	2.5%	-19.7%	-25.9%
	Owner	-19.3%	3.3%	-23.3%	-31.9%
Household Income	Less than 200% FPL	-11.9%	1.0%	-21.9%	-26.7%
	200–400% FPL	-17.3%	7.2%	-18.8%	-27.8%
	More than 400% FPL	-17.3%	2.4%	-22.8%	-30.6%

* These estimates *are based on 2023 rates applied to modeled energy consumption. They do not reflect reductions that households may see due to presence of rooftop solar PV, or from enrollment or participation in utility bill reduction or relief programs.*

Cost-Effectiveness

The impacts of upgrade scenarios on utility bills are useful, but for a full picture they must be analyzed with respect to the overall cost-effectiveness of the measures include in the upgrades. Cost-effectiveness is measured in this report in terms of the savings-to-investment ratio, or SIR. An SIR of 1 indicates that 100% of the upfront investment cost of a measure or package of measures is made up in savings from utility bill reduction over the lifetime of that measure. An SIR of less than one indicates that only a portion of the upfront cost is made back in bill savings, and an SIR of more than 1 indicates that more savings is generated that the original measure or package of measures costs. For this analysis, we have indicated N/A if there is not any anticipated utility bill savings associated with an upgrade. A list of measure costs and lifespans used for this analysis is included in Appendix C.

In addition, for the electrification upgrades modeled in this analysis we have provided high-level estimates for both total costs and incremental costs. The incremental cost is the cost difference that a household would pay for the electric appliance or system modeled in this analysis compared to replacing with the existing appliance[5]. Incremental cost is an important measure for assessing the cost-effectiveness of ECMs, because the estimated utility bill savings described above is only possible because of the appliance upgrade modeled. Therefore, for the electrification approach

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[5] Since all envelope measures modeled in this analysis are new measures (and are not replacing existing insulation or air sealing), the total cost and incremental costs are the same.

assumed in this analysis (to upgrade appliances at the end of their lifecycle), incremental cost may be a more effective way to assess whether or not an ECM pays for itself over its lifetime.

Below is an example of how total cost and incremental cost differ:

Based on our modeling and utility rate assumptions, if a Richmond household chooses to replace an 80% efficiency gas-powered furnace at the end of its life cycle with a similar model, they would incur the *total cost* up front for that replacement, but would likely see no savings in their utility bills once the replacement was made, since they are replacing it with a similar model. If, instead, they replaced the gas furnace with a higher-efficiency heat pump (as we have modeled in this analysis), they will incur a higher total cost up front, since heat pump technology is more expensive. However, they would expect to see a monthly savings on their utility bills, since heat pumps are significantly more efficient to operate. The difference between the total cost to replace a gas furnace with a heat pump versus another gas furnace is the *incremental cost*.

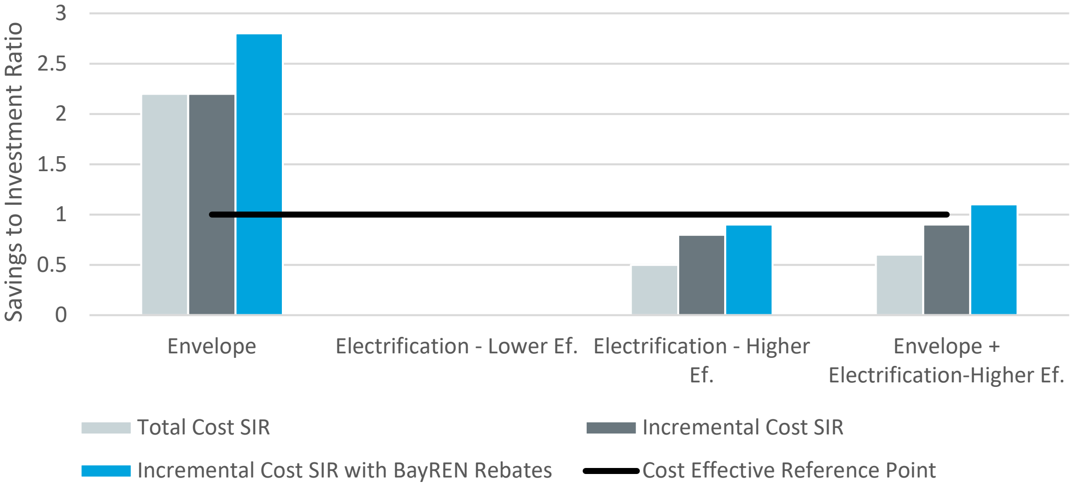
Table 6 below summarizes city-wide costs, savings, and SIR associated with each of the four upgrade scenarios. Based on total costs and savings, only envelope upgrades are cost- effective over the lifetime of the measures, at a city-wide scale. When looking at incremental costs, the higher-efficiency electrification upgrades come close to an SIR of 1. However, this varies greatly based on building type and vintage. As illustrated in the table below, single-family homes—especially homes built before 1980—are more likely to see higher SIRs above 1 for electrification upgrades, compared to newer units and multifamily units. Examples of how these impacts might be experienced on a household scale are provided in Appendix D.

Table 6. Estimated Savings, Total Measure Costs, and Incremental Costs for Modeled Upgrade Scenarios

Upgrade Scenario		Total Measure Lifetime Savings* (Million $)	Total Measure Costs		Incremental Measure Costs	
			Upfront Cost (Million $)	SIR	Upfront Cost (Million $)	SIR
Envelope		$696	$315	2.2	$315	2.2
Electrification	Lower Ef.	$(63)	$553	N/A	$95	N/A
	Higher Ef.	$464	$1,027	0.5	$569	0.8
Envelope + Electrification	Higher Ef.	$789	$1,342	0.6	$884	0.9

* Savings is based on utility rates for 2023. It does not take into account potential future rate changes and the impact on savings.

An important addition to this conversation is the impact of current rebates for envelope, energy efficiency and electrification work, most of which currently come through BayREN. If all households that pursue envelope and electrification upgrades as described in this analysis were to take advantage of these rebates, it could reduce the upfront cost of these upgrades by more than $130 million (split fairly evenly between envelope and electrification measures). Given these reductions, the higher-efficiency electrification plus envelope upgrades become cost-effective based on incremental costs, and higher-efficiency electrification alone are close (0.93).



* Savings is based on estimated utility rates for 2023. It does not take into account potential future rate changes and the impact on savings.

Figure 26. Savings-to-investment ratio for modeled residential upgrades

In addition, the City of Richmond should expect to see some benefits accrue to its residents from the recently passed federal Inflation Reduction Act. Although implementation and program design has not yet be released, the state of California was allocated more than $582 million to support energy and electrification upgrades in the homes of low- and moderate-income residents (DOE, 2022). If Richmond residents received a portion of this equal to their share of the state's overall population, this could amount to approximately $1.7 million, helping to further reduce the upfront cost of certain ECMs and improve the SIR for qualifying households.

A summary of all rebates and incentives for which Richmond residents may be eligible is provided in Appendix C.

Another item that could impact the cost-effectiveness of these building energy improvements is the availability of rooftop solar PV. Although this analysis does not address potential future increases in solar PV deployment for residential buildings in Richmond, our ResStock analysis estimates that more than 3,300 residential housing units currently have on-site solar PV, generating almost 25 million kWh of electricity annually. Using this and the 2023 MCE rate analysis, this could reduce city-wide residential electricity bills by more than $8 million dollars annually. And using a conservative 10-year estimated payback period for solar PV (Roth, 2022), it is possible that adding this to the energy upgrades could make all the scenarios cost-effective at a city-wide scale, based on incremental cost analysis. It is important to note that any future increases in solar PV deployment could further improve the city-wide SIR.

Although this combination seems promising, it would need to be investigated further with MCE and PG&E. This is because there is a mismatch between when PV generates its electricity and when Richmond residents consume the most electricity, which could lead to potential utility grid capacity concerns.

Employment Indicators

Baseline Data

Employment information can be addressed both in terms of quantity (number of jobs) and quality. This section begins with a discussion of job quantity. There is no data available on how many Richmond residents work in the energy efficiency sector. However, according to the organization E4TheFuture, there were at least 8,028 energy efficiency workers (residential and commercial work) in Contra Costa County in 2021, with one of the highest ratios of energy efficiency workers to total workers in the state (E4TheFuture, 2022). E4TheFuture uses data from the U.S. Energy and Employment Report, which defines energy efficiency workers as those that are involved in the production of certified energy-savings products (manufacturing), the provision of services that reduce building energy consumption (installers and technicians), and the professional services that support this work (architecture, engineering, financing, etc.) (E2, 2023). For Contra Costa County and Richmond, the majority of its energy efficiency workforce is in construction and professional services, with a majority of those working in HVAC.

If Richmond captured the same percentage of energy efficiency workers as it does for all workers in the County according to the U.S. Census, then Richmond might have 826 energy efficiency workers (residential and commercial) as of 2021.

Figure 27. California energy efficiency jobs by county Source: E4TheFuture, 2022

However, there are far more workers doing related work, who could shift their focus and/or be re-skilled to perform the types of building envelope and electrification work described in this report. According to BLS data for 2022 (the most recent year available), there are more than 1,300 businesses and 11,000 workers engaged in electrical, plumbing, HVAC, insulation, and remodeling, services work in Contra Costa County. More than half (7,307) do residential work. Average annual wages for these workers is $77,555. This is about 5% lower than the average wage for all occupations in Contra Costa County ($82,050), however it is 11% higher than the state average for the same occupations.

Table 7. Contra Costa County Employment in Select Residential Construction Industries, 2022

Industry Category (NAICS Code)	# Businesses	Total Employment	Annual Wages per Employee
Electrical Contactors	215	1,451	$83,247
Plumbing and HVAC Contractors	256	2,335	$75,318
Drywall and Insulation Contractors*	53	806	$102,671
Residential Remodelers	598	2,715	$68,980
Total/Average	1,122	7,307	$77,555
ALL INDUSTRIES	36,158	322,128	$82,050

**Residential and commercial contractors are combined for this BLS industry category. Numbers overlap with Residential Table 14.*

Source: *U.S. Bureau of Labor Statistics, 2022*

Upgrade Analysis

Based on the EUSS upgrades and measure cost data described in previous sections, and high-level jobs multipliers published by NREL in 2022, it is estimated that pursuing residential envelope and electrification upgrades in Richmond could support up to 7,500 jobs, with two-thirds of those likely to be local jobs (see Table 8 below). For this analysis, “jobs” is defined as both direct and indirect jobs, with each job assumed to be full time. Direct jobs are those involved in the actual installation of the measure (including project management and professional services like architects or engineers), while indirect jobs are those involved in the supply chain that gets a product from manufacturing, through distribution and into a home. It does not include induced jobs, which are those associated with additional spending in a region as a result of job growth. Direct jobs are most likely to be held by local workers, since they reflect work being done in and on Richmond homes. Indirect jobs could be held regionally, nationally, or even internationally depending on where items are manufactured.

Because the analysis in this report did not specify a timeline for when these upgrades would be completed, the job numbers shown here are absolute. This means that if all residential envelope work modeled in this report was done in one year, it could support 1,358 direct jobs for one year. If instead the work takes 10 years to complete, then this would be 1,358 jobs total which could look like 136 jobs per year. While most envelope measures only need to be completed once, most electrification measures would need to be replaced approximately every 15 years, meaning additional jobs will be supported whenever an electrified appliance needs to be replaced in the future.

Finally, it is important to point out that while all envelope measures are assumed to be new or additional jobs (since this is work that would not otherwise be done), most of the electrification jobs identified above would not be new jobs. Because this analysis assumes that households would pursue electrification at the end of an appliance’s lifecycle (i.e., when an appliance needs to be replaced), then most of the labor associated with the replacement would happen whether it was being replaced with a natural gas appliance or upgraded to an electric appliance option. The exception is jobs associated with actual fuel switching (plumbers to cap abandoned gas pipes and electricians to add new electrical wiring and outlets), as well as estimated service panel upgrades. Based on our cost data inputs, we estimate that 25% of total electrification jobs supporting this work would be “new” jobs.

Table 8. Estimated Jobs Supported by Upgrades to Richmond's Existing Residential Building Stock

Upgrade Scenario	Direct Jobs Only		Direct + Indirect Jobs	
	Total Jobs	Net/new Jobs	Total Jobs	Net/new Jobs
Envelope	1,358	1,358	2,148	2,148
Electrification (Lower/Higher Average)	3,413	853	5,396	1,349
Envelope + Electrification	4,771	2,212	7,544	3,497

The types of occupations and their characteristics would vary based on envelope versus electrification measures. For example, most of the residential electrification work would be done by plumbers, HVAC technicians, and some electricians, with support from engineers and permit technicians. Most envelope work would be completed by workers defined by BLS as "residential remodelers." A detailed breakdown of the types of occupations associated with the ResStock upgrades can be referenced in the Occupational Analysis developed by ICF for the Communities LEAP Program (Brown et al., 2023).

Finally, it is important to acknowledge that the jobs estimates provided above do not include any "readiness" work that may need to be done prior to envelope or electrification upgrades, other than service panel upgrades. For example, it does not address issues such as structural weaknesses in the home, roof leaks, mold, or pest infestations. It also does not include jobs associated with the installation of solar PV, which was discussed in the previous section.

Health and Safety Indicators

For this report, we worked with the Richmond Community Coalition to identify indoor air quality as the most appropriate measure of health and safety for this study as it related to building envelope and electrification upgrades. Because this can vary so much house to house, this section provides a more qualitative discussion of the potential impacts of envelope and electrification upgrades on indoor air quality (IAQ), as reported in research and literature.

Health Impacts of Common Indoor Contaminants

While the EPA governs ambient outdoor levels of air toxins such as nitrogen oxides (NO_{xs}) including nitrogen dioxide (NO_2), sulfur oxides (SO_{xs}), carbon dioxide (CO_2), and particulate matter (PM) with particles or droplets in the air that are two-and-a-half microns or less in width ($PM_{2.5}$), no federal, state, or local agencies in the US directly regulate indoor air quality. This is important since worldwide, people spend approximately 90% of their time in indoor environments (Mannan and Al-Ghamdi, 2021). Pollutants indoors can be naturally occurring such as radon, they can enter a building from the outdoors, or be produced by indoor manmade elements such as furnishings, carpet, building materials, or gas appliances (EPA, 2023). The most common of these related to this analysis are discussed below.

Unvented gas combustion appliances such as stoves, water heaters, and furnaces can emit NO_x, CO, and PM. These indoor air pollutants are a result of incomplete combustion due to insufficient oxygen, which is unavoidable even under ideal conditions (Zhu et al., 2020). The EPA reports that NO_2 levels in homes with gas stoves can exceed outdoor levels (EPA, 2023). Nitrogen oxides, have been well-documented in causing acute and chronic respiratory irritation, exacerbation of asthma symptoms (including increased hospital visits), and increased mortality from stroke, lung cancer, and cardiovascular disease (Zhu et al., 2020). Multifamily buildings can have higher concentrations of NO_2 due to smaller residence size. Children in homes with gas appliances may have increased risk of asthma, wheezing, and other respiratory symptoms associated with exposure to nitrogen dioxide (NO_2). Women may also be at greater risk due to increased time inside homes and exposure with higher frequency of cooking, as well as low-income households who are more likely to live in multifamily buildings (Zhu et al., 2020).

While carbon monoxide (CO) emissions from gas appliances functioning correctly can be minimal with little no health impact, dangerously high exposures can occur if the equipment is not properly maintained resulting in mechanical or ventilation failures. At low concentrations, CO_2 can result in fatigue even in healthy people and chest pain in those with heart disease. Moderate concentrations can impair vision and brain function, while high concentrations can lead to headaches, dizziness, confusion, nausea, and can be fatal at very high concentrations (EPA, 2023, Zhu et al., 2020). The California Air Resources Board (CARB) reports that each year since 2000, 13 to 36 deaths can be attributed to non-fire-related CO poisoning in the state (California Air Resources Board, 2023).

$PM_{2.5}$ has a well-established association with all-cause mortality, including increased risk of cardiovascular and respiratory mortality. Long-term exposure to $PM_{2.5}$ also increases risks of bronchitis, asthma onset, and exacerbation of asthma symptoms. Children and pregnant women face the greatest risk from exposure to $PM_{2.5}$ (Zhu et al., 2020).

Formaldehyde is commonly found in composite wood products such as plywood, building materials and insulation, as well as household products such as glues, paints, and lacquers. Human exposure is primarily through breathing air that contains off-gassed formaldehyde from the mentioned products. Established health effects include irritation of the skin, eyes, nose, and throat while high levels may cause some types of cancer (EPA, 2023)

Finally, homes without proper ventilation or building envelope construction may have increased risk of developing mold (Asthma and Allergy Foundation of America, 2020). When a building is sealed, the difference in temperature between indoors and outdoors, particularly in wetter and more humid climates, can result in moisture condensing on indoor surfaces or wall cavities. Left unchecked, this can then result in mold issues. According to the EPA, molds produce allergens and irritants that can cause allergic reactions, including asthma attacks, for some individuals (EPA, 2022). Nationwide, low-income households, as well as Black, Hispanic, and Indigenous households, have a disproportionately high occurrence of asthma (Asthma and Allergy Foundation of America, 2020). Although this is not directly attributable to mold or its causes, pursuing building upgrades that reduce the potential for mold may have higher impacts on these higher risk populations.

According to certain indicators, Richmond residents may experience higher rates of certain asthma and cardiovascular-related health issues, compared to neighboring communities. Figure 28 below shows maps generated by CalEnviroScreen highlighting that census tracts located in Richmond are in the top 10% in the state for highest rates of emergency room visits for asthma-related issues, and in the top 20% for emergency room visits for cardiovascular issues (heart attacks). Both rates are measured per 10,000 people.

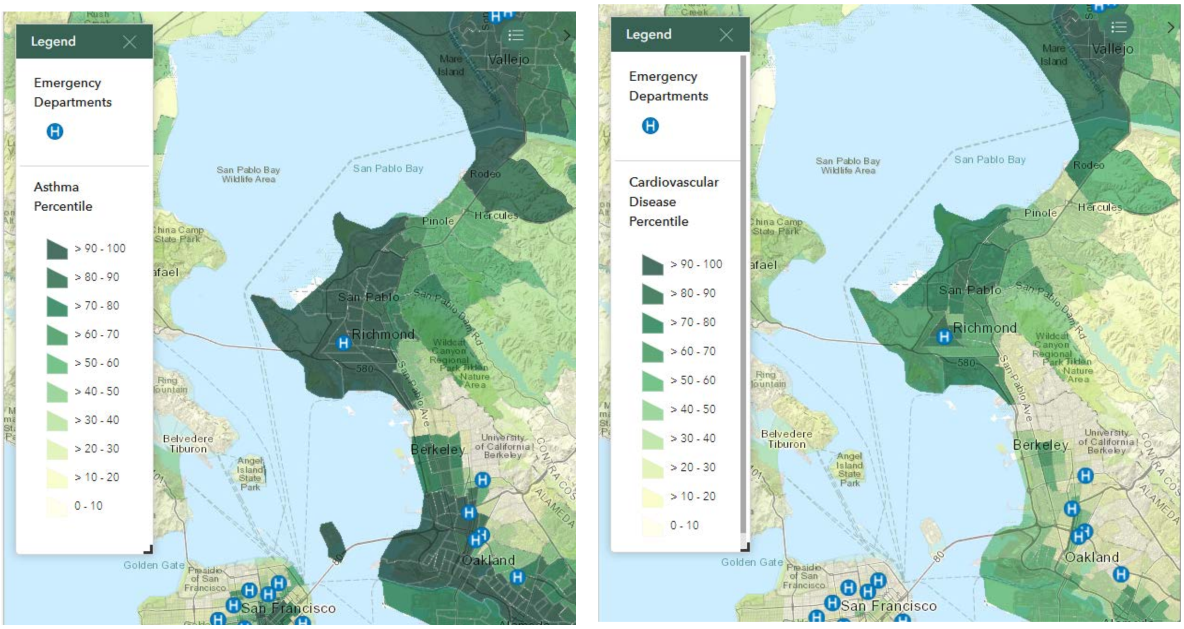


Figure 28. Rates of emergency room visits for asthma (left) and cardiovascular disease (right) by census tract. Source: California Office of Environmental Health Hazard Assessment, 2023

Based on data available, it is not possible to attribute specific health outcomes illustrated in the figures above to indoor versus outdoor pollutants, or other factors. However, the literature review below shows that pursuing envelope and electrification measures installed and inspected by qualified workers could be expected to have overall positive benefits to indoor air quality and the health of Richmond residents and workers, including health indicators such as asthma or cardiovascular disease.

Building Envelope Upgrades & Health

The purpose of the building envelope measures described earlier in this analysis is to reduce air leakage between indoors and outdoors in order to reduce the energy needed to maintain a comfortable indoor temperature (e.g., through increased insulation and air sealing). However, if envelope measures are not paired with proper ventilation measures, they might increase indoor pollutants which would otherwise be diluted by leakage between indoor and outdoor air (EPA, 2022).

The addition of ventilation measures helps address these potential issues. For example, one study found that more recent American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) ventilation standards (2010 compared to 1989) resulted in reduced concentrations of VOCs, CO_2, and first-floor radon, as well as ventilation airflows twice that of the older standard (Francisco et al., 2016). Another study examining multifamily units found that building envelope interventions resulted in increased $PM_{2.5}$, but this was mitigated by the installation of kitchen exhaust (to ventilate emissions from natural gas stoves) and HVAC filtration upgrades. (Underhill et al., 2020). And an evaluation of the Weatherization Assistance Program (WAP, which requires adequate ventilation when performing any building envelope upgrades) found that participants in WAP had reduced need for emergency room visits due to asthma by reducing the presence asthma triggers including insect allergens, molds, dust mites, and outdoor allergens, among others (Tonn et al., 2014). Finally, a 2014 study found that “children had lower odds of suffering from asthma and bronchitis in households where adults used ventilation when operating gas stoves” (Zhu et al., 2020).

The improvements in IAQ from mechanical ventilation are also impacted by location within the home. In the National Center for Healthy Housing's 2022 study of IAQ in affordable multifamily housing that compared homes rehabilitated to compliance with ASHRAE Standard 62.2 versus homes rehabilitated but not meeting this standard, bathroom exhaust ventilation was found to reduce $PM_{2.5}$, likely because it can help ventilate the entire house. Homes with kitchen exhaust ventilation had reduced levels of CO and formaldehyde, whose sources include gas stoves, certain cooking methods, and chemical reactions with cooking oil byproducts. Homes in compliance with ASHRAE 62.2, which includes continuous ventilation, had reductions in four of five studied air contaminants: $PM_{2.5}$, CO_2, CO, and formaldehyde (National Center for Healthy Housing, 2022).

The EPA has published recommended actions to ensure that building envelop improvements result in both cost benefits and improved IAQ (EPA, 2022). They provided best practices that include ventilation system requirements for properly managed house pressures and the removal of major indoor air pollutant sources as described in the following section.

Electrification Upgrades & Health

Electrification of the appliances used in buildings has also been shown in research to improve indoor air quality by removing combustion appliances that can be major emitters of certain pollutants described above. The article "Carbon Monoxide Measurements in Homes" compared the results of two studies: an examination of the WAP program and a study funded by the U.S. Department of Housing and Urban Development, both of which measured of indoor air CO levels in homes with gas furnaces, water heaters, range top burners, and ovens. These studies found that while furnaces and water heaters were not typically the cause of elevated CO in homes, those with venting problems did result in occasional elevated CO levels. Gas ovens and ranges were most often associated with elevated CO, with ovens in particular the most likely cause as they were more likely to exceed American National Standards Institute appliance standards for CO and also tend to operate for longer periods of time compared to ranges. Attached garages were also found to be a source of elevated CO even when there was no door connecting the garage to the house (Francisco et al., 2018).

While the effects of natural gas appliances can be reduced by pollution mitigation measures such as exhaust hoods and ventilation (Zhu et al., 2020), this strategy cannot always be relied upon; since some homes with gas stoves have hoods that only recirculate air instead of venting outdoors, and some who have adequate range hoods and other ventilation measures may choose not use them. The report "Gas Stoves: Health and Air Quality Impacts and Solutions," a collaborative effort by the Rocky Mountain Institute, Mothers Outfront, Physicians for Social Responsibility, and the Sierra Club, reviewed studies of IAQ and concluded that replacing gas stoves with electric stoves produces the greatest decrease in indoor NO_x concentrations, not only in the kitchen but throughout the home (Seals and Krasner, 2020). Replacement of other natural gas appliances such as heaters and water heaters, particularly those with pilots that lack appropriate ventilation, would also improve IAQ by eliminating other sources of NO_x, CO, and $PM_{2.5}$.

It is also important to point out that the IAQ effects from replacing natural gas appliances is more pronounced in apartments as they are typically smaller than single family homes, resulting in higher concentrations of air pollutants. Therefore, renters, who are more likely to be low-income, are disproportionately impacted by IAQ issues. Other equity concerns include the supplemental use of cooking appliances for heating (more common in low-income households); housing characteristics such as tenure, quality, size, and appliance maintenance; time-activity patterns (children in low-income households spend more time in the home; and the cumulative impacts of environmental justice communities disproportionately affected by adverse environmental conditions (Zhu et al., 2020).

While improperly installed building envelope measures may raise concerns regarding indoor air quality, these issues can be mitigated with appropriate measures such as improvements to ventilation and the electrification of appliances, particularly gas stoves. The potential benefits to households include both reduction in energy burden and increased air quality, particularly those in multifamily units, vulnerable populations such as children and those with asthma, and lower-income households.

Energy Consumption, Health, and Behavior

The materials and technologies investigated in this analysis have demonstrated potential for reductions in energy consumption and improvements in health. However, the "real world" effectiveness of the measures can always be influenced by human behavior. For example, according to ENERGY STAR®, smart thermostats "automatically adjust heating and cooling temperature settings in your home for optimal performance" (ENERGY STAR, n.d.). This can potentially save energy and money on utility bills, but those savings can be diminished if occupants override with less efficient settings and/or open windows in ways that lead to increased energy consumption. One study found that users of the EnergyHub smart thermostat were found to reduce energy use by 6% when savings were assessed over 4 summer months, but occupants "fiddling with the settings" reduced these savings slightly. A study in Oregon of the Nest smart thermostat found that up to 20% of participants reduced their potential savings by turning off the AutoAway function (Sussman and Chikumbo, 2016). Those researchers also noted potential impact of the rebound effect—that when energy is cheaper, people tend to use more of it.

This also relates to the health discussions in this section. Ventilation equipment, such as bathroom and kitchen fans that are installed alongside building envelope measures, must be used appropriately. If they are not, those ventilation measures may not mitigate their targeted indoor air pollutants that can negatively impact indoor air quality.

Behavioral sciences have identified some of the underlying reasons for the tendency of people to not make wise energy-use decisions. For example, a report from 2008 stated that the invisible nature of electricity can contribute to an unawareness of the link between energy use and environmental impacts, even for those highly concerned with these impacts (Tang and Bhamra, 2008). The authors also cited consumer surveys where 42% of respondents cited laziness rather than lack of awareness for their bad energy habits. According to that same report, even among those who wish to take action as consumers, many do not feel that individual behaviors make a difference due the global nature of climate change. And finally, there is also the effect of long-standing habitual behavior that is difficult for people to recognize or change. This may be particularly true with ventilation, if residents are not used to having or using range hood or bathroom fans regularly (Tang and Bhamra, 2008).

There is also significant research into factors that can influence changes in behavior, such as education, social norms, and comparing behavior with peers (Sussman and Chikumbo, 2016). Understanding the effective strategies to address behavior can help ensure that the energy and bill savings, and health benefits described in this analysis, are realized.

Commercial Building Energy Analysis

This section provides an analysis of the building stock and energy consumption patterns for commercial buildings located in the City of Richmond. As described in the methodology section, the commercial buildings included in this analysis represent about half of all non-residential buildings in Richmond, with a breakdown by category shown in Table 9 below.

Table 9. Share of Richmond Non-Residential Building Stock Analyzed by ComStock

Building Use Category	% of Buildings Included in Analysis	% of Floor Area Included in Analysis
Commercial/Institutional	65%	85%
Industrial	16%	39%
Total	48%	55%

As with the residential section, this section begins by sharing current (baseline) modeled data related to the city's commercial building stock, energy consumption and related GHG emissions. It then describes how this baseline data might change if two potential "packages" of building envelope and electrification upgrades were implemented in the modeled building types city-wide. The analysis that follows describes the potential impact of these upgrade scenarios on four of the five areas of analysis for this report: building energy consumption, GHG emissions, employment indicators, and health.

Building Stock Baseline Data

Figure 29 below shows the breakdown by use category of all commercial buildings in Richmond that are modeled in this analysis. Mercantile buildings make up the biggest share, with 57% of buildings and 27% of floor area. Office buildings make up 19% of buildings and 30% of floor area, and warehouse and storage buildings make up 10% of buildings and 32% of floor area.

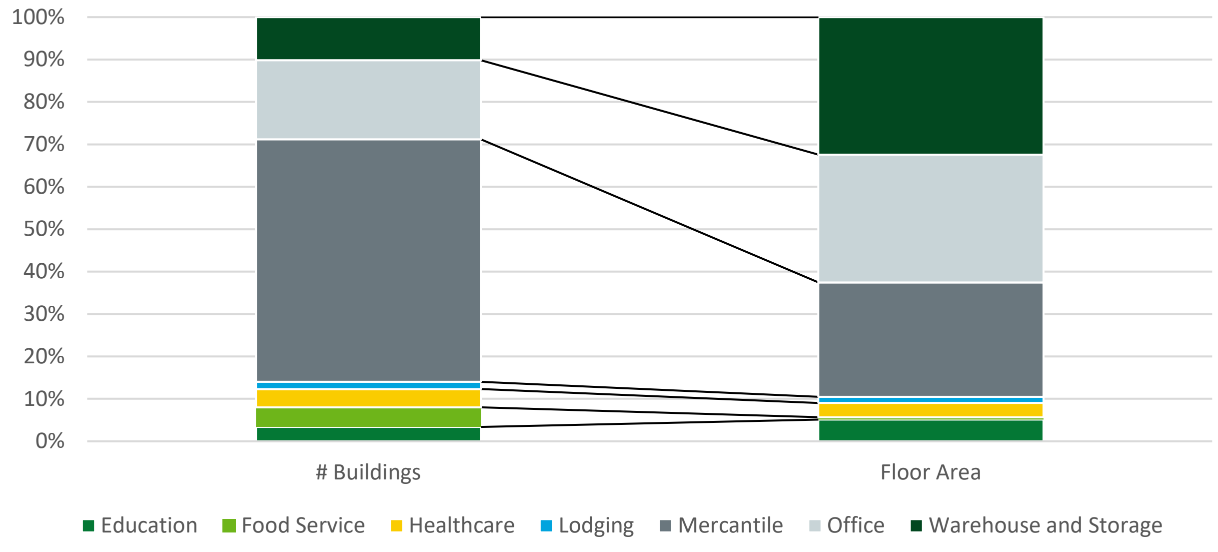


Figure 29. Modeled commercial building uses in Richmond

Of the commercial buildings with known construction dates[6], three-quarters were built before 1980, however this represents only half of the commercial square footage in the city. As discussed in the residential section, buildings constructed before 1978 tend to be less energy-efficient and are more likely to contain lead and asbestos. In terms of square footage, food service, healthcare, lodging, and mercantile buildings are more likely to be older, while education and warehouse and storage buildings are more likely to be newer. Office buildings are more evenly split across the time periods.

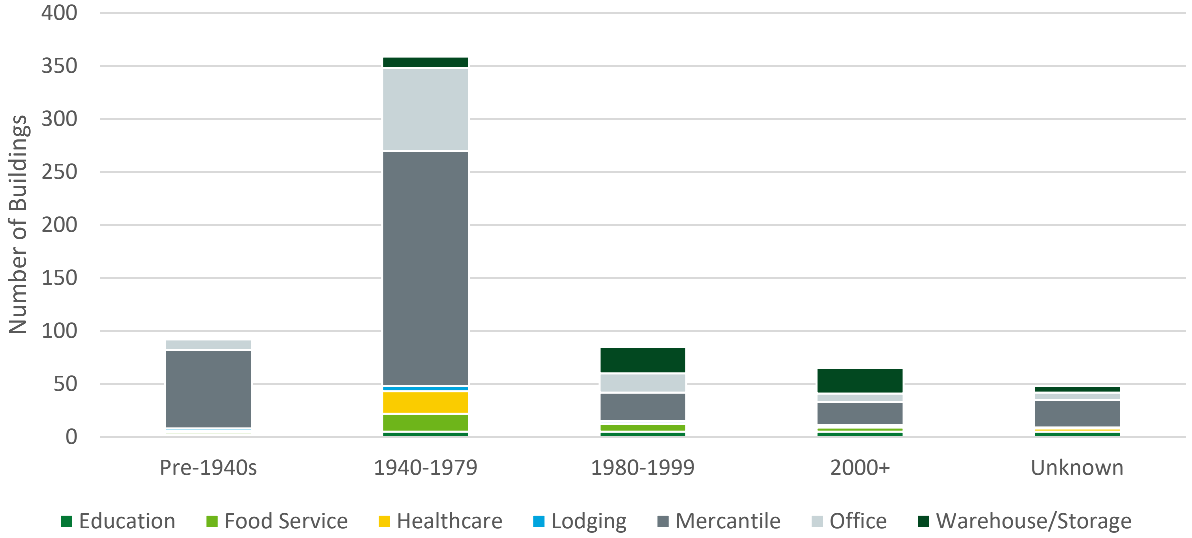


Figure 30. Modeled city-wide commercial buildings by use and vintage

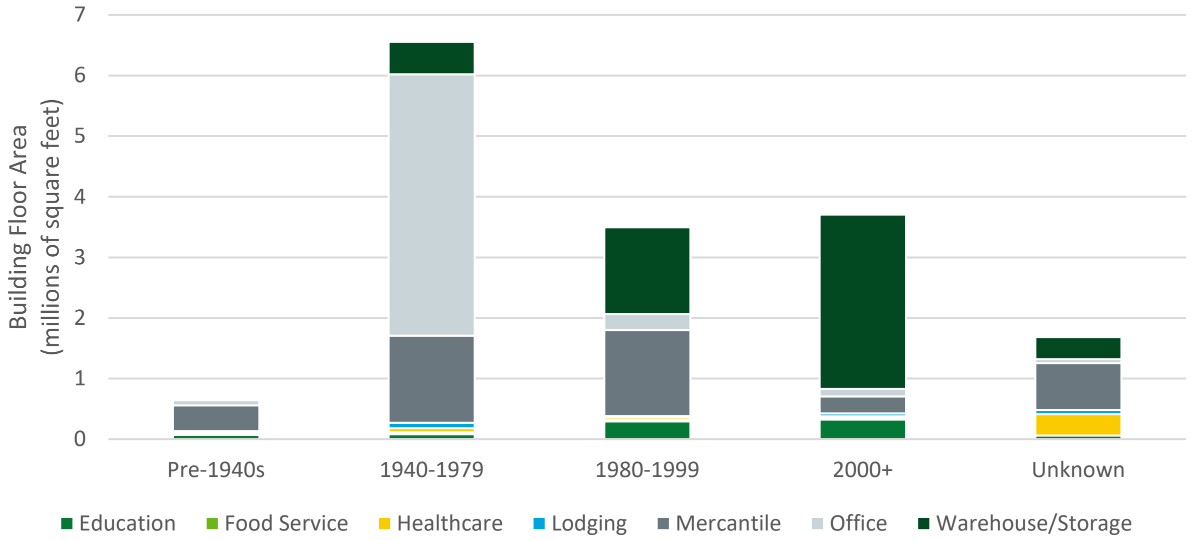


Figure 31. Modeled city-wide commercial building floor area by use and vintage

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[6] Eleven percent of the commercial buildings listed in the county assessor's data have no known construction date. Since the authors used assessor data as the baseline to which we aligned the ComStock analysis, the analysis by vintage may not accurately represent the city's full building stock.

Energy Consumption & Associated Greenhouse Gas Emissions

Baseline Data

The commercial buildings analyzed in this report are estimated to consume more than 295 million kWh of energy each year, with 77% of that being electricity and 23% natural gas (Figure 32). However, natural gas is responsible for 64% of the GHG emissions associated with that energy consumption. The total emissions are estimated at 21,250 metric tons of CO_2, which is equivalent to 4,729 gasoline-powered passenger vehicles driven for 1 year (EPA, 2022).

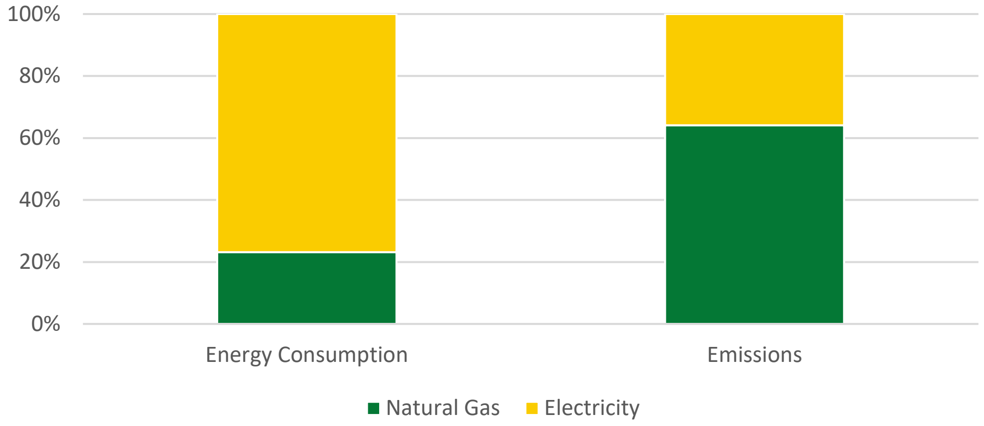

Figure 32. Modeled city-wide annual commercial energy consumption and emissions by fuel type

This fuel type split is very different from what we saw in the residential building analysis, mainly because of how energy is used in the different buildings. As shown in Figure 33, for the commercial buildings analyzed, space heating represented only 12% of total energy consumption, compared to 34% for residential buildings, and water heating was 3% compared to 22% for residential. The largest energy end use by far for commercial buildings is equipment and refrigeration, representing 36% of all energy use. But only one-third of that energy is natural gas. The other largest energy users for commercial buildings are pumps and fans (24%), space cooling (13%) and lighting (11%), which are entirely electricity-based.

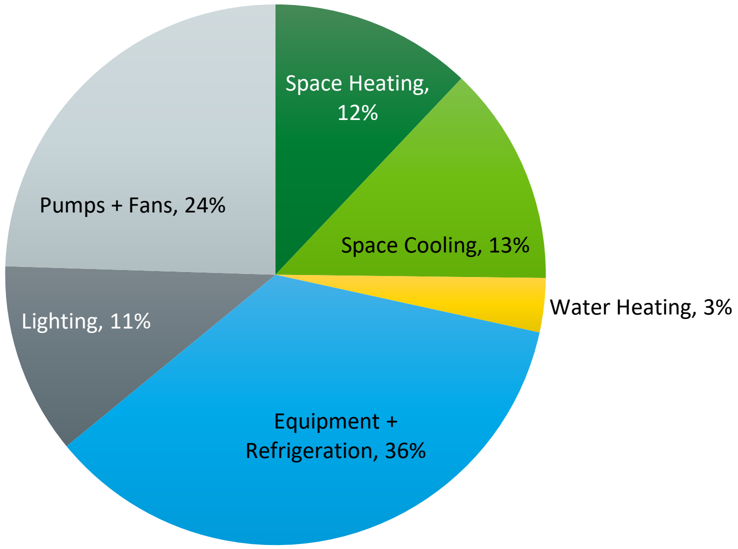

Figure 33. Modeled city-wide annual commercial energy consumption by end use

There are variation energy consumption patterns based on the type of building, mostly related to the end-uses described above. Mercantile uses, which represent 59% of buildings and 29% of floor area, are responsible for an estimated 46% of energy consumption and 52% of commercial GHG emissions. On the other end, warehouse and storage buildings have the largest portion of city-wide of floor area (32%), but are responsible for an estimated 20% of energy consumption and 17% of emissions.

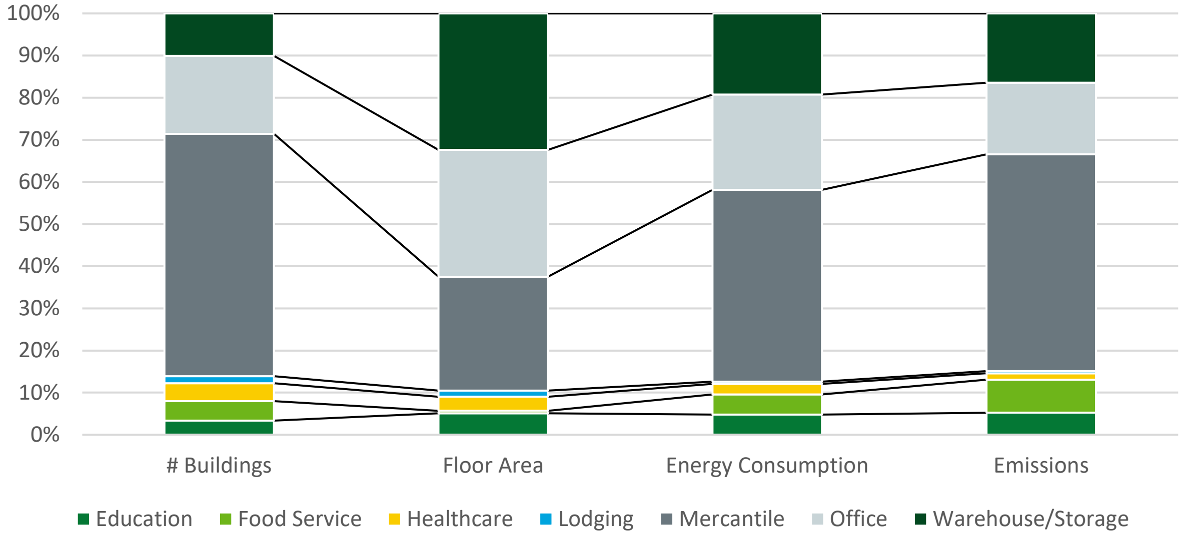

Figure 34. Modeled city-wide annual commercial energy consumption and emissions share by building use

However, on a per-square-foot basis, things again look different. As can be seen in Table 10, the highest energy consumers per square foot by far are food service establishments, which only represent 1% of the city's commercial floor area. They consume an estimated five times more energy per square foot than the second largest consumer, mercantile buildings, and 11 times more than the average for all other building types. Even more striking is the per-square-foot emissions, which is seven times higher than mercantile buildings, and 19 times more than the average for all other building types. The lowest-energy consumers and emitters per square foot are lodging and healthcare uses.

Table 10. Estimated Commercial Energy Consumption and Emissions by Floor Area and Building Type

Building Type	Energy Consumption Per 1,000 Square Feet Building Floor Area (MWh)	GHG Emissions Per 1,000 Square Feet Building Floor Area (MT CO2)
Education	17.3	1.35
Food Service	153.8	18.20
Healthcare	13.7	0.61
Lodging	6.8	0.45
Mercantile	30.9	2.53
Office	13.8	0.75
Warehouse/Storage	10.9	0.67
Average	35.3	3.51

The emissions values depend strongly on the intensity and fuel types of energy end uses. Food service buildings require space heating and cooling as do all buildings, but equipment and refrigeration are more intensive, as they are a core aspect of the services these businesses deliver. This impacts fuel mix as well, with food service buildings more reliant on natural gas compared to other building types, which along with high energy use intensity, is the reason for higher emissions per square foot.

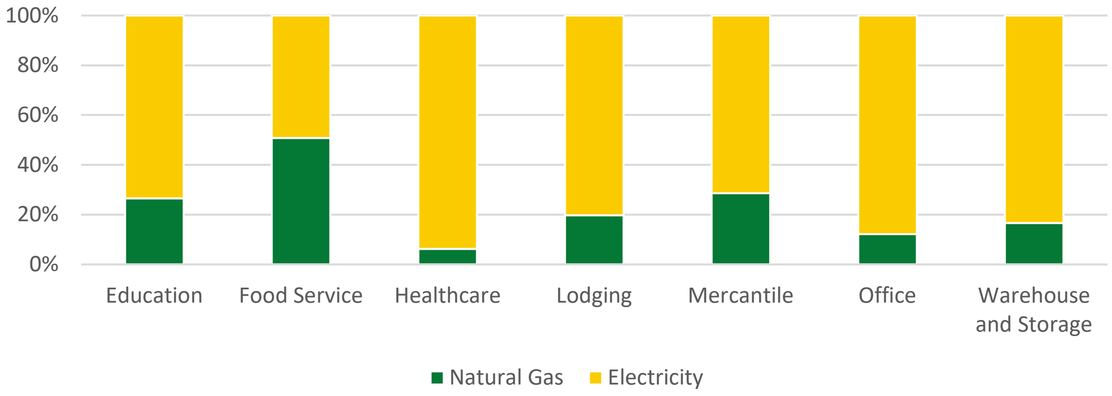

Figure 35. Modeled city-wide fuel mix by commercial building use

Finally, there are some important trends in modeled city-wide energy use and emissions related to building size. For example, the largest commercial buildings in the city— those larger than 100,000 square feet—make up 64% of floor area and are responsible for 62% of city-wide energy consumption and 64% of emissions, even though they only represent 5% of total buildings. There is no consistent trend to fuel mix by building size.

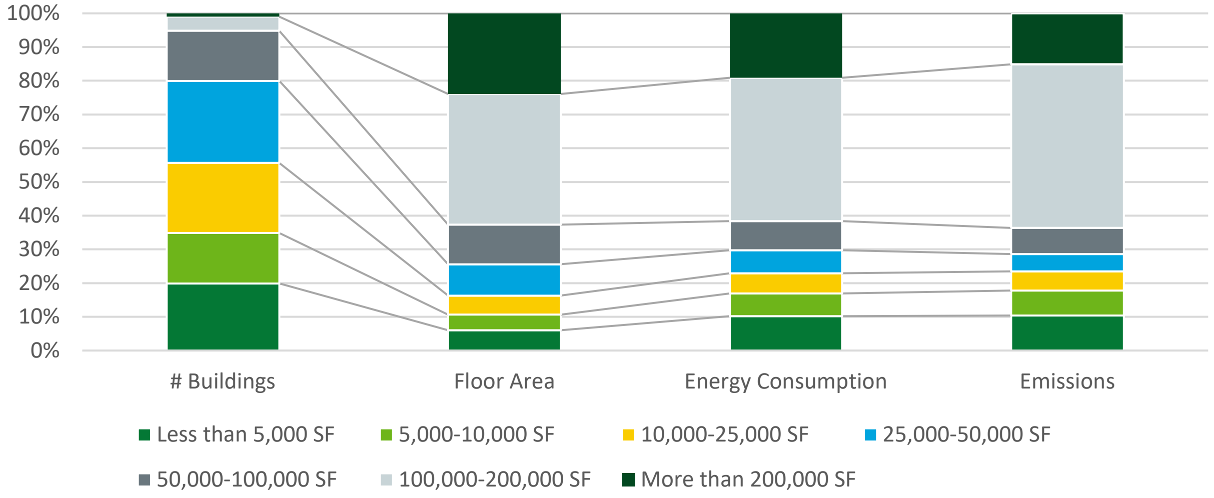

Figure 36. Modeled city-wide annual commercial energy consumption and emissions share by building size

Upgrade Analysis

We looked at how energy consumption and GHG emissions might be impacted by improvements to commercial building envelopes and the replacement of gas-powered appliances with electric ones. The two scenarios are summarized in Table 11 below, with more detail on specific insulation levels, air leakage, and appliance efficiency specifications provided in Appendix B.

Table 11. Commercial EUSS Upgrade Scenario Descriptions

Upgrade Scenario	Energy Conservation and Electrification Measures
Building envelope and enclosure (“Envelope”)	• Wall insulation • Roof insulation
Higher-efficiency electrification of appliances and heating/cooling systems **(“Electrification”)**	• For buildings with boilers: replacement with air source heat pump boilers • For buildings with gas or electric-resistance rooftop units: RTUs: higher-efficiency heat pump rooftop units.

As illustrated in Figure 37 below, it is estimated that pursuing envelope upgrades alone could reduce city-wide commercial building energy consumption in Richmond by about 3%, and associated GHG emissions by 5% compared to baseline. Pursuing higher-efficiency electrification (with no envelope changes) could reduce total commercial energy consumption by an estimated 20% and associated GHG emissions by 28%.

The energy consumption reductions modeled for commercial buildings in Richmond are less in terms of percentage change from baseline than they were for residential buildings, and there are several reasons. First is the difference in upgrades available through ResStock and ComStock: For envelope upgrades, ComStock offered only wall and roof insulation, while ResStock also offered foundation insulation and duct and air sealing. For electrification upgrades, ResStock offered electrification of space heating, water heating, cooking ranges, and clothes dryers, while ComStock only looked at space heating.

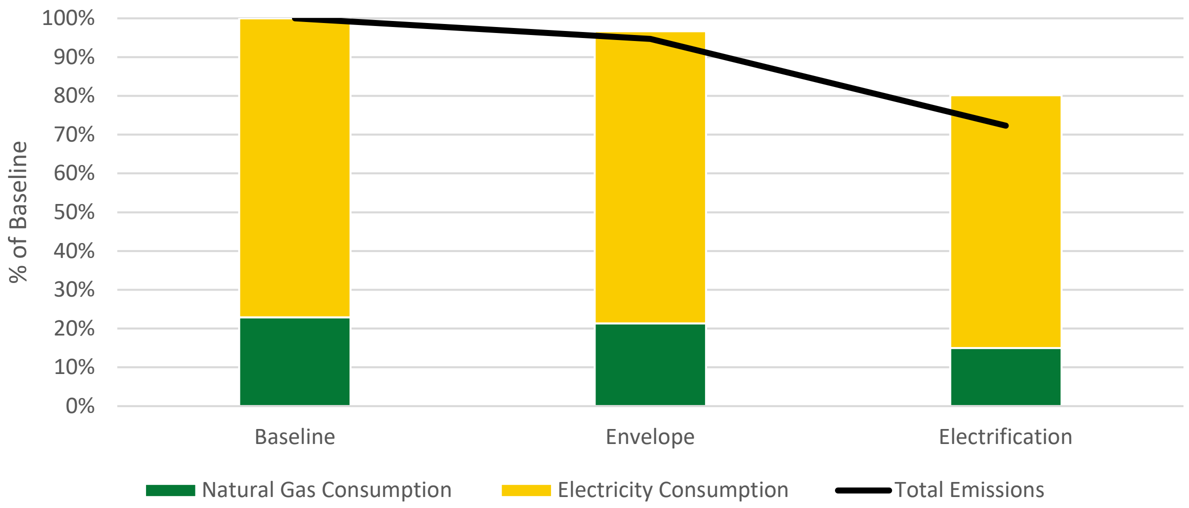

Figure 37. Modeled upgrade scenario impacts on city-wide commercial energy consumption by fuel type

However, a more important factor in the differences in modeled energy savings between residential and commercial buildings has to do with the current (baseline) use of energy in the different building types. For example, the envelope upgrades modeled for commercial buildings showed only 3% energy savings compared to 23% for residential buildings. Building envelope improvements most significantly impact energy for space heating and cooling, which represented more than 40% of residential baseline energy consumption but only about 25% of commercial energy consumption. Furthermore, compared to HVAC end uses in residential buildings, larger commercial building HVAC end uses tend to be more affected by internal heat gains and space ventilation requirements, and less affected by external envelope conductive heat gains/losses. And since the largest baseline commercial uses of energy already use electricity (equipment, refrigeration, pumps, fans, cooling), electrification with higher-efficiency products does not reduce overall energy consumption and emissions as dramatically as was modeled for residential buildings. A detailed breakdown of energy consumption by end use for each scenario is shown in Figure 38 below:

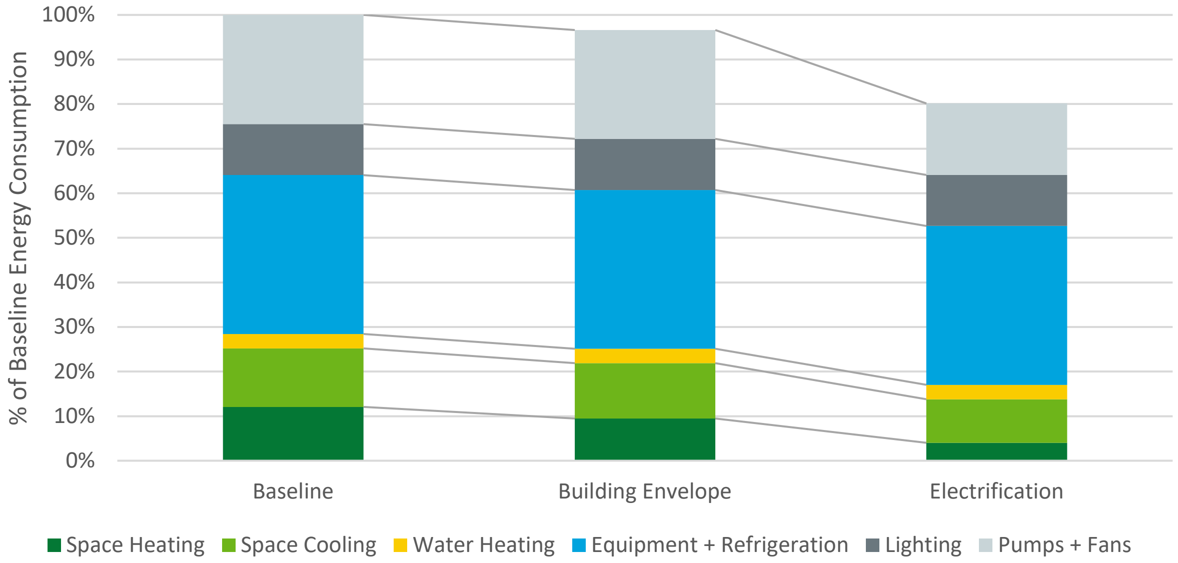

Figure 38. Modeled upgrade scenario impacts on city-wide annual commercial energy consumption by end use

Finally, as is illustrated in the tables below, these upgrades are estimated to have different impacts depending on the type of building. For example, envelope upgrades may have a higher impact overall for warehouse and storage space, where space conditioning is the primary energy use, reducing modeled energy consumption an estimated 9% and emissions by 18%, while the impact on food service would be minimal. Higher-efficiency electrification would also likely have the most significant impact on warehouse and storage space, reducing energy consumption by an estimated 42%, followed up healthcare (22%) and education facilities (19%).

Table 12. Upgrade Scenario Modeled Impacts on Energy Consumption and GHG Emissions by Building Type

Upgrade Scenario	Building Type	Total Energy Consumption		Total GHG Emissions	
		MWh	% Change	1,000 Metric Tons CO_2	% Change
Baseline	Education	14.3	N/A	1.1	N/A
	Food Service	14.1	N/A	1.7	N/A
	Healthcare	7.3	N/A	0.3	N/A
	Lodging	1.6	N/A	0.1	N/A
	Mercantile	134.5	N/A	10.9	N/A
	Office	66.9	N/A	3.6	N/A
	Warehouse/Storage	56.9	N/A	3.5	N/A
	Total	**295.6**	**N/A**	**21.3**	**N/A**
Building Envelope	Education	14.2	-0.7%	1.1	-0.5%
	Food Service	14.0	-0.8%	1.7	-0.9%
	Healthcare	7.1	-3.4%	0.3	-8.4%
	Lodging	1.5	-3.8%	0.1	-9.9%
	Mercantile	131.2	-2.5%	10.6	-3.3%
	Office	66.1	-1.2%	3.5	-2.6%
	Warehouse/Storage	51.5	-9.4%	2.9	-17.7%
	Total	**285.7**	**-3.4%**	**20.1**	**-5.3%**
Higher-Efficiency Electrification	Education	11.5	-19.4%	0.7	-34.0%
	Food Service	13.4	-5.2%	1.6	-5.7%
	Healthcare	5.7	-22.1%	0.2	-32.1%
	Lodging	1.6	-3.7%	0.1	-17.8%
	Mercantile	112.4	-16.4%	9.3	-15.0%
	Office	59.3	-11.4%	2.2	-40.2%
	Warehouse/Storage	33.1	-41.8%	1.3	-62.9%
	Total	**236.9**	**-19.9%**	**15.4**	**-27.7%**

Finally, it is interesting to point out that the connection between building vintage and energy consumption patterns is not as linear for commercial buildings as it was for residential buildings. For example, the impacts of building envelope improvements are fairly similar across vintages, all within margins of error for this analysis. The electrification upgrades do show some higher energy savings for older buildings, but this is likely as much of a reflection of the buildings' uses as it is their age.

Table 13. Upgrade Scenario Modeled Impacts on Energy Consumption and GHG Emissions by Building Vintage

Upgrade Scenario	Building Type	Total Energy (kWh)		Total GHG Emissions	
		MWh	% Change	1,000 Metric Tons CO_2	% Change
Baseline	Pre-1940s	40.5	N/A	3.8	N/A
	1940–1979	176.5	N/A	12.7	N/A
	1980–1999	57.9	N/A	3.6	N/A
	2000–Present	20.7	N/A	1.2	N/A
	Total	**295.6**	**N/A**	**21.3**	**N/A**
Building Envelope	Pre-1940s	39.8	-2%	3.7	-2%
	1940–1979	170.0	-4%	12,0	-6%
	1980–1999	56.0	-3%	3.4	-5%
	2000–Present	19.9	-4%	1.1	-9%
	Total	**285.7**	**-3%**	**20.1**	**-5%**
Higher-Efficiency Electrification	Pre-1940s	35.5	-12%	3.4	-11%
	1940–1979	137.3	-22%	8.8	-31%
	1980–1999	46.9	-19%	2.4	-34%
	2000–Present	17.2	-17%	0.8	-28%
	Total	**236.9**	**-20%**	**15.4**	**-28%**

Potential Utility Grid Impacts

Figures 39 and 40 below show estimated changes in *electricity* consumption by time of day for the commercial building upgrades modeled. This is important because a key concern in building electrification has to do with the capacity or ability of the electric transmission and distribution grid (operated in Richmond by PG&E) to handle increased electricity demand. In general, because so much of commercial building energy consumption is currently electricity-based, the higher- efficiency electrification upgrades modeled in this analysis only have positive energy savings at an aggregate level, and are not estimated to result in increasing the demands on the electric grid at any time during the day or year, at an aggregate level.

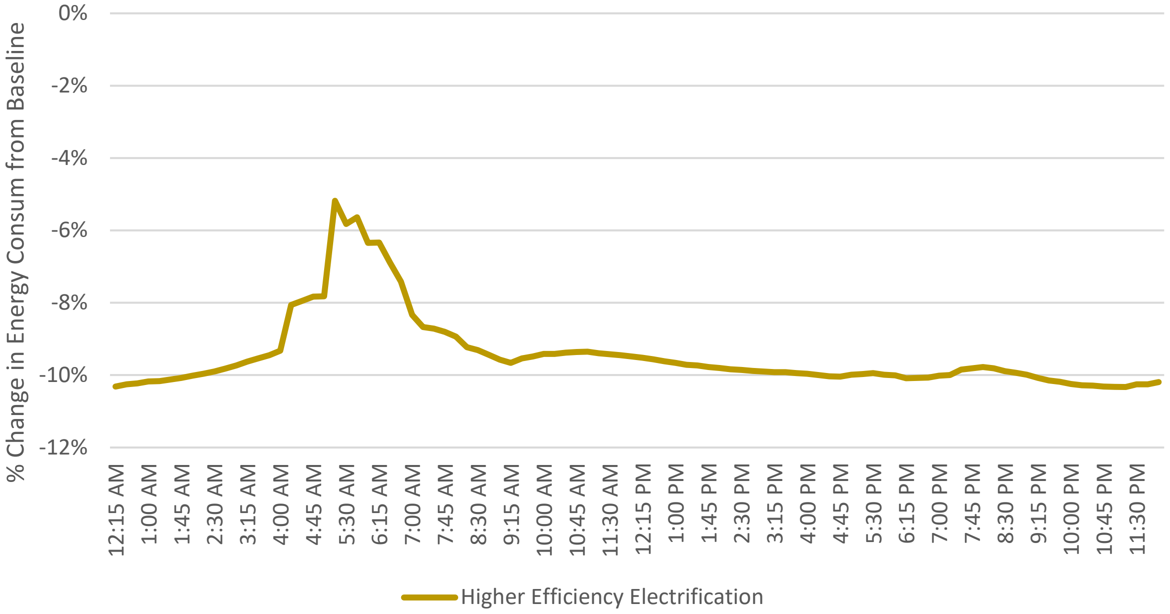

Figure 39. Average estimated daily city-wide residential electricity consumption for modeled building electrification upgrades by time of use

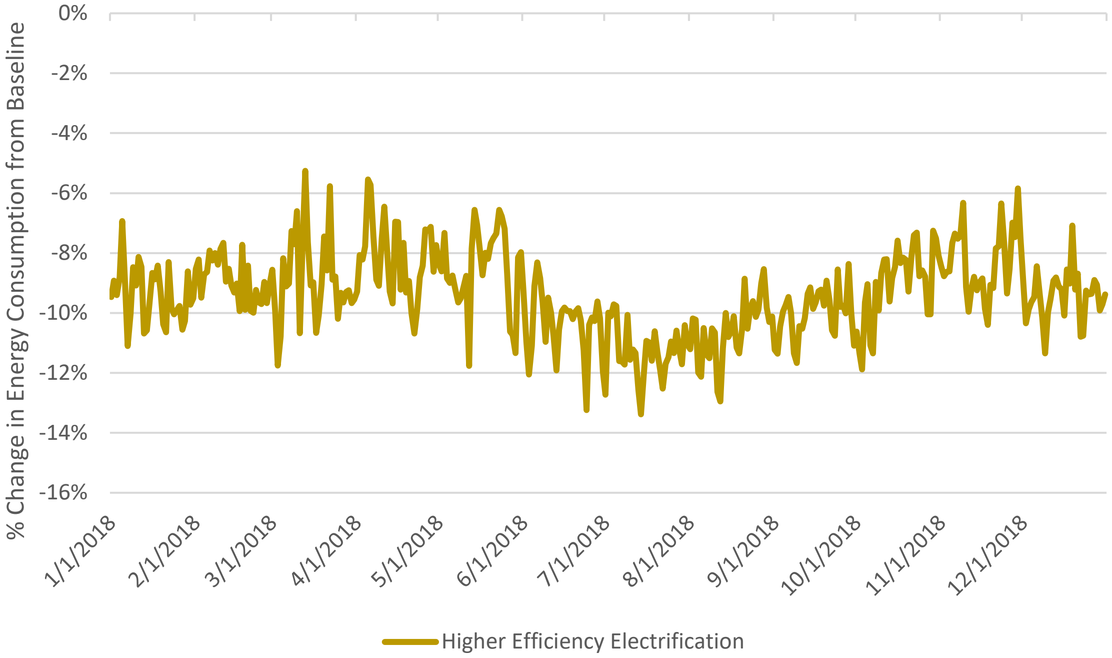

Figure 40. Average estimated annual city-wide residential electricity consumption for modeled building electrification upgrades

Employment Indicators

Baseline Data

The baseline employment information discussed in the residential section of this report is generally applicable to both residential and commercial building occupations and can be referenced there. According to the U.S. Energy and Employment Jobs Report and the E4The Future analysis, there are 8,028 energy efficiency workers in Contra Costa County in 2021, with one of the highest ratios of energy efficiency workers to total workers in the state (E4TheFuture, 2022). However, there are many plumbing, electrical and HVAC contractors, as well as architectural and engineering workers that are doing traditional work and could be upskilled to install the type of ECMs described in this analysis.

According to 2022 data from the BLS shown in the table below, there are as many as 4,085 workers employed at 190 business establishments in Contra Costa County that are engaged in work related to commercial building envelope and electrification upgrades. Average annual wages for these workers is $110,280. This is higher than 23% higher than the state average for the same occupations, and 34% higher than Contra Costa County's average wage for all occupations.

Table 14. Contra Costa County Employment in Select Commercial Construction Industries, 2022

Industry Category (NAICS Code)	# Businesses	Total Employment	Annual Wages per Employee
Electrical Contactors	80	1,998	$108,496
Plumbing and HVAC Contractors	57	1,281	$117,850
Drywall and Insulation Contractors*	53	806	$102,671
Total/Average	190	4,085	$110,280
ALL INDUSTRIES	36,158	322,128	$82,050

**Residential and commercial contractors are combined for this BLS industry category. Numbers overlap with Residential Table 7.*

Source: U.S. Bureau of Labor Statistics, 2022

Upgrade Analysis

Based on the EUSS upgrades and measure cost data described in previous sections, and high-level jobs multipliers published by NREL in 2022, it is estimated that pursuing commercial envelope and electrification upgrades in Richmond could support more than 14,000 jobs, nearly two-thirds of which could be direct jobs, which are more likely to be local (see Table 15 below). As in the residential section, since the analysis in this report did not specify a timeline for when these upgrades would be completed, the job numbers shown here are absolute, not per year. And finally, as with the residential analysis, all jobs associated with building envelope upgrades could be assumed to be new or net jobs, while only a portion of the electrification jobs would be new. Because this analysis assumes that building owners would pursue electrification at the end of an appliance's lifecycle (i.e., when an appliance needs to be replaced), then most of the labor associated with the replacement would happen whether it was being replaced with a natural gas appliance or upgraded to an electrical option and the jobs would not be new or net.

A detailed breakdown of the types of occupations associated with the ComStock upgrades can be referenced in the Occupational Analysis developed by ICF for the Communities LEAP Program (Brown et al., 2023).

Table 15. Estimated Jobs Supported by Upgrades to Richmond's Existing Commercial Building Stock

Upgrade Scenario	Direct Jobs Only		Direct + Indirect Jobs	
	Total Jobs	Net/new Jobs	Total Jobs	Net/new Jobs
Envelope	3,123	3,123	4,938	4,938
Electrification	5,950	1,190	9,407	1,881

Health and Safety Indicators

The connections between health (as measured by indoor air quality or IAQ) and buildings was discussed in depth in the residential section. The underlying health implications remain the same for commercial buildings, but they are experienced differently. IAQ in commercial buildings raises concerns mainly due to significant effects on worker and occupant health and productivity. Of greater concern is the IAQ of schools, since children are more susceptible to air pollutants than adults (Zhu et al., 2020) and spend a significant amount of time in schools.

A review of scientific studies of IAQ in both residential and commercial buildings in various countries looked at a range of indoor air pollutants (Mannan and Al-Ghamdi, 2021): A study in Korea of 55 schools found that the primary factors contributing to IAQ were emissions of chemicals from buildings materials or furnishings and unsatisfactory ventilation. A study they cited of small and medium commercial buildings in California that monitored particulate concentration(a significant contributor to IAQ) highlighted the disadvantages of low-efficiency filters in most of the observed buildings. A simulation study using EnergyPlus found that indoor concentrations of $PM_{2.5}$ in office buildings in 14 cities across the U.S. was mostly affected by weather patterns and ventilation systems. And a study of newly built low-energy preschools in Sweden found a strong relationship between IAQ and the functioning level of the ventilation systems (Mannan and Al-Ghamdi, 2021).

These studies repeatedly show the impact of building envelope and ventilation systems on IAQ and health. This reinforces the need for any efforts to include appropriate ventilation and filtration measures to filter indoor sources of pollutants and help prevent intrusion of outdoor air pollutants.

Equity Considerations

This section discusses equity considerations related to three of the five main areas of analysis for this report: utility bills and cost-effectiveness, employment, and health. Based on input from the Community Coalition, this analysis is focused mainly on upgrades to Richmond's residential building stock.

Residential Utility Bills & Measure Cost-Effectiveness

According to the baseline ResStock analysis, the lowest-income households (those earning less than 200% of the FPL) make up about 19% of Richmond households, but they are responsible for only 15% of city-wide energy consumption and 16% of city-wide utility bill costs.

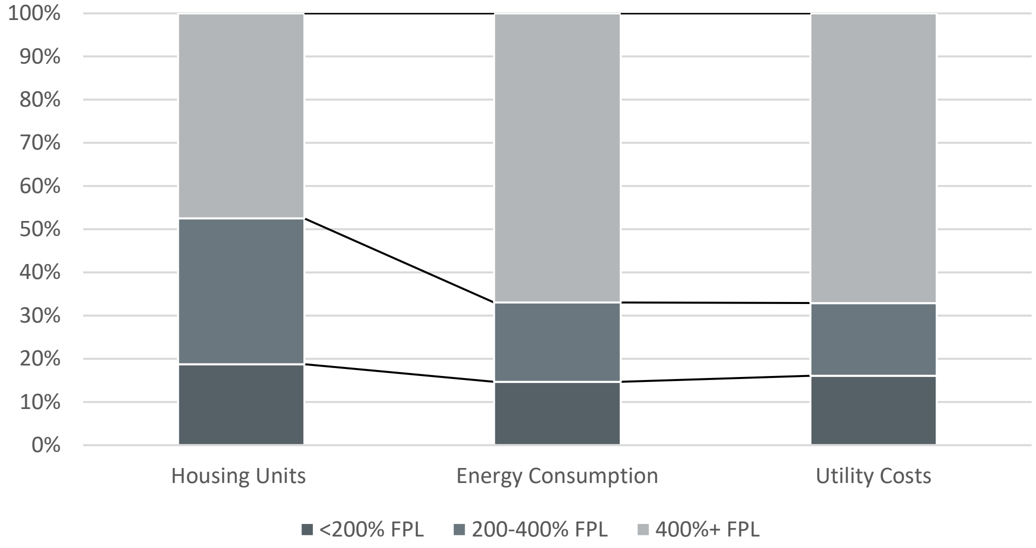

Figure 41. Modeled residential energy consumption and utility cost share by federal poverty level

However, this trend reverses if you look at the share of household income spent on energy costs, known as "energy burden," instead of actual dollars spent. According to DOE's Low-income Energy Affordability Data tool, Richmond's households pay an average of 2% of their income on energy costs. This is consistent with other cities in Contra Costa County and is higher than neighboring communities in Marin and Alameda Counties which average an energy burden rate of closer to 1%. However, extremely low-income households in Richmond (those earning less than 100% FPL) spend an estimated of 16% of their household income on average on energy, compared to about 1% for households earning more than 400% of FPL (Office of State and Community Energy Programs, n.d.). This occurs even though actual energy costs paid in dollars increase as income rises. This means that Richmond's lowest-income households are much more sensitive and vulnerable to even small variations in the dollar amount or percentage change in annual utility bills.

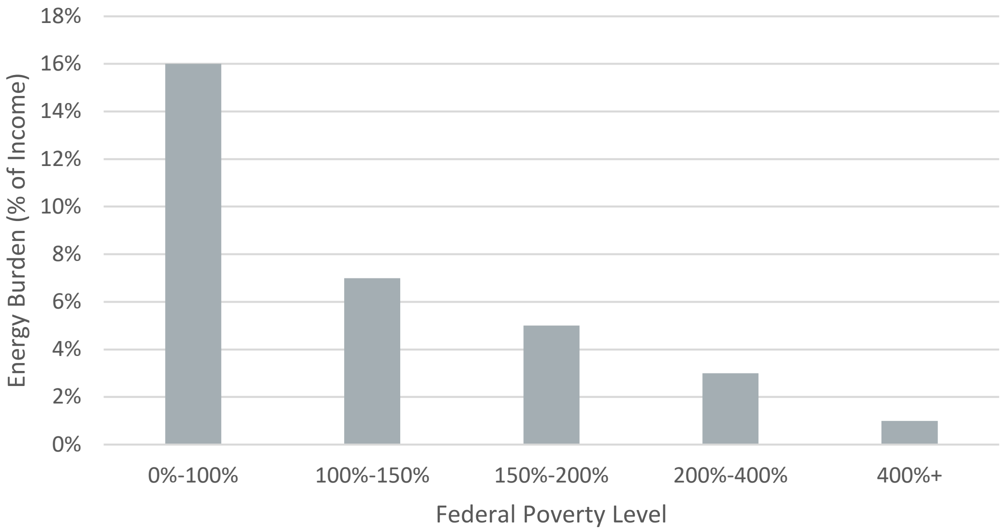

Figure 42. Estimated average energy burden rate by federal poverty level for Richmond.
Source: DOE Low-income Energy Affordability Data Tool

There is also a variation in estimated energy burdens for different census tracts within Richmond, though that variation is not as dramatic. As is illustrated in Figure 43 below, average energy burden rates range from 1%–3%, with no individual census tract within Richmond exceeding the 6% threshold for consideration as “energy-burdened” on average. However as shown in Figure 42, individual housing units within these areas are energy-burdened.

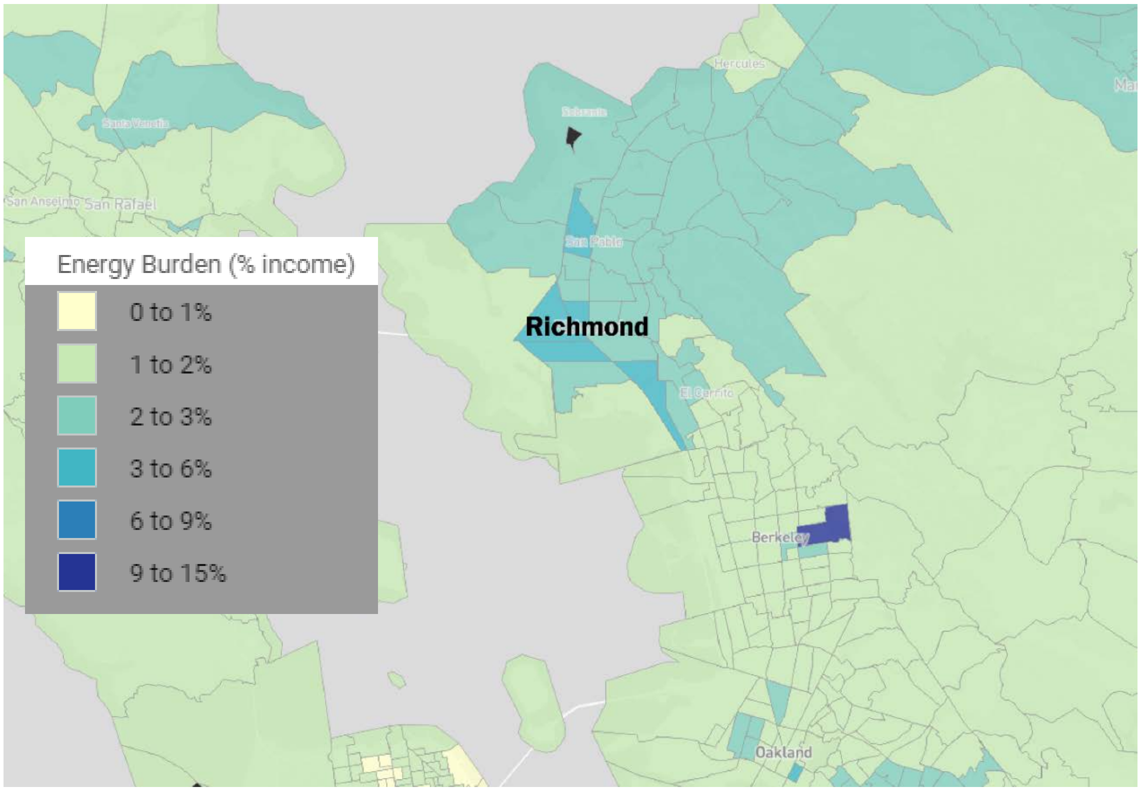

Figure 43. Estimated average energy burden rate by census tract.
Source: DOE Low-income Energy Affordability Data Tool

Returning to the ResStock analysis, many of the potential equity considerations identified in this analysis are a reflection of energy consumption patterns of the residential buildings in Richmond. As described in the residential analysis, single-family homes consume more energy (per unit and overall), and more of it is natural gas, compared to homes in multifamily buildings. This is an important point because building type is correlated with both tenure (whether residents are renters are owners), and income. For example, 94% of owners live in single-family buildings compared to just 40% of renters. In addition, less than half (43%) of households below 200% of FPL live in single-family buildings, compared to about three-quarters of households earning more than 400% FPL.

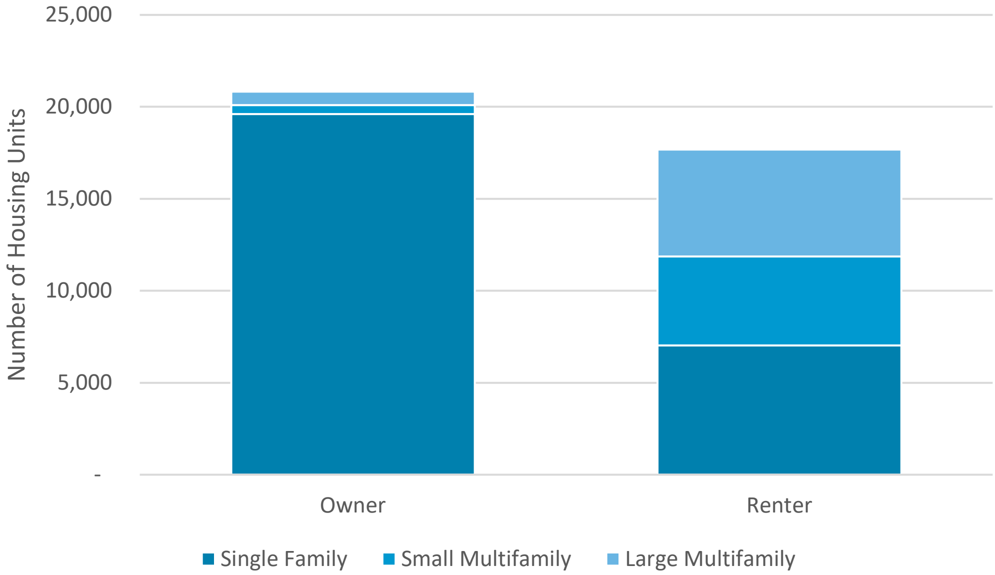

Figure 44. Modeled residential building type by resident tenure

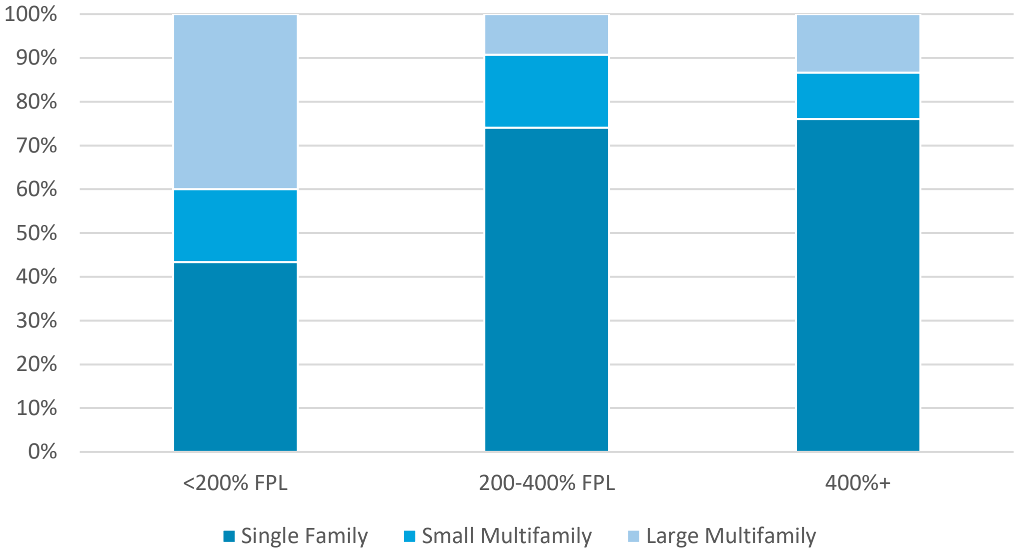

Figure 45. Modeled residential building type by federal poverty level

Although residents of large multifamily buildings (who are more likely to be renters and have lower household incomes) tend to pay lower utility bills in total dollars than residents of single-family and small multifamily households, they would also generally be expected to see less savings as a result of envelope and electrification upgrades, both in absolute dollars and percent savings. And because of this, there may be less chance of a positive return-on-investment for the upfront costs, particularly of electrification upgrades. These trends are illustrated in Figures 46 and 47.

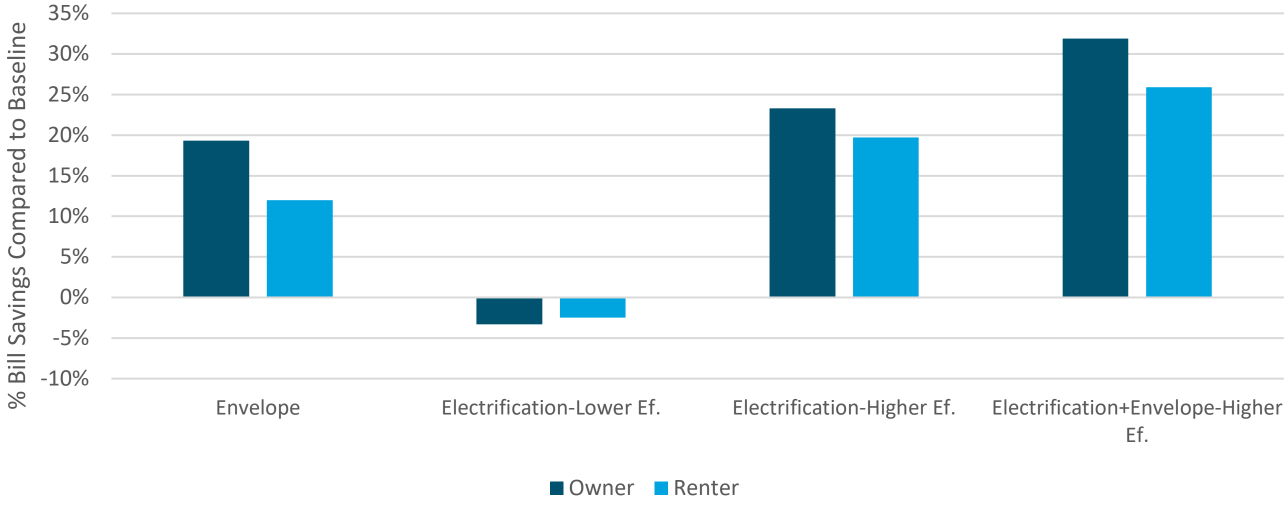

Figure 46. Modeled impacts of residential upgrade scenarios on estimated annual utility bill savings by tenure

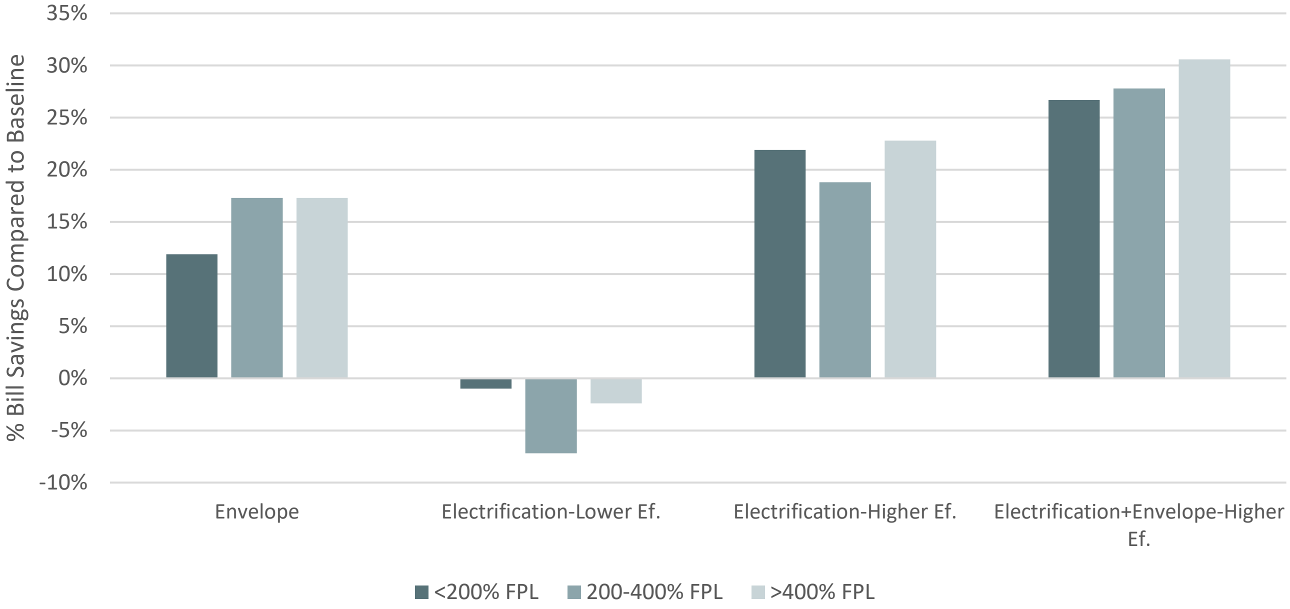

Figure 47. Modeled impacts of residential upgrade scenarios on estimated annual utility bill savings by federal poverty level

Another equity consideration related to building stock has to do with the relative cost of different energy fuels, and how utility bills are paid. Residents in multifamily buildings tend to have electricity as a higher share of their energy consumption compared to natural gas. This is because multifamily units are smaller (less need for space heating which is predominantly gas), and they tend to be newer (better insulation and air sealing which also leads to less heating demand). In addition, renters are more likely to be responsible for paying their electricity bill compared to their natural gas bill (which is often paid for by the landlord) (Gowda, 2023). Since electricity is more expensive that natural gas (in terms of equivalent units of energy, kWh in this analysis), multifamily residents (who are more likely to be renters and lower-income) could be more sensitive than single-family residents to electric utility bill increases that result from certain electrification improvements. In situations where landlords currently pay for gas and not renters, electrification could shift that portion of energy burden to renters. This is particularly true in the case of lower-efficiency electrification upgrades, which our analysis showed could result in increased electricity consumption and utility bills if not paired with envelope improvements.

Finally, the high upfront cost of both envelope and electrification measures may be a barrier to low- and moderate-income owner households, and to small-scale landlords (those that own single-family and small multifamily rental properties). Even when items are cost-effective over the lifetime of the measures, a 15–30-year payback may not be feasible for many households—especially low-income households and people of color—who are more likely to be living paycheck to paycheck and with limited savings (Despard et al., 2020). In addition, depending on interest rate levels which are currently at 15-year highs (FRED, n.d.), the cost to finance these measures will reduce some of the savings they could generate. Potential tools and programs to address this issue will be explored in the Implementation Strategies report that will be published at the close of this Communities LEAP project.

Commercial Building Location

For commercial buildings, this analysis did not look at utility bill costs, cost-effectiveness of measures, or income. However, there are potential equity considerations related to the location of commercial buildings within the City of Richmond. According to data available through Transparent Richmond, about half of the census tracts (53%) within the city's boundaries are in what are designated as "disadvantaged" census tracts according to the definition outlined in State Bill 535[7]. (see Figure 48).

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[7] California State Bill 535, passed in 2012, established standards for ensuring minimum state funding to what it called "disadvantaged communities" (OEHHA, n.d.). This definition has evolved over the last decade, and is tied to a variety of factors tracked through the CalEnviroScreen Tool, including pollution burden, health indicators, and population characteristics such as poverty, educational attainment, unemployment levels, linguistic isolation, and housing burden (August et al., 2021).

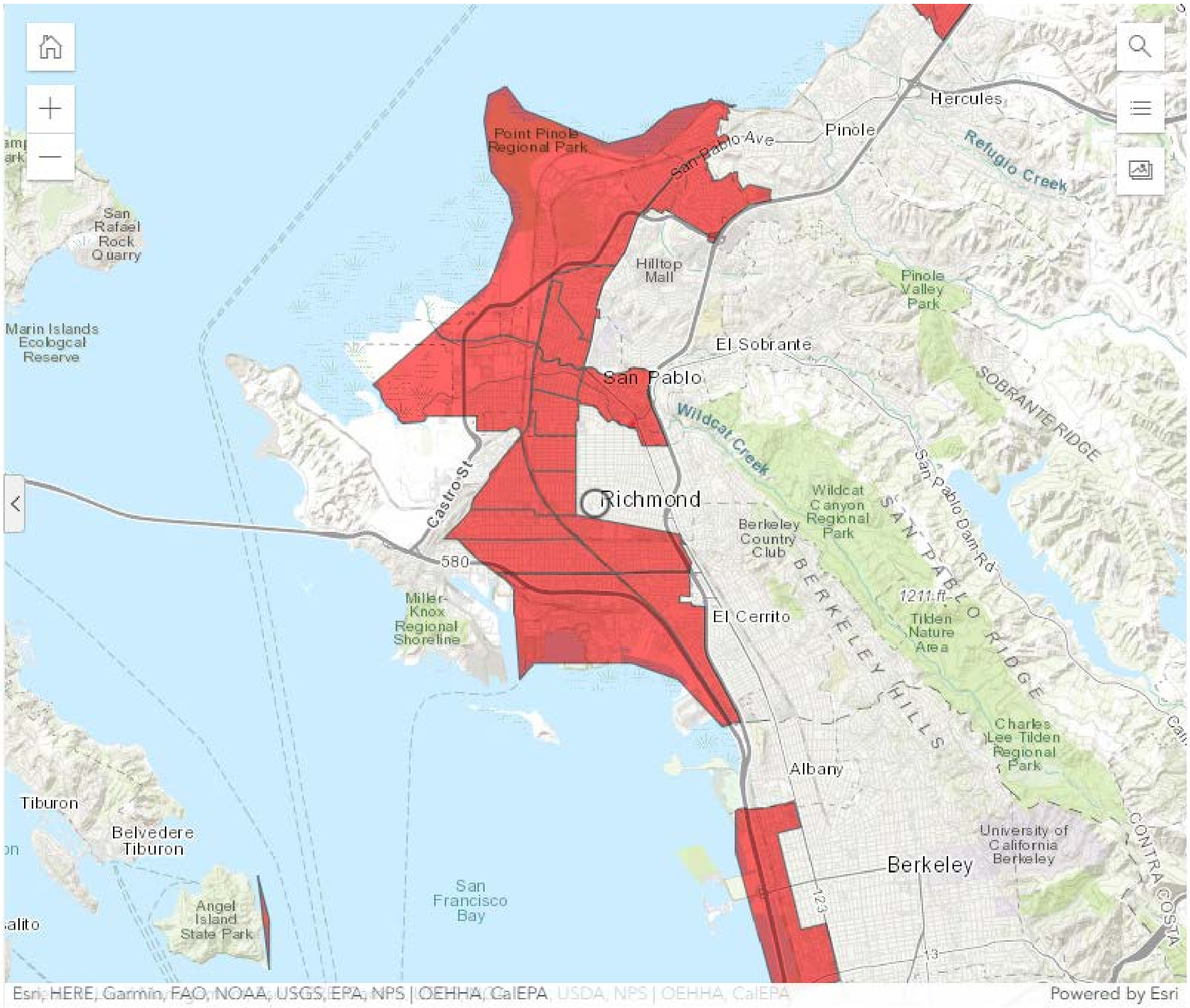


Figure 48. Disadvantaged census tracts in and around Richmond.
Source: California Office of Environmental Health Hazard Assessment, 2023

These “disadvantaged” tracts contain about 56% of all non-residential buildings in the city, and 50% of the non-residential building floor area (based on assessor’s data, not ComStock modeling). However, there is some variation based on building characteristics and use. For example, 81% of the city’s industrial buildings, 77% of public assembly buildings, and 66% of government-owned buildings are located in disadvantaged tracts. Looking at floor area, 86% of the square footage of government-owned buildings in Richmond are in disadvantaged census tracts, 79% of health care floor area, and 74% of public assembly. A full list is provided in Table 16.

While there is no clear alignment between location of commercial buildings and energy consumption patterns, it may be helpful for the city to consider the above when crafting policies or programs in the future.

Table 16. Share of Richmond’s Non-Residential Buildings Located in Disadvantaged Census Tracts

Building Use	% Located in Disadvantaged Census Tracts	
	Buildings	Floor Area
Convenience Store	60%	54%
Education	45%	27%
Food Service	23%	21%
Government Owned	71%	54%
Healthcare	57%	79%
Industrial	81%	69%
Lodging	18%	5%
Mercantile	54%	31%
Nursing Home/Assisted Living	80%	61%
Office	42%	7%
Public Assembly	77%	74%
Recreation	43%	49%
Religious Worship	61%	51%
Vehicle Service	53%	46%

Source: Contra Costa County Assessor’s Data and CalEnviroScreen

Employment Indicators

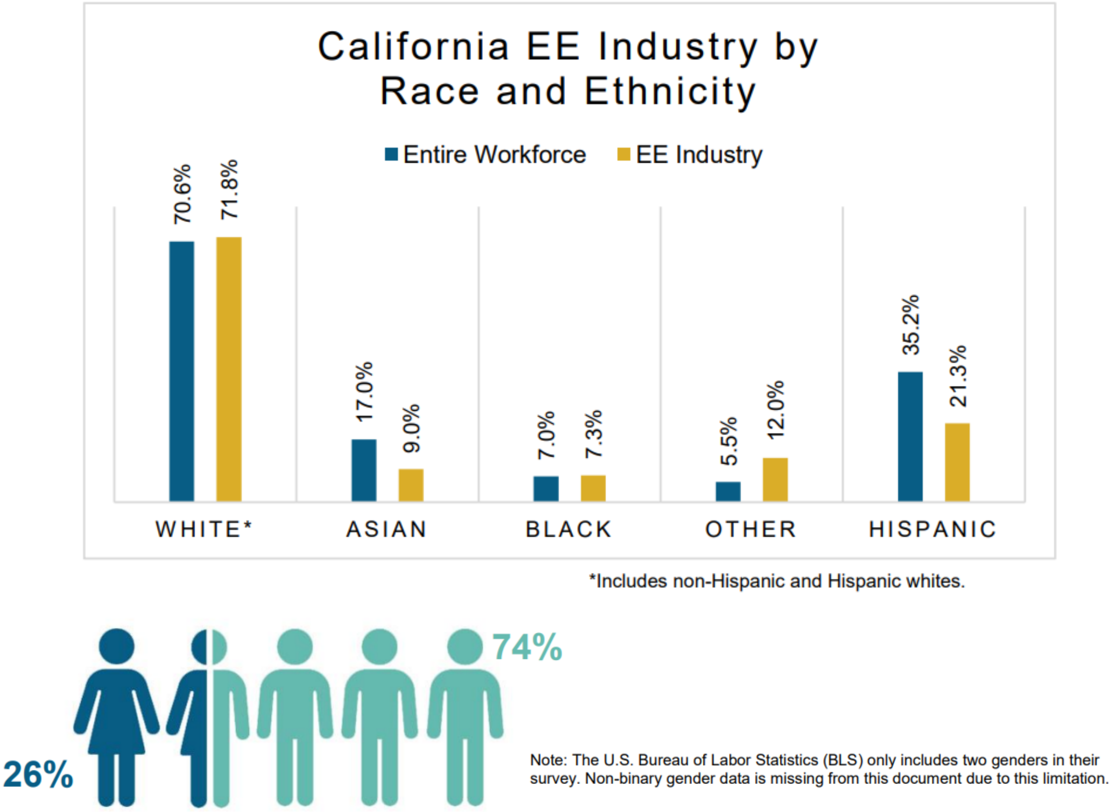
Equity in employment has many different facets, most of which can be summarized by the eight principles of a “good job” as defined by the U.S. Department of Commerce and Department of Labor (DOL) (DOL, n.d.)

1. **Recruitment and hiring** that is intentional, non-discriminatory, and based on evaluation of skills-based requirements that may include non-traditional pathways.
2. **Benefits** for both full- and part-time workers that can include health insurance, retirement plans, workers compensation, family leave, and access to remote work opportunities where feasible.
3. **Diversity, equity, inclusion, and accessibility** that enables workers to be treated fairly, including the provision of reasonable accommodations where applicable.
4. **Empowerment and representation** where workers contribute to decisions about their work and organizational direction. It can include ability of workers to form or join unions without fear of retaliation.
5. **Job security and working conditions** that are safe, healthy, accessible, and built on input from workers and their representatives.
6. **Organizational culture** that shows that all workers belong and are valued and respected.
7. **Pay** that is stable, predictable, and a living wage (as determined by local area cost of living).
8. **Skill and career advancement** opportunities for workers, including transparent promotion processes and access to on-the-job training and continuing education.

Most of the qualities described above are not captured in publicly available data for energy efficiency workers in Richmond. However, this section will share what information we found that is available. With regards to pay, our analysis of 2022 data from the BLS showed that average annual wages for all Contra Costa County workers engaged in industries relevant to the upgrades described in this report was $88,6271. This is higher than the county average for all industries ($82,050), but varies by individual industry. For example, according to the data shared in this report, wages for Contra Costa County jobs related to electrification upgrades (HVAC, plumbing and electrical contractors) are 22% higher in Contra Costa County than jobs related to envelope improvements. In addition, wages for workers in the commercial sector are 42% higher than the residential sector.

BLS data related to some of the other points captured by the eight “good jobs” principles is only available for all construction workers at the state or nation level, but is provided for reference. As of 2022, 75% of private industry construction workers nation-wide had access to employer-sponsored health care benefits, 81% had access to paid vacation benefits, 69% had access to paid sick leave, and 63% had access to retirement benefits plans. Twelve-point-four percent of construction workers nationwide were represented by unions, and median wages for those workers were 34% higher than non-union construction workers (BLS, 2023).

Finally, data from the 2022 E4TheFuture report illustrated in Figure 49 below shows that in California, the energy efficiency workforce has a lower share of Hispanic and Asian workers compared to the state’s overall workforce, and a much lower share of female workers (E4TheFuture, 2023). These are largely a reflection of demographic trends in the construction industry overall.



*Includes non-Hispanic and Hispanic whites.

Note: The U.S. Bureau of Labor Statistics (BLS) only includes two genders in their survey. Non-binary gender data is missing from this document due to this limitation.

Figure 49. Demographic indicators for all California energy efficiency worker. Source: E4TheFuture, 2023

Health & Safety Indicators

As described in previous sections, certain health indicators related to IAQ such as respiratory asthma and cardiovascular disease show that Richmond has some of the highest rates in the state of ER visits related to these things. The research reviewed in this report found that building electrification has the potential to improve IAQ for both Richmond residents and Richmond workers, by reducing or removing pollutants that result from incomplete combustion in natural gas appliances. This is especially the case for residents living in multifamily buildings, who are more likely to have higher levels of indoor air pollutants due to smaller living spaces, and for lower-income households who are more likely to live in those buildings. It may also have a higher benefit for certain populations: As noted earlier, children have increased risk of asthma, wheezing, and other respiratory symptoms associated with exposure to NO_2. Women may also be at greater risk due to increased exposure with higher frequency of cooking (Zhu et al., 2020).

The research related to building envelope improvements is more nuanced: Although building envelope improvements were shown in our cost effectiveness analysis to have the highest savings-to-investment ratio, pursuing these upgrades alone without electrification or proper ventilation, has the potential to make IAQ worse (EPA, 2022, Underhill et al., 2020). This is because insulation and air sealing decrease the exchange of air between indoors and outdoors, which in some homes serve as passive ventilation for clearing pollutants. Programs such as the national WAP include health and safety as part of their approach, ensuring that any envelope and efficiency measures provided will be paired with adequate ventilation improvements (Tonn et al., 2020). However not all private-sector contractors may take this approach on their own, particularly for homeowners or landlords trying to reduce upfront costs. This should be considered when crafting policies and programs related to building envelope improvements.

Conclusion and Next Steps

The data shared in this report is intended to support the City of Richmond and its City Council in making informed decisions regarding the development of policies and programs to improve the energy efficiency and reduce the GHG emissions of existing buildings under the city's jurisdiction. Using data tools development by NREL, this report was able to analyze approximately 98% of residential housing units, and 55% of non-residential building square footage in the city. The analysis looked at energy consumption and fuel use patterns, GHG emissions, costs and utility bill impacts, employment impacts, and health impacts of building envelope and electrification upgrades.

The findings presented in this report are modeled impacts only, but offer a snapshot of how changes to the Richmond's existing building stock might help the City in moving towards its goals related to reducing GHG emissions, reducing energy burdens particularly for renters and low-income households, promoting local employment, and improving resident and worker health. Our intention is to support Richmond's Communities LEAP coalition in presenting these findings to City Council so that they can identify a more specific policy direction.

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Appendix

Appendix A. Analysis Methodology Additional Details

General Details

As described earlier in this report, this analysis was based foundationally on data from the ResStock and ComStock tools. The data they offer are based on detailed models that incorporate a variety of building characteristics. These include building size and orientation, foundation type (basement, crawl space, slab), wall type (wood, steel, masonry), insulation and air sealing levels, existing appliance and HVAC system types and efficiency, thermostat settings, and more. These characteristics are the tools' inputs for modeling baseline energy consumption, which can then be compared to models when any of those elements is upgraded.

The following offers information on the methodology for this analysis, both generally and with details for the residential and commercial analyses.

Building Vintage

This analysis used the ResStock and ComStock tools to organize building data by vintage, or date built, using the following categories:

- *Pre-1940:* These buildings are less likely to have insulation or air sealing, as they were built prior to the adoption of the California Energy Code in 1978. They may also have lead-based paint and/or asbestos, as they were built prior to the EPA's ban in 1978, which can cause health issues and incur additional costs for completing energy efficiency upgrades.
- *1940–1979:* These buildings are less likely to have insulation or air sealing, as they were built prior to the adoption of the California Energy Code in 1978. They may also have lead-based paint and/or asbestos, as they were built prior to the EPA's ban in 1978, which can cause health issues and incur additional costs for completing energy efficiency upgrades.
- *1980–1999:* These buildings are more likely to have quality insulation and air sealing, though they may not always have adequate ventilation.
- *2000+:* These buildings are likely to have proper insulation, air sealing, ventilation, and more efficient appliances.

Site Energy Consumption

For this analysis, the authors looked at site energy consumption, which is the energy used by the building site. This is different from source energy, which includes energy consumed in the production of that energy (including any losses in the generation at the power plant), as well as transmission and delivery to the building site (Energy Star, n.d.). Energy consumption is measured in this report in kilowatt hours (kWh) for both electricity and natural gas. Natural gas is typically measured in Therms or British Thermal Units, not in kWh, but was converted for ease of analysis. At the direction of the Richmond Community Coalition, we excluded data for propane or other fuel oil use, since this data was very limited.

Greenhouse Gas Emissions

This analysis examines greenhouse gas emissions (GHG) associated with the generation, transmission, and consumption of energy used in Richmond's buildings. The ResStock and ComStock tools provide estimates for GHG emissions. We adjusted this data based on specific emissions estimates available on Transparent Richmond, which come from the utility providers in the area—PG&E and MCE. We took the electricity rate plan subscription percentages from the Climate Action Plan for PGE Base, MCE Light Green, and MCE Deep Green subscription. We then looked at the Power Content Label from the utilities websites to determine the emission factors from electricity for the three plans listed above. Using the emissions and the subscription percentages for each plan, a weighted average for average electricity emissions was created. The weighted average was then used to calculate the electricity emissions from electricity. For natural gas and propane emissions, emission factors were found on the U.S. Energy Information Administration website.

In this report, GHG emissions are shown in metric tons of carbon dioxide equivalent (MT CO_2e). CO_2 is not the only GHG associated with building energy consumption, however the impact of all GHGs has been standardized to units of CO_2 for ease of analysis.

Employment Outcomes

Due to the broad scope of this project and time and resource limitations, we were not able to conduct a detailed jobs or economic impact analysis to accompany the energy impact analysis. Instead, the authors worked with the Richmond Community Coalition to identify an approach that would provide a high-level estimate of the relative impacts of different types of building envelope and electrification investments. We first used high-level energy efficiency jobs multipliers for the state of California published by NREL (Truitt et al., 2022), and applied these to the estimated city-wide building upgrade costs. We used BLS data for the most relevant industries and downloaded data on wages and other characteristics of the jobs estimated to result from the upgrades modelled.

Residential Building Stock Analysis Details

ResStock Information

ResStock currently combines data from 11 sources to build its models. These sources include the U.S. Energy Information Administration's Residential Energy Consumption Survey, U.S. Census data, surveys from builders, and others and include buildings from across the country. Weighting factors are then used to scale the results of each model.

The ResStock tool and the data it offers may evolve in the future. For this analysis, we used the published data from September 2022, with the 2018 Actual Meteorological Year weather file. Because the ResStock tool uses a sample of the building stock in a geographic area and not data on every building, the smaller the geography, the fewer samples there are and therefore the larger the potential margin of error for the analysis. To ensure that the analysis would be as accurate as possible, we compared ResStock baseline data for the city of Richmond to information available through the U.S. Census Bureau, as well as building data from the City's General Plan, and energy use data available through the Transparent Richmond website.

The specific ResStock upgrades used in this analysis were:

- *Baseline:* Baseline
- *Envelope*: Upgrade #2, Enhanced Enclosure
- *Electrification – Lower Efficiency:* Upgrade #7, Whole-home electrification, min-efficiency
- *Electrification – Higher Efficiency*: Upgrade #8, Whole-home electrification, high efficiency
- *Envelope + Electrification – Higher Efficiency*: Upgrade #10, Whole-home electrification, high efficiency + enhanced enclosure package

Residential Building Stock Categorization:

For this report, we used the ResStock tool to organize Richmond's residential building stock into the following categories:

- *Single-family* includes single-family detached and attached (e.g., row homes) units
- *Small multifamily* includes housing units in buildings with two to four units
- *Large multifamily* includes housing units in buildings with five or more units

Household Income

For this report, we used 2018 FPL as the basis for the income analysis. A list of 2018 income brackets is provided below:

Table A-1. Federal Poverty Levels by Household Size

Persons in Family/Household	200% FPL	400% FPL
1	$24,280	$48,560
2	$32,920	$65,840
3	$41,560	$83,120
4	$50,200	$100,400
5	$58,840	$117,680
6	$67,480	$134,960
7	$76,120	$152,240
8	$84,760	$169,520

Source: U.S. Department of Health and Human Services, 2018

Utility Bill Charges

For this analysis, we worked with MCE to develop a formula for estimating residential utility bills based on the project natural gas and electricity consumption from the EUSS modelling. This consumption data was organized by month of year and time of day to account for seasonal fluctuations in rates, as well as different electricity rates for peak (4 p.m.to 9 p.m.) versus non-peak hours. It is important to note that all calculations related to utility bills use rate structures provided to NREL in January of 2023, and projected for the full year. This analysis does not attempt to project utility rates in future years, but instead estimates how electrification upgrades could impact bills in today's dollars.

Residential ECM Costs and Cost-Effectiveness

To estimate the costs of the measures included in the upgrade scenarios identified in this analysis, we collected, analyzed, and aggregated cost data from the following sources into high-level average cost estimates:

1. Two WAP agencies (Contra Costa County and Central Coast Energy Services, 2022 cost data)
2. Richmond Community Foundation costs from Net Zero Energy Home retrofits in Richmond
3. City of Richmond building permit project valuation data from 2020–2022 (City of Richmond, n.d.)
4. Costs from City of Berkeley Existing Buildings Electrification Strategy (City of Berkeley, 2021)
5. Costs listed in NREL's National Residential Efficiency Measures Database (NREL, n.d.)

To calculate whether an upgrade package was cost-effective, we looked at utility bill savings over the lifespan of each modeled measure and calculated a savings-to-investment ratio, or SIR. The lifespans were adapted from guidance provided by the U.S. Department of Energy's WAP (WAP, 2019), and NREL's National Residential Efficiency Measures Database (NREL, n.d.). For electrification upgrades, SIRs were calculated for total estimated upfront costs and incremental costs (the difference between the total upfront cost of an electric appliance and the total upfront cost to replace appliances with the same or similar to what currently exists). For streamlined calculations and timeline limitations for the projects, all baseline appliance costs used natural gas averages. However, the energy modeling is much more specific about existing appliances, fuel types, and efficiency levels.

No SIRs were calculated city-wide to reflect potential utility rebates or other incentives such as the Inflation Reduction Act. This is because not all households that qualify for rebates or incentives can or choose to use them. In coordination with the Richmond Community Coalition, it was determined that such a calculation might be misleading.

A list of measure costs and lifespans used for this analysis is included in Appendix C.

Commercial Building Stock Analysis Details

ComStock Information

ComStock uses several data sources to develop its building models. While some are public, such as the U.S. Energy Administration's Commercial Building Energy Consumption Survey, others are proprietary data sets from utilities and others. As with ResStock, weighting factors are then used to scale the results of each model.

The ComStock tool and the data it offers may evolve in the future. For this analysis, we used the ComStock published data from March 2023, with the 2018 Actual Meteorological Year weather file. To ensure that the analysis would be as accurate as possible, we compared ComStock data for the two Public Use Micro Data Areas located within Richmond city boundaries to county assessor data, and made adjustments to the weighting of models to bring building types and sizes into alignment.

The specific ComStock upgrades used in this analysis were:

- *Envelope*[8]: Upgrade #6, Exterior wall insulation, and Upgrade #7, Roof Insulation
- *Electrification:* Upgrade #1, Heat Pump Rooftop Unit

Commercial Building Stock Categorization:

It is important to note that according to 2022 county assessor data, there are 1,351 non-residential buildings located within the City of Richmond, representing more than 29 million square feet of building space. About 66% of the buildings and 43% of the floor area is commercial or institutional uses, 30% of buildings and 46% of floor area is industrial, and 4% of buildings and 11% of floor area is government owned. As described in the methodology section, the ComStock tool used for this analysis was able to model energy consumption for about half of the city's non-residential buildings, as shown in the table below.

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[8] At the time this analysis was completed, ComStock did not offer modeled packages of measures as ResStock did. If the two commercial building envelope measures cited above were modeled as a package (as will be available in later versions of ComStock), the modeled change in energy consumption would likely vary from the sum of the individual upgrades. In order to more easily compare residential and commercial upgrades, we chose to add the modeled energy savings of the individual upgrades together. This decision was made because the analysis showed that the modelled city-wide change in energy consumption from both of these upgrades was relatively small (3% combined), and therefor any variation for the combined modelled would likely result in less than 1% change overall to the data presented in this analysis.

However, we determined that adding the energy consumption changes of the envelope and electrification measures together would might produce results with a higher level of variation from a modeled package. For this reason, there is no commercial building offering describing envelope and electrification measures combined as there is for the Residential building stock.

Table A-2. Share of Richmond Non-Residential Building Stock Analyzed

Building Use Category	% of Buildings Included in Analysis	% of Floor Area Included in Analysis
Commercial/Institutional	65%	85%
Industrial	16%	39%
Total	48%	55%

The non-residential building uses *excluded* from this analysis include:

- Assisted care facilities and other congregate housing (less than 1% of units in Richmond)
- Laboratory facilities
- Grocery stores
- Entertainment venues
- Recreation centers
- Religious buildings
- Vehicle repair shops
- All industrial buildings, except for warehouse and storage facilities.

In addition, based on feedback from the community coalition, we chose to exclude certain buildings from the analysis which are not regulated by the City's building/planning departments. This included mobile/manufactured homes, public schools, and government-owned buildings. Although the city does have jurisdiction over city-owned buildings, these were excluded as there were not enough buildings to ensure the models were accurate. The non-residential buildings analyzed here are referred to as "commercial" buildings, even though they include some institutional and light industrial uses.

For this report, we used the ComStock tool to organize Richmond's commercial building stock data into the following building use categories:

- Private education
- Food service
- Healthcare
- Lodging
- Mercantile
- Office
- Warehouse and storage

Commercial ECM Costs

To estimate the costs of the measures included in the residential upgrade scenarios identified in this analysis, we collected, analyzed, and aggregated cost data from the following sources:

1. City of Richmond building permit project valuation data from 2020 to 2022
2. Costs from City of Berkeley Existing Buildings Electrification Strategy (City of Berkeley, 2021).
3. Costs shared by one contractor affiliated with members of the Contra Costa Building Trades Council (2023 cost data).

Based on project priorities and guidance from the community coalition, cost-effectiveness and utility bill impacts were not estimated for commercial buildings. However, in order to estimate commercial employment impacts, We worked with ICF to provide estimated commercial ECM costs. These were derived from data available through RSMeans.

Appendix B. Upgrade Scenario Details

The following table provides additional details on the building upgrades modeled using the ResStock and ComStock EUSS tools and datasets.

Table B-1. End Use Savings Shapes Upgrade Details

Upgrade Type	Description	Details
Residential Buildings		
Building Envelope Measures	Wall, Attic, and Foundation Insulation	Wall: R-13 drill-and-fill insulation applied to homes with wood stud walls and no existing insulation Attic: • R-30 attic insulation for homes in Climate Zone 1A with ≤ R-13 • R-49 attic insulation for homes in Climate Zones 21, 2B, 3A, 3B, 3C with ≤ R-30 • R-60 attic insulation for homes in other climate zones with ≤ R-38 Foundation • Add R-10 interior insulation to foundation walls and rim joists • Seal crawlspace vents
	General air sealing	30% reduction in ACH50, applied to homes with greater than 10 ACH50
	Duct Sealing	Ducts improved to 10% leakage, R-8 insulation added. Applied to homes with leaker or less-insulated ducts
Electrification Measures	Air Source Heat Pumps	• Centrally ducted heat pumps for homes with HVAC ducts - Lower efficiency: SEER 15, 9HSPF - Higher efficiency: SEER 24, 14 HSPF • Ductless minisplit heat pump for homes without HVAC ducts - Lower efficiency: SEER 15, 9HSPF - Higher efficiency: SEER 29.3, 14 HSPF • Electric resistance backup heat
	Heat Pump Water Heaters	• 3.45 UEF HPWH, 50–80 gallon depending on unit size
	Clothes Dryer	• Lower efficiency: Electric resistance • Higher efficiency: Ventless heat pump dryer
	Cooking Range	• Lower efficiency: Electric range and oven • Higher efficiency: Induction range and electric oven
Commercial Buildings		
Building Envelope Measures	Wall Insulation	Extruded polystyrene foam insulation added to buildings with mass, steel-framed or wood-framed walls, added to meet Advanced Energy Design Guide recommendations
	Roof insulation	Attic or roof insulation (depending on building type), added to meet Advanced Energy Design Guide recommendations
Electrification Measures	Air Source Heat Pumps	• For buildings with boilers: replacement with higher-efficiency air source heat pump boilers • For buildings with gas-fired or electric resistance rooftop units: replacement with higher-efficiency heat pump rooftop units

The upgrade packages that we descr

Appendix C. Upgrade Scenario Costs and Rebates

Below are the individual measure costs and rebate amounts used to estimate the cost-effectiveness of the residential building envelope and electrification upgrade packages analyzed in this report, and to estimate the employment impacts of both the residential and commercial upgrades. Costs include labor, materials, permitting, and energy auditing services. Costs were averaged across all housing unit types and sizes. The actual costs for any particular upgrade or package of upgrades on an individual can vary greatly depending on existing conditions, variations in scope of work, the contractors performing the work, the specific materials/equipment used, etc.

Table C-1. Residential Measure Costs Used for Analysis

Upgrade	Measure	Average Estimated Cost		Unit of Cost	Measure Lifespan*
		Single Family	Multifamily		
Envelope	Attic insulation (less than R-13)	$4.60	$4.60	Square foot	30
	Attic insulation (R-13-R-30)	$2.30	$2.30	Square foot	30
	Air Sealing	$1.80	$1.80	Square foot	20
	Wall Insulation	$4.50	$4.50	Square foot	30
	Foundation Insulation	$3.50	$3.50	Square foot	30
	Duct Sealing	$800	$400	Unit	20
Electrification – Lower Efficiency	Air Source Heat Pump	$9,036	$7,550	Unit	15
	Heat Pump Hot Water Heater	$4,900	$4,900	Unit	15
	Cooking Range	$1,198	$1,198	Unit	15
	Clothes Dryer	$1,255	$1,255	Unit	15
Electrification – Higher Efficiency	Air Source Heat Pump	$22,315	$12,200	Unit	15
	Heat Pump Hot Water Heater	$6,625	$8,350	Unit	15
	Cooking Range	$1,652	$1,652	Unit	15
	Clothes Dryer	$1,628	$1,628	Unit	15
Electric Service Panel Upgrade		$5,935		Unit	30
Electrification – Gas Equivalent	Gas Furnace	$8,968	$4,780	Unit	15
	Gas Furnace + Central AC	$14,890	N/A	Unit	15
	Gas Tank Hot Water Heater	$2,347	$2,347	Unit	15
	Gas Cooking Range	$851	$851	Unit	15
	Gas Clothes Dryer	$1,813	$1,813	Unit	15

* NOTE: Many building envelope measures may last longer than the lifespan cited here. However, we chose to use the more conservative lifespans utilized by WAP for this analysis.

Table C-2. Maximum Potential Residential Rebates and Incentives Used for Analysis

Upgrade	Measure	BayREN Rebates (SF)	BayREN Rebates (MF)	IRA Rebates <80% AMI	IRA Rebates 80-150% AMI
Envelope	Insulation	$1,000	$500/unit	$1,600	$800
	Air Sealing	$150			
	Duct Sealing	$800			
Electrification	Air Source Heat Pump	$1,000	$1,000	$8,000	$4,000
	Heat Pump Hot Water Heater	$1,000	$1,000	$1,750	$875
	Cooking Range	$750	$750	$840	$420
	Clothes Dryer	$300	$250	$840	$420
Other	Health Burden Adder	N/A	$500/unit	N/A	N/A
Wiring/Electric Service Panel Upgrade		N/A	$5,000	$6,500	$3,250

Table C-3. Commercial Measure Costs Used for Analysis

Upgrade	Measure	Average Estimated Costs							Unit of Cost
		Education	Food Service	Health-care	Lodging	Mercantile	Office	Warehouse/Storage	
Envelope	Wall Insulation	$3.59	$3.45	$5.16	$4.41	$4.29	$3.59	$3.50	Square foot exterior wall/ roof area
	Roof Insulation	$4.87	$4.96	$5.68	$4.45	$4.45	$4.45	$4.16	
Electrification	Air Source Heat Pump - Boiler	$18.38	N/A	$21.45	$23.26	$17.33	$23.26	N/A	Square foot building floor area
	Air Source Heat Pump - Rooftop Unit	$12.30	$15.87	$8.92	$8.41	$10.15	$8.41	$8.64	

Appendix D. Example Household-scale Impacts of Residential Building Upgrades

The case studies on the following pages illustrate how the analysis results of residential building upgrades modeled in the aggregate for the entire city of Richmond might be experienced by different households. The examples provided in this Appendix are:

1. Single-family housing unit built in the 1950s.
2. Single-family housing unit built in the 1980s.
3. Single-family housing unit built in the 2000s.
4. Multifamily housing unit built in the 1960s.

These examples do not provide data from actual Richmond households. Each of these examples looks at one of the individual housing unit models from the ResStock system for Richmond, describing both baseline energy consumption and impacts on energy consumption and utility bills from the different modeled upgrades. This is not intended as a precise prediction of household-scale impacts, but instead illustrates how residential buildings of different type, size, and vintage have different energy consumption patterns that impact utility bills and how different upgrades would impact them.

Single-Family Housing Unit, Built in the 1950s

- Unit size: 1,220 square feet; 2 bedroom
- Occupants: 1
- Building details: Single story, no garage, crawl space foundation
- Natural gas-powered appliances: Furnace, water heater, cooking range
- Air conditioning: Window unit
- Insulation level: Uninsulated
- Electric service panel: 100 amps (needs upgrade)

Based on 2023 estimated utility rates, this household could expect to incur $3,950 per year in utility bill charges. Natural gas currently makes up 75% of this home's energy consumption and 43% of the annual utility bill charges. The highest consumers of energy for this household are currently space heating (62%), water heating (10%), and space cooling (10%).

Modeled Baseline Energy Consumption by End Use

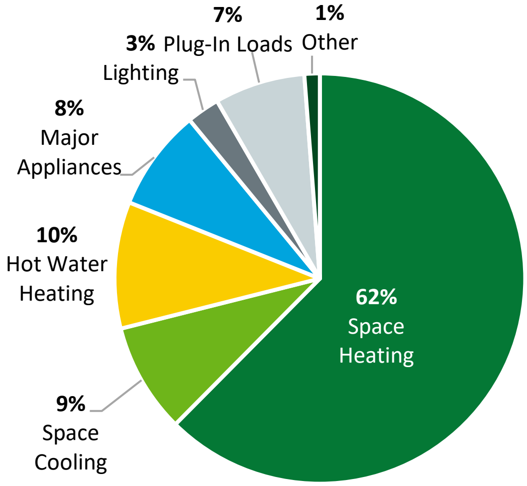

Table D-1. Potential Impact of Upgrades on Energy Consumption

	Electricity Consumption		Natural Gas Consumption		Total Consumption	
	kWh	% Change	kWh	% Change	kWh	% Change
Baseline	6,414	N/A	19,293	N/A	25,707	N/A
Envelope	5,899	-8.0%	8,315	-56.9%	14,214	-44.7%
Electrification – Lower Ef.	9,318	45.3%	0	-100%	9,318	-63.8%
Electrification – Higher Ef.	6,986	8.9%	0	-100%	6,986	-72.8%
Envelope + Electrification - Higher Ef.	5,749	-10.4%	0	-100%	5,749	-77.6%

Total energy consumption would decrease under every upgrade scenario for this household, with a 78% decrease for the Envelope + Electrification scenario. The biggest changes are the reductions in space heating and cooling, and water heating, which fall from 81% of the household's energy consumption to 26% under that scenario.

Table D-2. Potential Impact of Upgrades on Utility Bill (without rebates)

	Annual Utility Charges ($)	Utility Bill Savings ($)		Total Costs		Incremental Costs	
		Annual	Lifetime	$	SIR	$	SIR
Baseline	3,950	N/A	N/A	N/A	N/A	N/A	N/A
Envelope	2,800	1,150	34,515	20,452	1.7	20,452	1.7
Electrification – Lower Ef.	3,179	772	11,574	21,069	0.5	10,716	1.1
Electrification – Higher Ef.	2,196	1,754	26,312	36,528	0.7	26,175	1.0
Envelope + Electrification – Higher Ef.	1,807	2,143	37,978	56,979	0.7	46,626	0.8

Annual utility bills could be expected to decrease under every upgrade scenario for this household, including by 48% under the Envelope + Higher-Efficiency Electrification upgrade scenario. Looking at total costs, only envelope measures are cost-effective over the measure lifetimes. However, looking at incremental costs, both lower- and higher-efficiency electrification upgrades become cost-effective.

If BayREN incentives are added to this analysis, the upfront costs could be reduced by more than $5,000, improving the SIR of all upgrade scenarios.

Single-Family Housing Unit, Built in the 1980s

- Unit size: 1,690 square feet; 3 bedroom
- Occupants: 5
- Building details: Single story, garage, slab foundation
- Natural gas-powered appliances: Furnace, water heater, cooking range
- Air conditioning: Central AC, lower efficiency
- Insulation level: Medium (R-11 in walls, R-13 in attic, no foundation)
- Electric service panel: 200 amps (no upgrade needed)

Based on 2023 estimated utility rates, this household could expect to incur $6,587 per year in utility bill charges. Natural gas currently makes up 62% of this home's energy consumption and 29% of the annual utility bill charges. The highest consumers of energy for this household are currently water heating (32%) and space heating (26%).

Modeled Baseline Energy Consumption by End Use

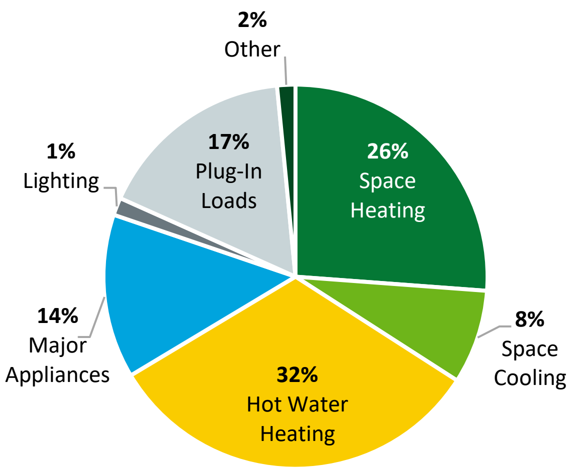

Table D-3. Potential Impact of Upgrades on Energy Consumption

	Electricity Consumption		Natural Gas Consumption		Total Consumption	
	kWh	% Change	kWh	% Change	kWh	% Change
Baseline	13,253	N/A	21,966	N/A	35,219	N/A
Envelope	12,816	-3.3%	17,293	-21.3%	30,109	-14.5%
Electrification – Lower Ef.	17,799	34.3%	0	-100%	17,799	-49.5%
Electrification – Higher Ef.	15,028	13.4%	0	-100%	15,028	-57.3%
Envelope + Electrification – Higher Ef.	14,329	8.1%	0	-100%	14,329	-59.3%

Total energy consumption would decrease under every upgrade scenario for this household, with a 59% decrease for the Envelope + Higher-Efficiency Electrification scenario. The biggest changes are the reductions in space heating and cooling, and water heating, which fall from 66% of the household's energy consumption to 29% under that scenario. In fact, in the Envelope + Electrification upgrade scenario, plug-in loads could account more energy consumption in this household than space heating, cooling and water heating combined.

Table D-4. Potential Impact of Upgrades on Utility Bill (without rebates)

	Annual Utility Charges ($)	Utility Bill Savings ($)		Total Costs		Incremental Costs	
		Annual	Lifetime	$	SIR	$	SIR
Baseline	6,587	N/A	N/A	N/A	N/A	N/A	N/A
Envelope	6,013	574	17,210	11,616	1.5	11,616	1.5
Electrification – Lower Ef.	6,072	515	7,726	21,069	0.3	4,794	1.6
Electrification – Higher Ef.	4,724	1,863	27,939	36,528	0.8	20,253	1.4
Envelope + Electrification – Higher Ef.	4,504	2,082	34,531	48,144	0.7	31,869	1.1

Annual utility bills could be expected to decrease under every upgrade scenario for this household. Looking at total costs, only envelope measures are cost-effective over the measure lifetimes, though higher-efficiency electrification comes close. However, looking at incremental costs, all upgrades become cost-effective. This is in part because the home has central AC, so incremental costs take into account the cost of replacing both a natural gas furnace and AC unit with a heat pump, which can do both.

If BayREN incentives are added to this analysis, the upfront costs could be reduced by more than $5,000, improving the SIR of all upgrade scenarios.

Single-Family Housing Unit, Built in the 2000s

- Unit size: 2,176 square feet; 4 bedroom
- Occupants: 2
- Building details: Single story, garage, slab foundation
- Natural gas-powered appliances: Furnace, water heater, cooking range, clothes dryer
- Air conditioning: Central AC, higher efficiency
- Insulation level: High (R-19 in walls, R-30 in attic, R-5 under slab)
- Electric Service Panel: 100 amps (upgrade needed)

Based on 2023 estimated utility rates, this household could expect to incur $3,696 per year in utility bill charges. Natural gas currently makes up 43% of this home's energy consumption and 16% of the annual utility bill charges. The highest consumers of energy for this household are currently space heating (32%), water heating (24%), and major appliances (17%).

Modeled Baseline Energy Consumption by End Use

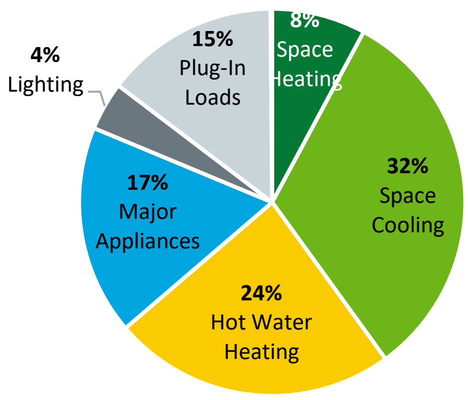

Table D-5. Potential Impact of Upgrades on Energy Consumption

	Electricity Consumption		Natural Gas Consumption		Total Consumption	
	kWh	% Change	kWh	% Change	kWh	% Change
Baseline	8,872	N/A	6,599	N/A	15,471	N/A
Envelope	8,351	-6.0	6,283	-4.8%	14,633	-5.4%
Electrification – Lower Ef.	9,911	11.7%	0	-100%	9,911	-35.9%
Electrification – Higher Ef.	8,091	-8.9	0	-100%	8,091	-47.7%
Envelope + Electrification - Higher Ef.	7,785	-12.3%	0	-100%	7,785	-49.7%

Total energy consumption would decrease under every upgrade scenario for this household, with a 50% decrease for the Envelope + Higher-Efficiency Electrification scenario. The biggest changes are the reductions in space heating and cooling, and water heating, which fall from 64% of the household's energy consumption to 41% under that scenario.

Table D-6. Potential Impact of Upgrades on Utility Bill (without rebates)

	Annual Utility Charges ($)	Utility Bill Savings ($)		Total Costs		Incremental Costs	
		Annual	Lifetime	$	SIR	$	SIR
Baseline	3,696	N/A	N/A	N/A	N/A	N/A	N/A
Envelope	3,469	227	6,803	5,805	1.2	5,805	1.2
Electrification – Lower Ef.	3,381	315	4,725	15,134	0.3	-1,141	4.1
Electrification – Higher Ef.	2,543	1,153	17,287	32,221	0.5	14,318	1.2
Envelope + Electrification - Higher Ef.	2,447	1,249	20,173	38,025	0.5	20,122	1.0

Annual utility bills could be expected to decrease under every upgrade scenario for this household. Looking at total costs, only envelope measures are cost-effective over the measure lifetimes. However, looking at incremental costs, all upgrades become cost-effective. This is in part because the home has central AC, so incremental costs take into account the cost of replacing both a natural gas furnace and AC unit with a heat pump, which can provide both heating and cooling. In the case of lower-efficiency electrification, the incremental cost could actually be negative, meaning that a lower-efficiency heat pump might cost less than the combined cost to replace both a furnace and central AC.

Multifamily Housing Unit, Built in the 1960s

- Unit size: 1,138 square feet; 2 bedroom
- Occupants: 2
- Building details: 4-story building with 67 units
- Natural gas-powered appliances: Furnace, water heater, cooking range
- Air conditioning: None
- Insulation level: Low (R-19 in attic)
- Electric service panel: (upgrade needed)

Based on 2023 estimated utility rates, this household could expect to incur $1,776 per year in utility bill charges (however, renters may not be responsible for paying this full amount). Natural gas currently makes up 56% of this home's energy consumption and 24% of the annual utility bill charges. The highest consumers of energy for this household are currently water heating (33%), lighting (18%), and plug-in loads (18%).

Modeled Baseline Energy Consumption by End Use

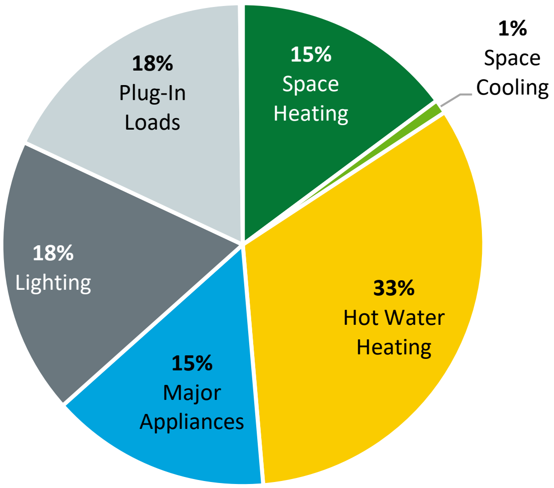

Table D-7. Potential Impact of Upgrades on Energy Consumption

	Electricity Consumption		Natural Gas Consumption		Total Consumption	
	kWh	% Change	kWh	% Change	kWh	% Change
Baseline	3,830	N/A	4,903	N/A	8,733	N/A
Envelope	3,790	-1.0%	3,655	-25.5%	7,445	-14.8%
Electrification – Lower Ef.	6,309	64.7%	0	-100%	6,309	-27.8%
Electrification – Higher Ef.	5,519	44.1%	0	-100%	5,519	-36.8%
Envelope + Electrification - Higher Ef.	5,367	40.1%	0	-100%	5,367	-38.5%

Total energy consumption would decrease under every upgrade scenario for this household, with a 39% decrease for the Envelope + Higher-Efficiency Electrification scenario. The biggest changes under this scenario are the reductions in space and water heating. However, energy consumption for cooling actually increases, since the unit currently has no cooling but would be expected to use a heat pump for cooling under any of the electrification upgrade scenarios.

Table D-8. Potential Impact of Upgrades on Utility Bill (without rebates)

	Annual Utility Charges ($)	Utility Bill Savings ($)		Total Costs		Incremental Costs	
		Annual	Lifetime	$	SIR	$	SIR
Baseline	1,776	N/A	N/A	N/A	N/A	N/A	N/A
Envelope	1,652	124	3,717	3,754	1.0	3,754	1.0
Electrification – Lower Ef.	2,215	-439	-6,582	14,903	0	5,108	0
Electrification – Higher Ef.	1,938	-162	-2,422	23,003	0	13,208	0
Envelope + Electrification - Higher Ef.	1,884	-108	-821	26,757	0	16,962	0

Annual utility bills could be expected to *increase* under every upgrade scenario except for envelope upgrades, in part because the household is expected to spend energy on space cooling with the electrification upgrades, but was not before. Looking at both total and incremental costs, only envelope measures are cost-effective over the measure lifetimes. We have listed the SIRs for all electrification measures as 0, since there is no anticipated bill savings, only increases.

An important consideration here is that since the only bill savings here is in natural gas, it is likely that this savings would not be passed along to residents considering that most renter households in Richmond living in large multifamily buildings do not pay for their natural gas consumption.

For more information about Communities LEAP, visit:
energy.gov/communitiesLEAP

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