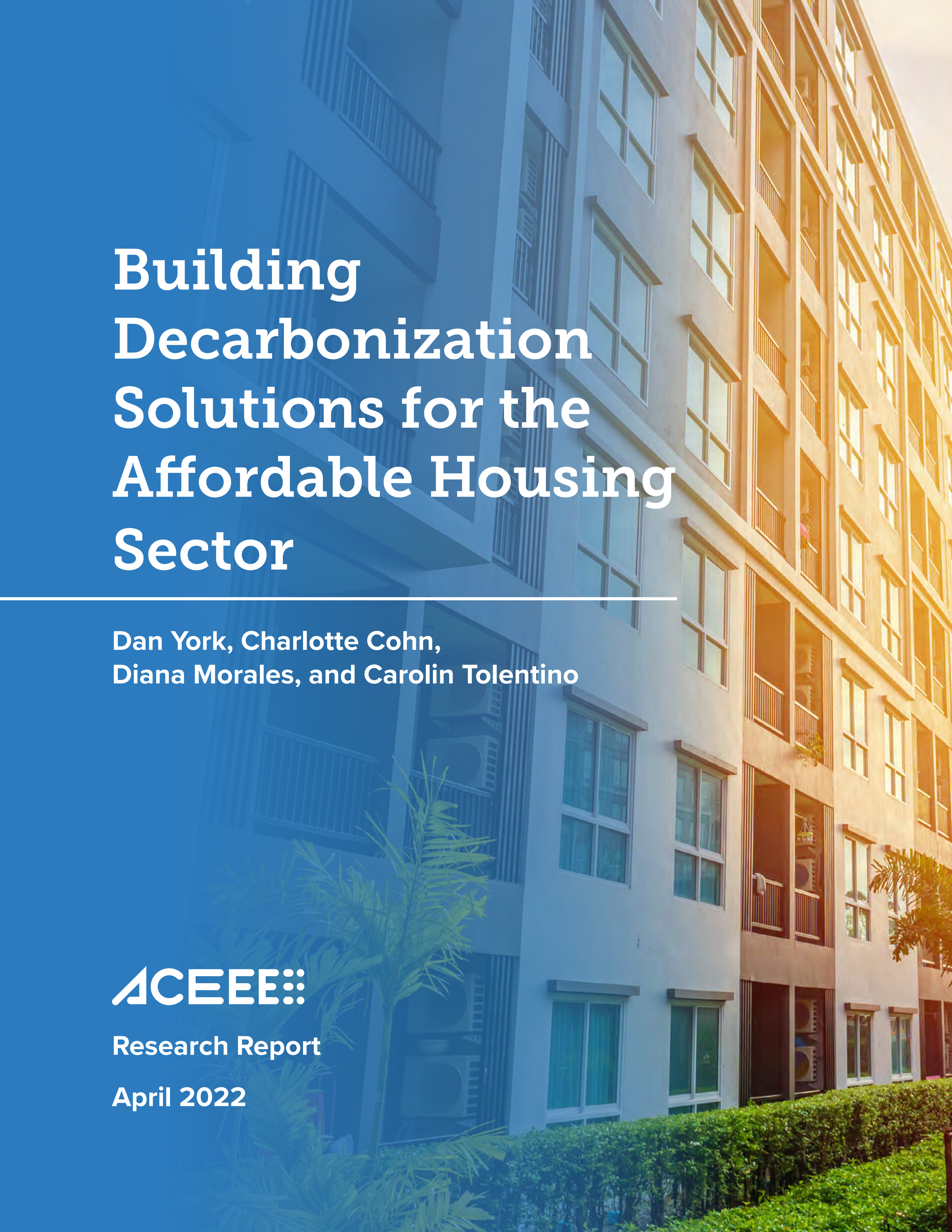

Building Decarbonization Solutions for the Affordable Housing Sector

Dan York, Charlotte Cohn,
Diana Morales, and Carolin Tolentino

ACEEE

Research Report

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Contents

About ACEEE

The American Council for an Energy-Efficient Economy (ACEEE), a nonprofit research organization, develops policies to reduce energy waste and combat climate change. Its independent analysis advances investments, programs, and behaviors that use energy more effectively and help build an equitable clean energy future.

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Executive Summary

KEY FINDINGS

- Decarbonization for affordable housing should generally emphasize two key interrelated components: (1) energy efficiency of the building shell, equipment, and systems; and (2) conversion from fossil fuel use through electrification.
- The affordable housing community has much to gain from building decarbonization. Benefits include reduced energy burdens; improved health, safety, and resilience; and reduced GHG emissions.
- Efforts to achieve decarbonization of affordable housing are at early stages of development and implementation. We found relatively few examples of such projects or programs. Those we identify tend to be single demonstration projects or pilot programs, not full-scale programs serving large customer populations.
- Decarbonization initiatives should take advantage of multiple offerings (city, state, federal, utility incentives, financing) to leverage and layer available resources. Collaboration among the many affordable housing stakeholders is also critical to leverage organizational knowledge, relationships, skills, and experience.
- Current barriers to adoption stem from the complexities of replacing existing fossil fuel technologies with decarbonized technologies. There may be additional costs to existing building systems to install replacement electric technologies. Building systems and appliances also may be in poor condition, requiring upgrades such as electrical wiring and service panels, which can greatly increase total project costs.
- Other barriers include (1) lack of familiarity with electrification technologies among both customers and suppliers; (2) uncertainty and variability of monthly energy cost savings from electrification, particularly heat pumps for space heating, due to differences in climate, electricity rates, fuel costs, and equipment efficiency (particularly for replacing existing fossil fuel technologies with heat pumps in cold climates); and (3) existing rules and regulations governing affordable housing that may hinder or prevent electrification, especially in multifamily housing.
- Despite the challenges of retrofitting for decarbonization, doing so will be necessary to meet climate targets and ensure that the benefits of decarbonization are shared by all customers, including the affordable housing community.

Decarbonization has rapidly emerged as a key means to address climate change. At least 50 utilities in the United States have established goals to achieve large reductions of carbon emissions—some going as far as carbon free or net zero. Cities, other local governments, and states have similarly set high carbon reduction goals as part of their climate change policies. In this report we examine the opportunities and challenges of decarbonization in the affordable housing sector.

While reducing carbon overall is the primary objective of such policies and utility plans, achieving such reductions equitably is a priority for many policymakers, utilities, other program administrators, regulators, and stakeholders. This means that plans must include programs that adequately serve the affordable housing sector and its needs. Achieving energy equity goals requires creating opportunities for underserved and under-resourced communities to contribute to and benefit from the many positive changes involved in reaching carbon reduction targets. Meeting these targets typically involves electrification of existing fossil fuel end uses (primarily water and space heating), improving energy efficiency of buildings, and rooftop or community solar generation. In cold regions, carbon-neutral fuels (e.g., biogas and "green" hydrogen) might also play a role.

Reducing energy use and costs in affordable multifamily housing not only helps reduce emissions but also alleviates energy burdens for renters and creates opportunities for owners and property managers to use the savings for upgrades or maintenance work needed to preserve affordable housing. Bringing energy equity and decarbonization goals into utility customer programs or building projects is relatively new. If affordable households are left behind in the process of building decarbonization, the consequences for customers and residents in those buildings could be significant and long-lasting.

Improved energy efficiency must be an essential component of any overall effort to reduce carbon emissions because of its multifaceted benefits and relatively lower up-front costs. These benefits have been valued and verified to varying degrees in cost-benefit analysis and cost-effectiveness screening of energy efficiency measures.

Improving energy efficiency and electrifying housing are intertwined strategies for decarbonization. Electrification retrofits, particularly in cold climates, must crucially include building shell efficiency upgrades to improve resident comfort, reduce electrification installation and operating costs for customers, and minimize potential additional electric system supply costs, such as upgrades to utility distribution systems due to increased loads. For new construction, both efficiency and electrification can easily be implemented at comparable costs to constructing new buildings with fossil fuel technologies. Cost savings can even result in some cases by avoiding the need to install gas service in new buildings or extend natural gas service lines.

In contrast to all-electric new construction, electrification retrofits have unique challenges and considerations. Costs for electrification retrofits can be high. Many existing homes will require upgrades to electric service panels, which add to the costs of purchasing and installing electric technologies such as air-source heat pumps for space heating and cooling. Decarbonization and electrification are not completely interchangeable in the context of building retrofits. Decarbonization generally involves electrification, but the carbon emission impacts of electrification depend on the type and efficiency of the retrofit technologies and the fuel mix of electric generation.

The high up-front costs of electrification can particularly deter affordable housing owners, including low-income homeowners and multifamily property owners. Such stakeholders typically lack the means to invest in electrification technologies; they might have other priorities for any available investment dollars. Thus, investing in electrification technologies generally requires significant aid to affordable housing owners, whether single family or multifamily. Additional barriers to electrification include uncertainty and variability of monthly energy cost savings from electrification, particularly heat pumps for space heating, due to differences in climate, electricity rates, fuel costs, and equipment efficiency (particularly for replacing existing fossil fuel technologies with heat pumps in cold climates). Affordable multifamily property owners who receive federal or state subsidies may also face disincentives for installing efficient electric technologies due to the way utility allowances are set. In some cases, such retrofits could result in the utility allowances rising and the rent owners are able to charge decreasing.

Our review of decarbonization policies and programs targeting affordable housing reveals common keys to success. These include

- Setting specific carbon reduction goals
- Securing adequate funding and financing
- Establishing collaborations among affordable housing stakeholders
- Engaging with affordable housing residents
- Educating residents, building owners, contractors, and suppliers

Of these, securing adequate funding and financing is perhaps the biggest hurdle and most vital, particularly for retrofitting buildings. Affordable housing providers generally cannot substantially upgrade without financial and technical assistance. Many have limited staff and access to capital. Even where capital is available, the cost of financing needs to be low in order to maintain affordability.

A push for more coordination and flexibility in taking advantage of and combining different programs and incentives is necessary for addressing housing affordability and decarbonization at the same time. Policies and programs aimed at decarbonizing affordable housing should be created with collaboration from the communities they will serve: Programs that engage and involve residents in creating and implementing programs can best address their needs, interests, and abilities. The many organizations and stakeholders involved in affordable housing should be partners and collaborators, including local governments, developers, financiers, utilities, community-based organizations, environmental justice organizations, affordable housing providers, and residents. It is important to avoid structural silos in both development and implementation.

Of all income groups, affordable housing communities have the most to gain from decarbonization's health benefits and energy savings. Moreover, they cannot afford to be among the last to electrify, or they are likely to experience a disproportionate future financial burden maintaining stranded fossil fuel infrastructure—this will inevitably occur if we depend on the market alone.

Decarbonizing affordable housing is challenging. It will require some new approaches but can draw upon a strong legacy of policies, programs, and projects that address energy equity and sustainability through energy efficiency and other distributed energy resources, such as onsite renewable energy systems. These emerging approaches for the clean energy transformation underway can also be equitable, reaching all households, regardless of income or race.

Key Concepts and Definitions

Decarbonization

Decarbonization means reducing carbon emissions from buildings through energy efficiency, electrification, distributed generation, and/or burning of carbon-free fuels. While the primary purpose of decarbonization is a reduction in greenhouse gas emissions, additional benefits to property owners and residents may include improved indoor air quality, reduced utility bills, and greater ease of maintenance. See the text box at the end of this section for a brief summary of the context for building decarbonization.

Electrification

Electrification involves replacing fossil-fueled end uses, such as heating, cooking, and transportation, with electric-powered technologies. When combined with energy efficiency to reduce total building energy costs and carbon emissions, it is often considered *beneficial* or *strategic* electrification. Because electricity can be generated from 100% carbon-free power sources, energy efficiency measures combined with all-electric appliances and distributed generation can dramatically reduce greenhouse gas emissions to levels approaching net zero.

Affordable Housing

Affordable housing can come in a variety of forms, including single family or multifamily, subsidized or unsubsidized, public housing, and rental or owner-occupied. Though the definition can vary by jurisdiction, the U.S. Department of Housing and Urban Development (HUD) defines affordable housing as "housing in which the occupant is paying no more than 30% of gross income for housing costs, including utilities." Because utility costs, particularly energy costs, impact housing affordability, energy efficiency and home energy upgrades are critical to keep housing affordable.

Energy Burden

ACEEE defines energy burdens as the percentage of household income spent on home energy bills (Drehobl, Ross, and Ayala 2020). The average U.S. household spends 3.1% of annual income on home energy bills. Households that spend 6% or more of annual income are considered energy burdened, while households that spend more than 10% are considered severely burdened. High energy burdens are more likely to impact low-income households, where the median spend is 8.1% of annual income. High energy burdens are also more likely to impact Black, Hispanic, and Native American households, as well as renters, older adults, and residents of manufactured housing.

Energy Equity

Although energy equity has more than one definition, in this report energy equity is intended to acknowledge the historic disinvestment and systemic harm targeting communities of color, seen today in high energy burdens, high rates of health issues linked to pollution, low-quality housing, and more. A transition to a more just energy system requires righting these historic harms. Committing to equity in energy efficiency and clean energy programs, policies, and investments can improve and expand clean energy services and technologies for marginalized groups while creating more just processes, outcomes, and systems. Visit our website to learn more about ACEEE's energy equity research and initiatives.

Low and Moderate Income (LMI)

A broad term, LMI refers to household income levels used to determine eligibility for certain incentives and utility, state, and/or federal assistance programs. Eligibility may vary based on jurisdiction and program design. LMI may relate to a certain percentage of the Federal Poverty Level (FPL) or the Area Median Income (AMI). Certain programs may use other terms or criteria beyond household income to qualify participants, such as disadvantaged communities (DACs) in California or environmental justice (EJ) communities, which are disproportionately burdened with health impacts related to burning fossil fuels.

Split Incentive

The "split incentive" refers to a frequent problem in delivering electrification, efficiency, and other programs and benefits to rental housing units. In rental homes where the resident pays their own utility bill, the property owner or manager has little to no financial incentive to invest in energy efficiency, electrification, and other home energy upgrades. If renters do *not* pay their own energy costs, they have little incentive to reduce their energy use. Renters also may lack control over their home energy systems, particularly space and hot-water heating, which together account for 62% of total residential energy consumption in the United States (EIA 2018). Programs targeting the rental housing sector for home energy upgrades need to work with both parties to address this tension.

Electrification Technologies

Below are basic definitions of primary electrification technologies for residential applications. Appendix B provides expanded definitions and explanations of these technologies.

Heat Pump

A heat pump is a technology used for both heating and cooling—most often with electricity, though some natural gas heat pumps exist. In this report, we focus on electric heat pumps. Rather than generating heat through electric resistance, heat pumps transfer it from one place to another, much like refrigerators and air conditioners do. This method is much more efficient than resistance-based electric heating systems or combustion-based fossil fuel heating systems. Heat pumps employ a vapor-compression refrigerant cycle that uses an outdoor compressor and an indoor heat exchanger, as well as refrigerant lines that run between the two. A refrigerant is a mixture that easily absorbs heat due to its very low boiling point; its function is to cycle through the recirculation loop, collecting and releasing heat from one point to another. Heat pumps for space heating come in many varieties, including ducted and ductless, air-source and ground-source.

Heat Pump Water Heater (HPWH)

A type of air-to-water heat pump, HPWHs heat water instead of indoor space. Although not yet common, *desuperheaters* combine space heating and water heating systems—this small auxiliary heat exchange unit uses residual heat from the heat pump's cooling cycle to heat water in a tank. This creates additional efficiency in the system by recovering energy that would otherwise be wasted.

Induction stoves

These cooktops produce heat through a process called electromagnetic induction. A high-frequency alternating current flows through a coil under the cooktop surface, creating a magnetic field. Contact with ferrous (i.e., magnetic) cookware creates an eddy current, generating heat directly inside the pan. These cooking systems heat up more rapidly than conventional electric resistance cooktops and cool off more quickly. Because the cookware rather than the stove top gets hot, they are generally safer than conventional stoves. However, they may require specialized cookware.

Introduction and Background

Decarbonization of our energy systems has rapidly emerged as a central goal to address the climate crisis. At least 50 utilities in the United States have established goals to achieve large carbon emission reductions—some going as far as carbon free or net zero. Cities, other local governments, and states have similarly set high carbon reduction goals as part of their climate policies and corresponding initiatives.

While reducing carbon overall is the primary objective of such plans, achieving such reductions equitably is a priority for many utilities, other program administrators, regulators, and stakeholders to ensure that the benefits of decarbonization are available to all customers. Prioritizing energy equity in tandem with decarbonization objectives can also drive program dollars toward those most in need, reduce inequality and substandard housing, support economic development, and prevent future inequities. Decarbonization plans must include programs and initiatives that specifically target the affordable housing sector, so these households can contribute to and benefit from reducing carbon emissions. Such programs typically involve both energy efficiency and electrification of existing fossil fuel end uses (primarily water and space heating) and may also include rooftop or community solar generation. In cold regions there may also be a role for carbon-neutral fuels (e.g., biogas and hydrogen produced using electricity from zero-carbon, renewable resources such as wind or solar).

Housing affordability is one of America's most pressing challenges and evidence suggests that this issue will continue to worsen (Kingsley 2017). Decarbonizing affordable housing represents an opportunity to achieve energy equity and create inclusive environmentally sustainable building policies. Such efforts also can yield additional benefits for affordable housing residents, including improved health, safety, and resilience as well as reduced utility costs.

In this report we explore and analyze decarbonization programs serving affordable housing markets. The focus of our research is on program approaches that pair electrification and energy efficiency to reduce cost of living and carbon emissions. We also assess the opportunities and potential for greenhouse gas (GHG) reductions from electrification of affordable housing.[1] This report describes effective approaches and provides selected examples of programs and policies for decarbonizing affordable housing.

Equitable decarbonization melds two distinct goals: energy equity and decarbonization. The Center for Energy and Environment (CEE 2021b) defines equitable decarbonization as follows:

> *…[T]he just and equitable transition from the carbon-intensive energy services that our economy currently relies on (for transportation, heating, industrial processes, and more) to decarbonized technologies and fuels in planned, managed steps, so that the benefits and costs of that transition are equitably distributed across society. If successful, all groups—across class, race, geography, and gender—will have parity in outcomes and fully realize the economic and health benefits of this new energy system.*

[1] Decarbonized fuel options (renewable natural gas, biofuels, hydrogen, etc.) can reduce carbon emissions, but in most cases electrification is the primary approach, so we limit the scope of this report to electrification and energy efficiency.

Housing decarbonization strategies address end uses of energy within homes (e.g., cooking, space and water heating, cooling) and the generation resources (coal plants, natural gas plants, solar or wind energy) that supply electricity to our homes. Electrifying an existing fossil fuel use in a home, such as replacing a natural gas furnace with an electric heat pump, reduces carbon emissions, especially if the electricity is generated by low- or no-carbon resources (Nadel 2018). Parallel decarbonization efforts are underway to "green the grid"—replacing fossil fuel generation with no-carbon generation, such as solar and wind.

Reducing energy use through improved energy efficiency can also reduce carbon emissions. The relationship is very direct: Using less energy in our homes decreases the need for generation, much of which is currently from fossil fuels. Reduced carbon emissions constitute one of many non-energy benefits that have been valued to varying degrees in cost-benefit analysis and cost-effectiveness screening of energy efficiency measures. ACEEE research (York, Cohn, and Kushler 2020) on state evaluation practices found that 20 states report including carbon reductions in their evaluation of program cost effectiveness.

Combining energy efficiency and electrification is critical to achieve decarbonization. Energy-efficient building envelopes complement building electrification by reducing the needed capacity of HVAC equipment and possibly the associated electrical capacity. This reduces up-front costs and yields lower energy costs. The same principle of high energy efficiency applies to other energy uses in homes and is especially important for affordable housing.

Decarbonization and electrification are not completely interchangeable in the context of a retrofit. Electrification often is key to decarbonization, but the latter requires added considerations, specific retrofit methods, and a strong focus on energy efficiency to reduce a building's energy consumption, utility costs, and carbon emissions. Weatherization and other energy efficiency improvements are critical complements to electrification to reduce energy burdens and keep monthly energy costs affordable. Weatherization also reduces winter peak power demands; without it, electrification can significantly increase winter peaks in some regions, requiring additional generating capacity (Specian, Cohn, and York 2021). Another important consideration is that a decarbonization retrofit is only as successful as the electricity grid is clean. For instance, in Chicago electricity is currently largely generated from coal and is thus more carbon intensive ("dirtier") than natural gas (Billimoria et al. 2018). In such cases, electrification would increase—not reduce—the carbon associated with energy use in the short term. However, the transition to cleaner sources of energy like renewables and natural gas could still make this switch less carbon intensive in the long term. This illustrates the importance of decarbonizing generation in parallel with decarbonizing energy end uses, such as in our homes.

Energy efficiency and decarbonization programs and incentives are most often administered by electric and natural gas utilities or non-utility energy efficiency program implementers. Customer energy efficiency programs may include rebates for purchasing efficient equipment, home energy assessments, direct installation of selected measures, financing for home energy upgrades, incentives to homebuilders for highly efficient new construction, and other incentives and services. Such programs, whether administered by utilities or other organizations, are funded through utility rates and operate within regulatory and policy frameworks that vary among states.

RESEARCH OBJECTIVES

Electrification and broader decarbonization efforts are relatively recent policy and program developments, emerging over the past few years as a means to achieve carbon reduction goals. Our research captures the current landscape of decarbonization targeting affordable housing. Key objectives of our research are

- Identify and analyze opportunities and barriers for decarbonization in affordable housing, both single family and multifamily
- Assess the potential for carbon reductions in affordable housing
- Identify and provide examples of policies and programs

Our scope includes both single-family and multifamily affordable housing, and affordable housing that is both subsidized and naturally occurring. Our focus is primarily utility-led and local policies/programs that are newly established or already in place, particularly projects that have concrete results for reducing carbon and energy costs. We also include state-level initiatives and (briefly) federal leadership on decarbonization for affordable housing, as these are enabling and driving programs and implementation.

METHODOLOGY

We conducted a literature review, interviews with selected experts involved in decarbonization and affordable housing, and a review of selected program data. We had additional input from utility working groups that ACEEE leads for low-income and multifamily energy efficiency programs. We also drew upon public data and tools—for example, the U.S. Energy Information Administration's (EIA) 2015 Residential Energy Consumption Survey (RECS) (EIA 2015) and the U.S. Census Bureau's 2019 American Housing Survey (AHS)—for some of our analyses, such as characterizing the market and calculating the potential GHG reductions in the affordable housing sector that can be achieved through energy efficiency and electrification.

STRUCTURE OF THE REPORT

This report describes benefits, barriers, and strategies for decarbonizing buildings in the affordable housing sector. The preceding sections define key terms, research objectives, and methodology. The following section addresses the potential benefits from decarbonization in affordable housing: climate impacts, energy and cost savings, health and safety benefits, grid flexibility, reliability, and resilience. Following that, we discuss barriers to adoption of various specific electrification technologies, including heat pumps and induction stoves; broader barriers such as up-front and ongoing costs; and challenges associated with retrofits in existing buildings. We conclude that section by indicating several emerging technologies that can help address these barriers.

Following the discussion of benefits and barriers, we discuss policy and program approaches to deliver affordable housing decarbonization. We examine the role of multiple actors on the federal, state, utility, and local levels. For each actor, we discuss the role they can play and examine several case studies of affordable housing decarbonization programs. Finally, we conclude with our key findings and recommendations to advance decarbonization in the affordable housing sector.

Decarbonization in the Context of Building Energy Use

In the United States today, about 45% of residential onsite energy use is in the form of electricity, and most of the rest is in the form of fuels such as natural gas, propane, heating oil, and wood (EIA 2022). Electric power generation is steadily decarbonizing, including growing use of renewable energy and the retirement of many coal-fired generating plants. President Biden has set a goal as part of U.S. climate commitments to reach 100% carbon-free electricity by 2035 (White House 2021). Based on these plans for a clean electric grid, many analysts and policymakers have called for converting residential space heating, water heating, cooking, and clothes drying to electricity, using heat pump technology for most of these uses and induction stoves for cooking (e.g., CCST 2011; Heinrich 2021). Alternatively, we could continue to use fuels that are carbon neutral, meaning the carbon they emit is captured, such as by new biomass or carbon capture technologies. Examples of fuels that are *approximately* carbon neutral are methane generated from biomass and so-called "green" hydrogen, which is produced using carbon-free electricity.

Research by ACEEE and others finds that in warm and temperate climates, electric heat pumps can efficiently and cost effectively provide space and water heating and cooling (e.g., Nadel 2016, 2018). But in very cold climates, a backup source of heating may be needed, either electric resistance heat or some use of fuels. For example, field tests in Minnesota retrofitting heat pumps designed for cold climates onto existing propane-heated homes found that on average over 60% of space heat can be provided by the heat pumps, with backup fuels providing the rest (Shoenbauer, Kessler, and Kushler 2017).[2] In a follow-up study installing an even higher-efficiency cold-climate heat pump in a recently built duplex apartment located in Saint Paul, Minnesota, the heat pump provided over 98% of the wintertime heat, with an electric resistance booster heater providing the rest (CEE 2018). These findings are consistent with results from other cold-climate studies indicating that new homes can be built to use only electricity, but older homes may need a backup (Nadel 2018). Other studies, such as in British Columbia (BC), Canada, have found that it may be less expensive to use a hybrid approach, with some homes electrified and others combining energy efficiency upgrades, gas-fired heat pumps (a technology just reaching the market), and mainly carbon-neutral fuels (Guidehouse 2020). It should be noted that while natural gas is relatively inexpensive in the United States, biofuels and green hydrogen are significantly more expensive. For example, the BC study assumed that by 2050, 73% of the gas used in homes would be renewable, but at costs several times higher than present natural gas prices. Some gas companies are realizing that use of natural gas for space heating will decline. For example, the BC study discussed above, which was commissioned by a gas utility, included transitioning 25% of residential space and water heating to electricity (Guidehouse 2020).

Given this background, this paper focuses on electrification as a decarbonization strategy, since it appears appropriate for at least new construction and retrofits in warm and temperate climates. But readers should bear in mind that electrification may not be cost effective for all homes today, and there will likely also be a role for carbon-neutral fuels, particularly in very cold climates.

[2] This project did not include improvements to the building envelope, which would reduce the amount of backup heat needed (CEE 2021).

Benefits from Decarbonization of Affordable Housing

Decarbonization presents a wide range of potential benefits for building residents and society at large. The following section details some of the key advantages in delivering carbon-free technologies and carbon reductions through energy efficiency for affordable housing.

ENERGY SAVINGS AND GREENHOUSE GAS EMISSIONS REDUCTION

Because affordable housing constitutes a substantial share of total residential housing, decarbonization of affordable housing could yield significant carbon reductions. We estimated the potential energy and greenhouse gas (GHG) emissions reductions in affordable housing units (subsidized and unsubsidized) occupied by low- and moderate-income (LMI) households.

We primarily used data from the 2015 Residential Energy Consumption Survey (RECS) and the U.S. DOE's Low-Income Energy Affordability Data (LEAD) Tool. RECS contains energy usage information of sample households from different regions, income levels, family structures, and housing types. To form a sample of LMI households' energy use, we excluded most households that fell outside federal income guidelines.[3] We then calculated two savings scenarios: 30% energy efficiency improvements through a moderate decarbonization retrofit, and 50% efficiency improvements through a deep decarbonization retrofit.[4] Both scenarios assume full electrification. A deep retrofit would include full envelope (i.e., wall and attic insulation, air sealing, window replacements, etc.) and full equipment upgrades (i.e., heating, ventilation and air-conditioning (HVAC) and domestic hot water (DHW)). A moderate retrofit might pursue priority envelope improvements, such as attic insulation and air sealing, but exclude costly wall insulation and window replacements, and include an HVAC upgrade and DHW measures. We calculated energy and carbon emissions savings by housing type, and then used data from the LEAD tool to aggregate those savings to the 49 million LMI households[5] that comprise our sample. Refer to Appendix A for more details on our methodology.

Assuming a moderate retrofit scenario, decarbonizing LMI housing could lead to 2 quadrillion Btus in annual energy savings and 140 million metric tons in annual avoided CO_2 emissions. A more ambitious, deep retrofit would reduce annual energy use by 2.4 quadrillion Btus and annual CO_2 emissions by 177 million metric tons . This is equivalent to avoiding the CO_2 emissions from 17 million to 21 million American homes in one year, respectively. Figures 1 and 2 show a breakdown of total and average yearly energy savings by housing type.

In a scenario where the remaining electricity is generated from carbon-free sources, the carbon reduction potential in affordable housing is an estimated 268 million metric tons a year, accumulating to at least 2.7 billion metric tons over the course of 10 years. While this assumes a 100% carbon reduction and does not account for population growth, this ballpark estimate nevertheless depicts the magnitude of GHG emissions reduction potential.

[3] The available dataset from RECS does not provide exact household income, but rather income ranges in increments of $20,000. This makes it difficult to get a fully accurate sample of low-income households. Nevertheless, excluding certain ranges based on household size gave us the closest approximation possible using the available parameters. See Appendix A for more details.

[4] These estimates come from energy modeling done by ACEEE and coincide with actual energy reductions from case studies presented in a Stopwaste report, *Accelerating Electrification in Multifamily Buildings* (2019).

[5] We define low- and moderate-income households as those earning a total annual income at or below 80% of the Area Median Income (AMI). The authors recognize that some advocates, programs, and policymakers use up to 120% of AMI to indicate the people that affordable housing should be able to serve.

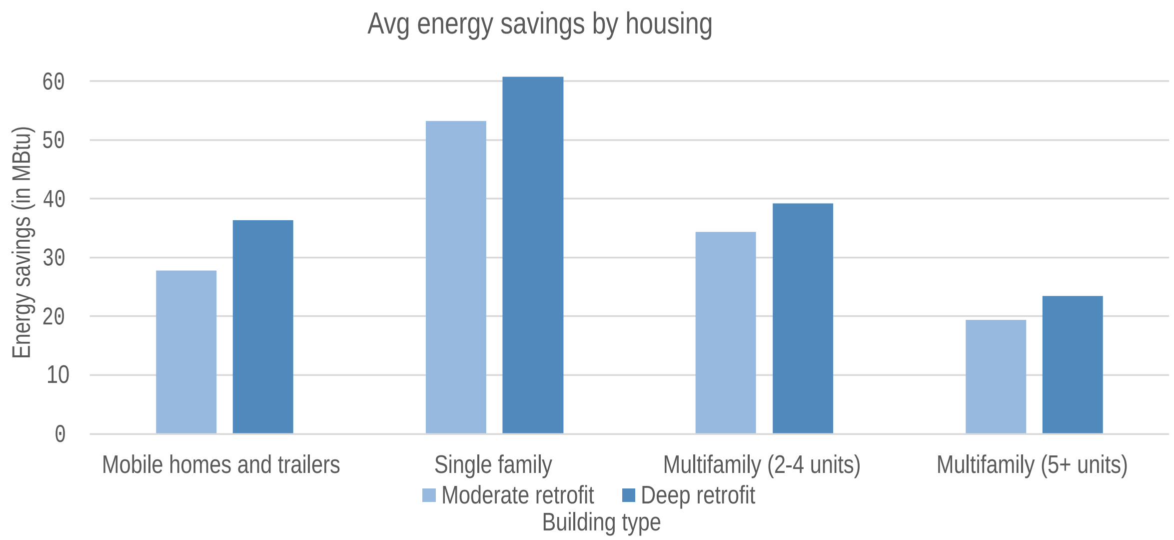

Figure 1. Average annual energy savings per home from the moderate and deep retrofit packages, in million Btus

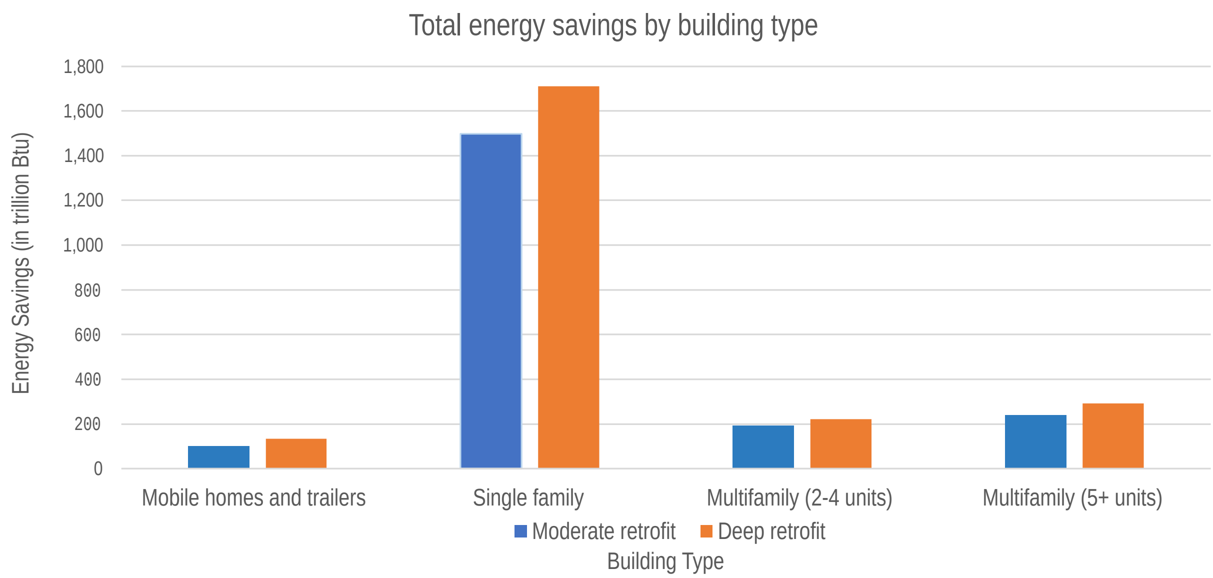

Figure 2. Total annual energy savings across building sectors from the moderate and deep retrofit packages, in trillion Btus

ENERGY COST SAVINGS

Reducing energy use and costs in affordable housing from improved energy efficiency has several benefits in addition to reducing emissions. For homeowners and renters, it helps reduce energy burdens (Drehobl and Ross 2016). For property owners and building managers, it creates opportunities to use the resulting savings for upgrades or maintenance work needed to preserve affordable housing (Schaaf, Wongbuphanimitr, and Ponsor 2021). According to the 2021 climate initiative from the Department of Housing and Urban Development (HUD), energy and water utility expenditures for HUD-assisted properties account for approximately 14% of the agency's total budget and emit an estimated 13.6 million metric tons of carbon (HUD 2021a). To capitalize on the savings opportunities and GHG reductions, the affordable housing sector has already started investing in energy efficiency upgrades and renewable energy, and many cities are actively considering the development of programs specifically geared toward achieving decarbonization of their affordable housing stocks.

Because heat pumps are more efficient per unit of fuel than both electric resistance and fossil-based heating systems, efficient electrification can sometimes yield energy cost savings for customers, although this depends on factors such as climate, the existing technologies being displaced, and local fuel and electricity costs. Complementary energy efficiency and the inclusion of distributed energy generation (e.g., solar) may further reduce household energy costs. A direct and linear reduction in utility bills occurs when switching from electric resistance heating to the much more efficient air-source heat pump (ASHP). Oil is priced roughly the same as electricity (on a Btu basis), making the switch from oil-fueled space heating often cost effective as well (EIA 2021). However, the difference compared to natural gas depends on the region's utility rates and the ASHP's efficiency.

Similar cost considerations apply to heat pump water heaters compared to electric resistance, oil, and natural gas water heaters. Alstone et al. (2021) estimate that, with the energy prices at the time of their report and the average HPWH efficiency, 78% of residential (single-family and multifamily) customers would achieve savings by converting their existing fossil- or electric resistance-based water heating systems to heat pump water heaters. Roughly 80% of low-income households (compared to 70–76% of higher-income groups) would save on utility bills with a coefficient of performance (COP) of 3.0 (Alstone et al. 2021).[6] This is well within the range of heat pumps currently in the market—in fact, the Energy Star COP requirement for HPWHs is over 3. This forecast may be even more promising as of early 2022, given higher and more volatile natural gas prices.

HEALTH AND SAFETY BENEFITS

The condition of our indoor environment, including temperature and air quality, has a significant impact on our health and well-being. Because of decades of systemic inequality (disproportionately affecting Black and Hispanic households), rising housing costs, and gentrification pricing residents out of some urban areas, low-income residents tend to live in older, poorer quality homes with a higher incidence of environmental harms (Tan and Jung

[6] A heat pump's COP is dependent on operating conditions such as outdoor temperature. COP is usually tested at 47°F or 17°F. As the cited report does not specify, our assumption is a testing temperature of 47°F.

2021). Poor insulation, exposure to air pollution, and insufficient heating or air-conditioning can increase residents' susceptibility to a variety of illnesses (asthma, hyper- and hypothermia, trips and falls for seniors, etc.). For instance, emissions from gas stoves can lead to serious respiratory conditions, especially in children—who are 32% more likely to have both current and lifetime asthma if they live in a home with gas cooking (Lin, Brunekreef, and Gehring 2013). This is in addition to the well-known danger of carbon monoxide poisoning, which causes 430 deaths and 50,000 emergency room visits in the United States every year (CDC 2022; EPA 2009). In addition to environmental impacts, chronic discomfort can contribute to poor mental health, including stress, depression, and anxiety (IEA 2019).

Energy efficiency, weatherization, and electrification are all logical interventions to address these adverse health impacts. By improving the built environment and removing localized sources of harmful air emissions such as fossil fuel–based stoves, furnaces, water heaters, and boilers, decarbonization can improve resident health and well-being and reduce the risk of premature death due to environmental air quality issues (Tan and Jung 2021).

The health benefits from building decarbonization are particularly important for low-income residents. In projecting the impacts of its climate action plan, the New York City (Tan and Jung 2021) found that electrifying its large buildings would reduce asthma emergency visits in low-income neighborhoods 10 times more than in wealthier neighborhoods. These findings are consistent with those of a medical study showing that these communities have disproportionate prevalence of childhood asthma compared to wealthier NYC communities (Tan and Jung 2021). As more evidence emerges showing the detrimental health impacts of substandard housing and of heating and cooking with fossil fuels, some energy programs are working to acquire funding from nontraditional sources, such as those supporting public health.[7] These additions can help programs overcome cost barriers to more comprehensive retrofits and reach more households.

Beyond improving the conditions of the indoor environment, displacing flammable fossil fuels in homes improves safety by preventing catastrophic accidents such as explosions caused by gas leaks. Though uncommon, these disasters can cause extensive property damage, injury, or death—and disproportionately affect residents of older buildings with poorly maintained infrastructure (Gutman 2018). Methane (the primary component of natural gas) is a potent greenhouse gas with a heat-trapping factor more than 84 times higher than carbon dioxide, and these leaks are systematically underreported, especially in older buildings (Marchese and Zimmerle 2018; Billimoria et al. 2018). This makes replacing and decommissioning gas infrastructure in older buildings a necessary strategy to address climate change and to protect public health.

Another health benefit of electrifying space heating is that air-source heat pumps provide cooling capacity in units without existing air-conditioning. As climate change contributes to increasing temperatures worldwide, prolonged heat waves can have deadly consequences for people living in homes without access to space cooling. In a recent example, the unprecedented heat wave that affected the Pacific Northwest in 2021 caused more than 3,000 heat-related emergency room visits and over 100 confirmed deaths from hyperthermia in Washington and Oregon (Popovich and Choi-Schagrin 2021). Expanded access to space cooling will be vital to avoid these needless deaths in future extreme weather scenarios.

[7] For more information and examples, see ACEEE's 2020 report: *Braiding Energy and Health Funding for In-Home Programs: Federal Funding Opportunities*. www.aceee.org/research-report/h2002.

Finally, electrification often sparks discussion about electric power outages, which—particularly during extreme weather events—can carry life-threatening risks. However, most fossil-fueled heating systems also require electrical components to function, such as fans for circulation in natural gas HVAC systems. Therefore, in the case of an outage, fossil fuel heating and hot-water systems have little advantage over electric systems. A fully decarbonized reliability solution is possible through technologies such as battery storage or passive home heating and cooling. The following section describes approaches to manage reliability risks during extreme weather events and how they pertain to low-income customers and affordable housing residents.

RELIABILITY AND RESILIENCE

Decarbonization, particularly in the form of weatherization and energy efficiency, can produce additional life-saving benefits by improving grid reliability and resilience. As climate change leads to an increase in extreme weather phenomena such as droughts, flooding, wildfires, severe storms, and other natural disasters, the consequences and costs of these crises are borne disproportionately by marginalized communities. Some examples of these natural disasters in recent years are the 2021 Winter Storm Uri in Texas and the 2021 heat wave in the Pacific Northwest, both of which resulted in exposure to extreme temperatures and loss of life. Weatherization and energy efficiency could have mitigated this impact. Energy efficiency upgrades are particularly important alongside electrification, as pursuing the latter without energy efficiency could increase the demand on the power grid. When outages do occur, homes that are weatherized and well insulated offer better protection and will sustain livable indoor temperatures for much longer than poorly insulated buildings. Since much affordable housing is not properly weatherized and insulated, such residents are particularly vulnerable when extreme weather events occur.

Various strategies can and should be implemented to enhance grid reliability and resilience for all types of customers, including those living in affordable housing. Energy efficiency is a crucial measure. Reduced energy consumption means less strain and a lower failure risk for the grid, especially at times of peak demand (Nadel, Gerbode, and Amann 2021; Specian, Cohn, and York 2021). In cold climates, backup fuel heating can moderate the growth of peak electricity demand, which can also help avoid strain on the grid; energy efficiency is important in minimizing our reliance on this strategy. Another key grid management strategy, demand response, can be facilitated by grid-interactive technology and device controls, such as smart thermostats, preheating and cooling, battery storage, electric vehicles, and more. For instance, heat pumps with smart controls and variable speed motors can respond to grid signals and reduce their energy use during peak times. Flexible demand can also support renewable energy growth by better utilizing intermittent resources like solar and wind, help to balance the grid by shifting load away from peak demand hours, and can maximize GHG reductions.

COST SAVINGS FOR AFFORDABLE NEW CONSTRUCTION

Electrification and high energy efficiency can yield large cost savings for new construction. It is generally less cost-prohibitive to incorporate electrification technologies and energy efficiency from the early planning stages of new construction projects. Building all-electric generally saves developers project time and thousands in avoided gas infrastructure costs. These savings are helping electric new construction gain traction. Multifamily developers in California save an average of $3,300 per unit, or more than $20,000 for an eight-unit property (Armstrong et al. 2019). The savings trickle down to homebuyers as well; single-family homeowners in California can save up to $30,800 in avoided gas-related infrastructure costs, and up to $800 annually on utility bills (Higbee et al. 2020; Armstrong et al. 2021).

In addition, installing electrification technologies in new construction is less cost-prohibitive than in retrofits, since no building upgrades are needed. Table 1 compares the typical costs of installing residential technologies in single-family new construction.

Table 1. Up-front costs of heating technologies in single-family new construction

End use	Equipment type(s)	Total fixed costs (equipment + installation)
Space heating	Oil + new AC	$6,700
	Gas + new AC	$7,573–8,345
	Propane + new AC	$7,573
	Electric resistance + new AC	$7,100
	Ducted heat pump	$4,752–5,770
	Ductless heat pump (1- and 2-zone)	$3,957–5,464
Water heating	Natural gas	$1,242–1,444
	Oil	$2,190
	Propane	$1,375
	Heat pump water heater	$1,759–2,003

Sources: Less, Walker, and Casquero-Modrego 2021; Drennen et al. 2021; Billimoria et al. 2018

To ensure long-term affordability, builders should prioritize high energy efficiency throughout the design and construction of new housing to yield homes with low energy demand, possibly even meeting net-zero energy criteria or similar performance standards. Specifically, builders and developers should employ effective insulation, tight envelope construction, and energy-efficient appliances. Building owners also need to actively engage in the planning process to prioritize high energy efficiency and to specify electric technologies. This can prevent later problems and high costs for electrification retrofits (Drennen et al. 2021).

Technologies

Electrification technologies have become more efficient and cost effective compared to their fossil fuel counterparts due to technological advances. Combined with other benefits to occupant health, safety and comfort, grid flexibility, and greenhouse gas emissions, they offer attractive alternatives to fossil fuel equivalents. Heat pumps in particular have emerged as an important technology as they perform both space and water heating—the two main end uses for natural gas in both single-family and multifamily housing. They are a vital strategy to building decarbonization in the affordable housing sector due to their high efficiency, ability to provide cooling in addition to heating, and increasing capability to function in cold climates. Electric and induction stoves are also garnering attention as the significant impacts of gas stoves on occupant health become more apparent (Tan and Jung 2021; Lin, Brunekreef, and Gehring 2013; EPA 2009). Appendix B describes these residential electrification technologies and explains their operation and performance. Their use is growing, but the rate of growth varies by region and type of technology.

Along with the benefits, these technologies also present certain challenges to their widespread adoption, especially in retrofits and even more so in affordable housing. High up-front costs characterize all the electrification technologies highlighted in this report—air-source heat pumps for heating and cooling, heat pump water heaters, and induction stoves—and pose a significant barrier in affordable housing, where funding is often limited. Programs serving this sector are tasked with fully funding these retrofits, as neither residents nor property owners can afford them. Other major barriers include physical and electrical constraints, operating costs, workforce development, and lack of customer confidence. Program administrators, policymakers, and stakeholders should be aware of the barriers and the strategies and program designs that can address them—described in more detail in the following sections.

BARRIERS IN AFFORDABLE DECARBONIZATION RETROFITS

Electrification retrofits present several challenges. Existing buildings must be carefully evaluated, as their current electrical infrastructure and building conditions are not always suitable for electrification. Additionally, as many customers electrify, the local power distribution system may require substantial upgrades—ranging from a new transformer on the distribution system to a new substation—to support a substantial increase in electrical load. For large projects, extensive coordination with the local utility may be needed, and these upgrades may increase costs unless non-wires alternatives are pursued. A variety of factors influence both technical and financial aspects of a retrofit—size and configuration (i.e., single family versus high-rise multifamily), type of resident (owner- versus renter-occupied), and the existing heating and cooling systems' ductwork, to name a few. Even within affordable housing, distinctions exist between federal subsidized housing and unsubsidized (or naturally occurring) affordable housing (Aitchison et al. 2021); the latter is a subsector of market-rate housing that is unsubsidized but still affordable[8] for low-income households.

Implementing measures and upgrades in multifamily buildings can be especially challenging for contractors or program staff because multiple households are affected. For multifamily buildings with a centralized fossil heating system, the infrastructure for thermal distribution is either hydronic or steam. Reusing this infrastructure is not possible with current heat pump technologies, which require a shift to decentralized heating, such as in-unit heat pumps. This may overburden the existing electric service capacity and infrastructure. It also may require disaggregating heating costs and shifting them to residents if such costs had been bundled with rent payments, posing a possible risk of residents incurring higher combined costs. The shift can also affect the utility allowances provided to owners of multifamily buildings subsidized by HUD. On the other hand, there is an emerging potential technological solution for electrifying centralized hydronic heating systems. This solution is using air-to-water heat pumps to replace fossil fuel boilers. Such units are now sold in Europe (Mitsubishi Electric 2022) and may soon be coming to the United States (Daikin Global 2022).

[8] Rent that is 30% or less of a household's income is considered affordable.

Physical Limitations in Existing Buildings

Building and envelope condition. The age and condition of a building and its envelope are important considerations for older properties because they have a major impact on the feasibility of efficient electrification. Davis, Baylon, and Strand (2006) found that newer homes had a 30% lower heat-loss rate per square foot than pre-1985 homes. A well-insulated and well-sealed building envelope is crucial to ensuring the installed technologies perform as expected. An older, leaky building will force the appliances to work harder to deliver resident comfort, particularly for space heating and cooling, and will partially negate the benefits of upgrading to efficient electric technologies. Given that electricity rates are generally higher than gas, this could have the undesired effect of increasing utility bills. In a retrofit, reducing the building's energy demand as much as possible through energy efficiency should precede equipment replacement. Improving a building's thermal envelope by properly insulating the windows, walls, attic, and foundation ensures the building can retain heat in the winter and keep it out in the summer, thereby reducing its HVAC load. In fact, EPA estimates that such measures can save a typical home 15% on heating and cooling costs or 11% of all energy costs (EPA 2018). The same applies to ductwork in buildings with central heating and cooling. Ductwork in bad condition will decrease the appliance's efficiency by leaking heated or cooled air, especially if it is located in unheated spaces.

The 2009 RECS responses suggest that low-income housing is more likely to have poor insulation. In the 2009 sample, 28% of Weatherization Assistance Program (WAP)-eligible households reported inadequate insulation in their homes, compared to 17% of non-eligible households (Eisenberg 2014, as cited in Rose and Hawkins 2020). Insufficient insulation, in addition to older appliances, explains why these same WAP-eligible households had an average energy intensity of 31 MBtus per square foot compared to 24 MBtus in non-eligible households—despite consuming 18 MMBtus less energy annually than the latter (Eisenberg 2014, as cited in Rose and Hawkins 2020).[9]

Electrical capacity. An existing home or building may not have enough electrical capacity to support a full decarbonization retrofit. All-gas and mixed-fuel buildings tend to have smaller electrical loads that warrant the smallest electrical panel allowed by building energy codes. Electrifying a home can add significantly to its load—particularly if adding EV chargers, electric cooktop/oven, and heat pumps—and would often trigger various electrical upgrades, including a new panel of up to 200A.[10] The cost of these upgrades can vary widely depending on the building. Estimates for single-family homes range from $1,000 to $5,000 (Pecan Street 2021; Mahone et al. 2019); those for multifamily buildings range from $13,500 to $122,000 per building, depending on the number of units and complexity of the upgrade (Aitchison et al. 2021). Most of the U.S. building stock may not need this upgrade, as 25 million housing units (one out of every five) are all-electric and many of the remaining use central air-conditioning—an indicator that there is enough electrical capacity for a heat pump and other electric technologies (Census Bureau 2020). Almost 38 million units do not have central air-conditioning, however. Most of these would need to evaluate and potentially upgrade their electrical service panel. Southern states have a more robust all-electric building stock than average, as 44% of households in 2015 were all electric. On the low end of the spectrum, the Northeast building stock is only 7% all

[9] "Energy intensity" is a metric for the total amount of household energy (all sources) used per unit area. "MBtu" is 1,000 British thermal units (Btus); "MMBtu" is one million Btus. A "British thermal unit" is a standard unit of energy.

[10] However, this depends on the appliances used. Please refer to the "Overcoming the Electrical Capacity Barrier" section for more details.

electric (Pecan Street 2021). Figure 3 shows a breakdown by region. For a detailed breakdown of the heating fuel used in each region by building type, refer to Appendix C.

Some program administrators such as the Sacramento Municipal Utility Department are addressing this added cost of electrification by offering incentives for wiring and panel upgrades in electrification projects, further detailed in the “Utility Policies and Programs” section below.

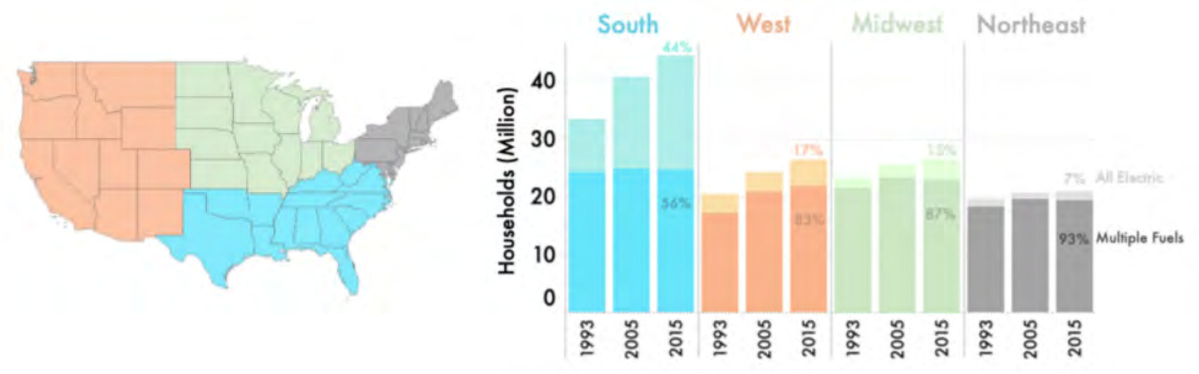

Figure 3. Share of all-electric versus mixed-fueled homes by region 1993–2015 (all-electric in light shading, mixed fuel in dark shading). ***Source***: Pecan Street 2021.

Space limitations. In some applications heat pumps may be physically larger than the technologies they replace. This is especially true for heat pump water heaters, which are bigger and require more space for ventilation than their conventional counterparts. According to ENERGY STAR, most models need 750 to 1,000 cubic feet of air (EPA 2021a). Installation in a confined space can decrease an HPWH’s efficiency by 16% (Shapiro and Puttagunta 2016). This is especially challenging in multifamily and affordable housing, where mechanical closets tend to be minimally sized due to space limitations. HPWHs can be placed in a basement or garage if the building has those spaces. Alternatively, they can be ducted to the outside or to a closed off corridor, but this increases cost and complicates installation.

Heat pumps for space heating and cooling generally do not pose this problem, as much of the technology (external units/heat exchangers) is located outdoors. However, outdoor space constraints can pose problems for multifamily housing in dense urban areas. If space limitation is a concern with ASHPs, variable refrigerant flow (VRF)[11] central heat pumps can offer a viable alternative because of their small refrigerant piping and indoor units (Hopkins et al. 2018). However, without additional external funding opportunities, this technology is generally inaccessible to most affordable housing due to its higher cost.

[11] VRF heat pumps can serve multiple zones’ different heating and cooling needs with a single outdoor unit.

Additionally, more challenges arise for decarbonizing multifamily buildings that lack centrally ducted HVAC systems. While a mini-split air-source heat pump system may allow tenants to freely control their indoor heating and cooling environment, these types of systems quickly multiply in complexity for larger buildings, requiring separate outdoor heat exchangers for every zone in a mini-split system. A similar issue arises in buildings that rely on hot-water distribution for heating. More complex systems with greater numbers of indoor and outdoor units can quickly increase the cost of a retrofit, making affordability a challenge for certain types of buildings. This highlights the need for a flexible decarbonization approach to deliver solutions that fit the specific needs of a building and its tenants; one example of such a program is the Low-Income Weatherization Program in California, described in the "Policy and Program Approaches" section below.

Up-Front Costs

Upgrades to the building envelope, appliances, and selected systems—such as electrical service panels—are costly. The exact figure depends on specific building conditions and systems, but estimates place the cost of a single-family retrofit between $10,675 and $50,000 (Armstrong et al. 2021). Depending on a project's total installation costs and local energy rates, some upgrades may have long or no paybacks, which may make them ineligible for available program incentives (Tajima et al. 2021).

The prognosis for technology costs does look promising—projections by the National Renewable Energy Laboratory (NREL) estimate cost declines of 20–38% for air-source heat pumps and 42–48% for heat pump water heaters by 2050 (Mai et al. 2018; Billimoria et al. 2018). Currently, however, cost remains a key barrier. When comparing total costs (i.e., equipment and installation), ASHPs tend to be much more expensive than electric furnaces and gas- and oil-fueled furnaces due to high installation costs resulting from changes to existing building infrastructure and systems required for switching to ASHPs. The equipment costs alone of ASHPs and fossil fuel furnaces are more comparable. Research shows that mini-split installation in multifamily buildings can cost up to $5,000, even more in some markets, due to contractor unfamiliarity with multifamily installs, labor time, or complications with running the refrigerant line longer distances (Drennen et al. 2021). Comparing water heaters, HPWHs cost approximately twice as much as electric resistance and only slightly more than gas water heaters. Table 2 compares the equipment and installation costs of different HVAC and water heating technologies.

Table 2. Up-front costs of heating technologies in single-family retrofits

End use	Equipment type(s)	Total cost (equipment + installation)
Space heating	Oil	$3,000
	Oil + new AC	$9,534
	Gas	$3,156–3,581
	Gas + new AC	$9,853–11,088
	Propane	$3,323
	Propane + new AC	$9,853
	Electric resistance	$1,100
	Electric resistance + new AC	$7,100
	Ducted heat pump	$7,500–10,951
	Ductless heat pump (1- and 2-zone)	$3,957–5,464
Water heating	Natural gas	$1,230–1,426
	Oil	$2,175
	Propane	$1,359
	Heat pump water heater	$2,000–2,400

Total fixed costs are typical values and vary by specific installation.

Sources: Alstone et al. 2021; Less, Walker, and Casquero-Modrego 2021; Billimoria et al. 2018.

Likewise, the main barrier to widespread adoption of induction cooktops is high up-front cost. The price for most induction cooktops ranges from $1,000 to $3,500—and some high-end models can cost as much as $6,000, though some portable models can sell for $100 or less (Snell 2021; BDC 2021a). Although not significantly pricier than mid- to high-quality gas or electric stoves, the most economical full-sized options are more expensive than introductory-level gas and electric equivalents (gas stoves, for example, can cost less than $700) (Snell 2021; BDC 2021a). Until equipment prices go down, induction stoves are often not a viable option for affordable housing owners or residents without financial assistance. Additionally, homes with gas stoves may not have the dedicated 220V outlet induction cooktops need, adding to the installation costs. AHS data indicates that only one-third of affordable housing units have gas stoves (Census Bureau 2019),[12] so this upgrade may not be necessary in over two-thirds of affordable housing units—but when it is, it will pose an additional financial hurdle to be addressed by decarbonization programs

Financing and Split Incentives

The high up-front costs detailed above are strong deterrents for low-income homeowners. These households already face multiple economic barriers and likely do not have the means to invest in electrification technologies without significant aid. On the other hand, if they are last to electrify, they risk experiencing higher energy burdens should fossil fuel rates rise due to infrastructure that may become stranded in the long term (Greenlining Institute 2019). Although this transition will not happen immediately, research suggests that the residential natural gas customer base may decrease 15% by 2030, 40% by 2040, and 90% by 2050. Each of these reductions would trigger annual bill increases of $31, $116, and $1,565 per customer, respectively (Davis and Hausman 2022). Pressure to decarbonize natural gas systems is illustrated by recent laws on natural gas decarbonization in Colorado and Minnesota (Colorado Energy Office 2021; Jossi 2021). Ultimately, the price to consumers for decarbonized fuels could be on the order of five to six times present natural gas prices according to some analyses (Drake and Partridge 2021; Maryland Commission on Climate Change 2021).

Electrification can be cost-prohibitive for affordable housing building owners. Multiple sources of funding and limited cash reserves can complicate the project approval process for subsidized housing retrofits, leaving providers with little flexibility to consider technologies with perceived operational or financial risk (DOE Better Buildings 2021; Drennen et al. 2021). Including non-energy benefits (discussed earlier in this report) in cost-effectiveness screening or setting different thresholds for affordable housing can make these technologies more feasible and increase eligibility for available incentives and services.

Some utilities have taken the approach of on-bill financing for energy retrofits (DOE 2022). Through these types of programs, property owners can repay the cost of upgrades through monthly payments on their energy bills. In the case of energy efficiency upgrades that save more money per billing period than the financing payment, homeowners can realize savings right away at little to no up-front cost. Additionally, using alternative mechanisms like bill payment history to assess eligibility for financing makes these programs more accessible to customers with poor credit histories. While historically many of these programs prioritize energy efficiency

[12] This is comparable to the prevalence of gas cooktops in non-LMI household, which is 40%. The figures also vary widely across the country—public housing in New York City overwhelmingly uses gas cooking. NYCHA has committed to replacing all units' stoves with induction.

upgrades only, some programs like the Switch It Up! Program offered by Orcas Power and Light Cooperative in Washington offer financing for electrification upgrades and EV charging stations as well (EESI 2022).

Another barrier is that affordable housing building owners have little incentive to invest in energy efficiency measures unless they cover utility costs. If renters pay their own bills, owners face the split incentive problem—they pay for upgrades, but renters get the financial benefit of lower bills. In the unsubsidized housing sector, property owners who do pursue retrofits may pass on the costs to tenants through rent increases, further burdening low-income residents or pricing them out of the housing market. .

Split incentives can work the opposite way for subsidized affordable housing. Renters in such units may receive utility allowances, a sum that is usually deducted from their rent bills to account for reasonable use of utilities. Many states and local public housing authorities, which help set utility allowances, lack awareness of recent advances in electric space and water heating technologies, still assuming that electric equipment necessarily means high energy bills. Thus, in some instances, owners may actually be penalized for switching to electric equipment, with the utility allowances for their property rising and the rent they are able to charge decreasing. In this case, the owner is disincentivized from installing efficient electric technologies. On the other hand, if the renter's allowance decreases due to reduced energy use post-retrofit, some programs give the affordable housing owner the difference in additional rent subsidy (Drennen et al. 2021; National Housing Law Project 2009). That means better profit margins for affordable housing owners without burdening their low-income residents.

Operating Costs

For affordable housing, a primary objective of electrification is to reduce customer energy costs. Yet the impacts depend on several key factors. Costs are influenced by fuel and electricity pricing, the type of equipment being replaced, and the efficiencies of the existing and replacement technologies. Complementary energy efficiency and solar photovoltaic panels also positively impact utility bills costs. The difference in customer utility bills is often negligible, if not beneficial, when switching from oil- and propane-fueled systems to electric (EIA 2021). However, electricity rates are currently higher than natural gas rates in most U.S. locations and if not done properly, this switch has the potential to exacerbate the higher-than-average energy burdens low-income households already experience (Drehobl, Ross, and Ayala 2020). Similarly, because heat pumps can provide air-conditioning as well as space heating, higher summer energy costs can result in units that previously had no air-conditioning—although this may also substantially improve quality-of-life for residents. This risk of increasing residents' utility costs is especially plausible if shifting from central to in-unit systems (e.g., replacing hydronic/steam heating for multifamily buildings with in-unit ductless heat pumps and heat pump water heaters), as the resident would be responsible for a utility previously covered by the building owner. Contrary to the split incentive described above, some owners may consider this an incentive to retrofit their buildings (SWA 2019). As mentioned in the previous section, this can work out well for both resident and building owner if the rent is subsidized and utility allowances are adjusted appropriately. Moreover, this shift to renter-paid utilities can inspire lower energy usage, especially if coupled with smart controls to manage energy use.

To mitigate the potential for rising costs due to electrification, upgrades should be paired with conventional energy efficiency measures. Building envelope improvements such as weatherization allow a smaller heat pump to provide full load heating, leading to reduced equipment, installation, and operating costs for the system, as well as a reduction in peak electricity demand.

Customer and Industry Perceptions

Knowledge and awareness of heat pumps. Contractors and customers alike are largely unaware of heat pumps as options for space and water heating in most regions—a significant barrier to achieving greater deployment of these technologies across all sectors.

Currently, the market penetration of heat pumps is relatively low. Among households that use electricity for space heating, 28% primarily use ASHPs, or 10% of all homes (Hopkins et al. 2018); cold-climate heat pumps (discussed in the next section) are even rarer, though they are becoming more common in such places as Maine, Vermont, Idaho, and Montana. HPWHs made up just 2% of all national residential storage water heater sales in 2020 (EPA 2021b).

Their small market size means that a limited number of contractors have sufficient knowledge of and experience with the installation and design needs for heat pumps and their different applications (SWA 2019). Contractors tend to install and recommend the systems and manufacturers/brands they have relied on for years. There is a perceived risk to switching to new unfamiliar technologies, even if they are effective and beneficial. Market research by the Center for Energy and Environment and Elevate Energy (Drennen et al. 2021) indicates that many contractors sell heat pumps when customers request them, but do not promote them.

Most respondents (28 out of 30) reported a positive impression of heat pumps. However, misconceptions about fuel pricing, perceived complexity of (hybrid) heat pump systems, and lack of customer knowledge deter contractors from making a recommendation they consider neither the simplest nor the most cost effective (Drennen et al. 2021). Moreover, the contractors surveyed noted that heat pumps' perceived poor performance in cold-climate regions is another deterrent in Wisconsin. As discussed below, however, some heat pump models can deliver relatively high and reliable performance in temperatures as low as –10°F, particularly when combined with building shell improvements.

This lack of awareness exists among building owners as well. The same market research captured the barriers multifamily building owners and managers face on the road to heat pump adoption. The majority of participants listed technical support and availability of knowledgeable contractors as crucial in considering a switch to heat pumps. Some also expressed concern over resident comfort during winter and resident retention. Both concerns indicate a lack of confidence in and knowledge of the technology's operation and maintenance needs. Unfortunately, the surveyed contractors indicated that teaching customers about heat pumps is challenging and time-consuming. Yet without trusted experts recommending and promoting the technology and offering technical support, customer awareness of and demand for heat pumps is unlikely to increase.

Robust workforce development, customer education efforts, and sustained market signals from policymakers—such as building electrification targets and/or mandates—are needed to close this knowledge gap, promote wider adoption of heat pumps, and ensure the efficiency of heat pumps once installed. Beyond policy goals and utility and state programs, manufacturers of heat pumps can also play a role by providing contractors with education and training, particularly in heat pump system installation and maintenance. These manufacturer-led initiatives can both address workforce capacity issues and help grow the market presence of heat pumps.

Perception of heat pumps' cold-climate performance. Because heat pumps operate by exchanging heat with the outdoor environment, the ambient outdoor temperature can affect their performance. This was specially the case with earlier models, whose efficiency and heating capacity drastically decreased at 20°F and below. Newer models use an inverter-driven compressor that calibrates the fan speed based on heating demand, as well as improved refrigerant optimized for colder settings. These advancements enable them to perform efficiently at much lower temperatures, down to 0°F or lower (see figure 4). Performance has been monitored in several field studies and while efficiency and heat output are somewhat lower than in milder climates, they still deliver significant energy savings over conventional heating systems. The Vermont Department of Public Service conducted field tests in which the real performance of cold-climate air-source heat pumps (ccASHPs)[13] was 88% of their rated efficiency (Walczyk 2017). The Center for Energy and Environment ran a 2018 Minnesota-based study where ccASHPs delivered 36–56% in site energy reductions and 26–56% in heating cost savings compared to propane furnaces and electric resistance heaters (McPherson, Smith, and Nelson 2020). Another heat pump tested in Alaska delivered 75% of its rated efficiency at –30°F (Shen et al. 2017).

[13] The Northeast Energy Efficiency Partnerships (NEEP)'s cold-climate heat pump specification defines how these must perform in order to be classified as ccASHPs. They must prove a COP of at least 1.75 at 5°F while at maximum capacity operation. As of September 2021, close to 26,000 products are on the list (NEEP 2022; McPherson, Smith, and Nelson 2020).

A key feature of ccASHPs is the defrost cycle. In subfreezing conditions, frost can form on the outdoor coils and hinder performance. During the defrost cycle, the heat pump temporarily works in reverse and transfers a small amount of heat outside. However, the cycle can occasionally malfunction and interfere with the heating performance, preventing heat from going indoors and resulting in a COP of 0 (Schoenbauer, Haynor, and Kessler 2018). Further research and field tests are needed to inform best installation practices, fine-tune the defrost cycle, and make these heat pumps even more efficient.

Figure 4. Outdoor unit of a ductless ccASHP in Dillingham, Alaska.
Source: NREL 2021, courtesy of Tom Marsik.

Public perception of gas and electric cooking. Similarly, a significant barrier for induction stoves is the general public's attachment to gas cooking and misconceptions about induction. Unfamiliarity with induction, caused by its low market penetration, results in assumptions that it works like electric resistance. Customers often consider the latter inferior and prefer the more controlled cooking experience that gas provides (Snell 2021). In fact, induction outperforms both electric resistance and gas in cooking speed and degree of precision. In a study by the Building Decarbonization Coalition, survey participants gave largely positive feedback and predominantly preferred the experience of induction over cooking with gas or electric resistance (BDC 2021b). A robust education campaign could be helpful in counteracting this misconception and raising awareness about the realities of gas and electric induction.

Customer Adaptations to Electrification Technologies

Water recovery time. Although significantly more efficient, HPWHs usually have slower recovery rates than electric resistance heaters. While the latter can heat 20 gallons of water per hour, a typical HPWH might heat 8 gallons per hour (Shapiro and Puttagunta 2016). Large households may be hesitant to upgrade if the demand for hot showers is concentrated at any given time. Most HPWHs are hybrids with backup electric resistance elements that kick in with increased hot-water demand; however, frequent usage of this feature would diminish the product's overall efficiency. Other solutions include choosing HPWHs with larger storage tanks and installing a thermostatic mixing valve. Finally, reducing hot-water demand with water conservation measures, such as installing low-flow showerheads and faucet aerators, can maximize efficiency and mitigate potential issues with recovery time.

Incompatible cookware. While an induction stove's mechanism provides remarkable performance, it also sets certain limitations. Cookware must have ferromagnetic material to be useable with induction stoves. Such materials include cast iron, enameled cast iron, carbon, and certain alloys of stainless steel. Aluminum, copper, glass, and nonmagnetic stainless-steel pans, however, are not compatible (Snell 2021; BDC 2021a). As the latter are common in U.S. households, obtaining suitable cookware to simply operate the new cooktop could add to the up-front costs and place a disproportionate burden on low-income households, whether homeowners or renters.

Promising Retrofit Approaches and Technologies

Several emerging approaches could become part of an arsenal to address the barriers to retrofitting existing housing. A building's energy load can be minimized by installing and correctly sizing the HVAC and water heating appliances. If the building's electrical capacity still cannot support them, low-power plug-in appliances could be effective. This approach includes incorporating technologies to manage and monitor existing electrical capacity. Smart panels and smart splitters use load shifting and prioritization (changing when loads occur) to limit simultaneous power draw. These energy management systems can make a panel upgrade unnecessary as two high-power appliances will not run at the same time and require more voltage. Although still under development and in need of more research and case studies, these systems could make decarbonization more feasible for affordable housing owners. Using this strategy, a single-family home can undergo full electrification with an existing 100A panel for as little as $2,000 (Armstrong et al. 2021).[14]

Employing off-site construction can also ease the difficulties of a retrofit. The Netherlands pioneered this model on a large scale through their Energiesprong retrofit program. Projects use off-site manufactured components, such as prefabricated panels, to reduce project timelines during net-zero energy retrofits and minimize overall disruption to tenants—a major barrier for multifamily buildings. Renovations can take as little as 1 day, but most take around 10 (Energiesprong 2021). About 5,000 housing units have been retrofitted in the Netherlands and construction costs have dropped 50% since the program launched in 2012. Energiesprong has expanded to other European countries and has inspired New York State's RetrofitNY, which will use Energiesprong's approach to retrofit affordable housing units across the state.[15] The Advanced Building Construction (ABC) initiative by the U.S. Department of Energy also funds building retrofits modeled on this approach (DOE 2020). Other organizations, such as the Association for Energy Affordability (AEA), are conducting research on a mass deployment model for zero net carbon retrofits and prefabricated envelope solutions (AEA 2021).

Another solution by the New York City Housing Authority (NYCHA) similarly harnesses the power of technological advancements and market transformation. It released a request for proposals in 2021 that challenges manufacturers to design and create heat pumps that can be installed either through a window opening (like a window AC) or into an existing through-wall sleeve (like packaged terminal air conditioners). Such heat pumps do not currently exist and could help address the challenges that come with installing heat pumps in larger existing buildings. NYCHA has committed to purchasing at least 24,000 units for its affordable housing stock.[16]

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[14] Armstrong et al.'s (2021) *A Pocket Guide to All-Electric Retrofits of Single-Family Homes* includes a comprehensive product guide for the above and many other end uses.
[15] For more information about RetrofitNY, visit www.nyserda.ny.gov/All-Programs/RetrofitNY/What-is-RetrofitNY.
[16] See the following article for more information: "NYCHA looks to clean technology for heating and cooling," www.ny1.com/nyc/all-boroughs/news/2021/12/22/nycha-looks-to-clean-technology-for-heating-and-cooling.

Policy and Program Approaches for Decarbonization of Affordable Housing

The following sections describe the policy landscape and tools that decision makers at the federal, state, local, and utility levels can take in order to effectively tackle barriers and increase deployment of carbon-free solutions for the affordable housing sector.[17] The barriers that these policies and programs aim to address are summarized in table 3.

[17] In this report, we do not detail energy efficiency and climate-related programs or policies by HUD's Office of Native American Programs (ONAP), part of the Office of Public and Indian Housing. For more information on the current programs supporting pathways to decarbonization of housing in Native communities, see the HUD's ONAP website. Also see HUD's Climate Action Plan for further details on ONAP's commitment to addressing climate change and creating environmentally sustainable affordable housing.

Table 3. Barriers to decarbonization for affordable housing

Issue	Details
Access to funding and financing	Low- and moderate-income customers have limited access to capital to invest in efficiency and/or electrification measures.
Renter/Owner split incentive	Property owners have limited incentive to invest in efficiency and home energy improvements for renters who pay for their own utility costs.
Higher electricity costs	Natural gas is inexpensive compared to electricity in many markets, so electrification risks increasing energy burdens for residents and negatively impacting housing affordability in cases where owners pay for utilities.
Retrofit challenges in older buildings	Buildings, systems, and appliances may be in poor condition, requiring upgrades such as electrical wiring, metering, and service panels, which can greatly increase total project costs.
Multi-unit dwellings	Implementing measures and upgrades in multifamily buildings can be especially challenging for contractors or program staff because multiple households are affected. Electrification also may shift utility costs to individual households if replacing central heating systems, such as hydronic or steam heating.
Limited program budgets	Government agencies working to support the preservation of existing buildings or the construction of new affordable housing face additional costs for electrification measures that do not have a positive return on investment, straining limited budgets.
Lack of institutional capacity	Government agencies, developers, policymakers, and other stakeholders working to preserve existing or build new affordable housing may not have the internal capacity to quickly incorporate decarbonization into their institutional practices, such as project design standards and specifications, RFP language, staff training, and existing contracts with suppliers and service providers who lack the expertise necessary to execute decarbonization projects.
Lack of contractor capacity	Building contractors often lack familiarity with decarbonization technologies like heat pumps, making it challenging for homeowners and property managers to find qualified contractors within a reasonable time frame to perform electrification retrofits and maintenance.

Decarbonization programs and policies for the affordable housing sector must address these barriers in addition to those specific to different electrification technologies as discussed earlier.

FEDERAL GOVERNMENT POLICIES AND NATIONAL PROGRAMS

Policy Landscape

Since the early 1930s, the federal government has played a role in providing affordable housing programs for low-income households. This role has shifted over time from creating public housing to enabling tax credit financing and providing other subsidies such as project- and tenant-based rental assistance programs. The federal government today primarily funds affordable housing, providing financial support for rental assistance, assistance to state and local governments, and assistance for homeowners as well as tax credits that fund the development and rehabilitation of affordable housing (Jones, McCarty, and Perl 2019). The Department of Housing and Urban Development (HUD) administers many of today's federal affordable housing programs.[18] Over time, the federal government has increasingly relied on and provided financial support to the private sector to create affordable housing, such as through the Treasury Department's Low-Income Housing Tax Credit (LIHTC) program. This shift has resulted in a complex landscape of financing and ownership of affordable housing throughout the United States. Nevertheless, federal agencies such as HUD and U.S. Department of Agriculture (USDA), among others, have created several programs that can help affordable housing owners complete energy-related improvements. Many state agencies have chosen to incorporate minimum energy standards and/or preferences into their funding allocation decisions for federal LIHTC funding (Bartolomei 2021). Although the accessibility of the programs listed in the following section varies, these programs have funding available to subsidize energy efficiency and facilitate electrification of affordable housing.

Federal Low-Income Housing Tax Credit

The most prominent tool for encouraging the development and rehabilitation of affordable housing—and one that holds considerable potential for facilitating the decarbonization of affordable housing—is the Federal Low-Income Housing Tax credit. LIHTC is the federal government's primary mechanism for encouraging private investment in affordable rental housing. LIHTC credits come in two amounts: 9% and 4%, with the 9% credit being the most competitive and attractive for new construction, while the 4% credit is less competitive and more often used for retrofitting affordable housing.

Through LIHTC, state Housing Finance Agencies (HFAs) have been able to incorporate and incentivize green practices into the maintenance, operations, construction, and rehabilitation of affordable housing properties through selection criteria outlined in Qualified Allocation Plan (QAP) requirements and preferences. Applications for these tax credits must meet the criteria outlined in QAP, and applicants who meet certain preferences are more likely to be selected in this competitive process. Some states supplement these tax credits with state tax credits.[19] These tax credits are sold to investors who make a large direct equity investment in the project(s), which

[18] For more information on federal programs, see Maggie McCarty, Libby Perl, and Katie Jones, *Overview of Federal Housing Assistance Programs and Policy* (Washington, DC: Congressional Research Service (CRS)). 2019. crsreports.congress.gov/product/pdf/RL/RL34591; also see localhousingsolutions.org/fund/federal-programs-for-affordable-housing/.
[19] For more information on state programs, see www.novoco.com/resource-centers/affordable-housing-tax-credits/application-allocation/state-lihtc-program-descriptions.

in turn reduces the financing needed to construct or rehabilitate existing properties, allowing the owners of affordable housing to charge lower rents to residents (Jones, McCarty, and Perl 2019).

One of the most common methods to ensure energy and water efficiency in both new construction and retrofits is the use of third-party green building standards such as LEED or Enterprise Green Communities. Other common strategies include (Bartolomei 2016)

- green capital or physical needs assessments
- energy and water audits or modeling
- performance-based requirements or incentives
- required energy professionals on staff
- energy and water benchmarking
- water conservation requirements or incentives
- coordination with utility energy efficiency programs
- project-specific utility allowances and renewable energy incentives

Though these strategies are an encouraging trend, creating goals for deep decarbonization such as incentivizing fuel switching or a focus on building envelope could also be embedded in QAP requirements. One option could be for QAPs to require applicants to demonstrate carbon reduction and not just energy use reduction. The state of Oregon allows 9% LIHTC funding to be combined with other resources such as the Weatherization Assistance Program (WAP), making it possible to optimize mechanical systems once factors such as heating and cooling loads are reduced (Bartolomei 2016; Sahagian and Christian 2021). The states of Connecticut, Pennsylvania, and Minnesota require LIHTC applicants to contact their local utility providers prior to application and demonstrate how they will leverage energy rebates to achieve energy savings (Bartolomei 2021). HFAs should acknowledge that decarbonization is more challenging for retrofits than for new construction, and the requirements or preferences should be separately tailored such that either type of project is able to go further with a similar level of effort.

DOE's Weatherization Assistance Program (WAP)

DOE's Weatherization Assistance Program (WAP) targets low-income households. WAP provides funding and technical assistance to state agencies, which then work with local governments, nonprofit organizations, and developers to allocate and administer funding for targeted low-income energy and weatherization assistance. In 2009, HUD and DOE collaborated to use $16 billion in funds appropriated by Congress through the American Recovery and Reinvestment Act (ARRA) for weatherization of existing affordable housing (HUD 2010). The departments created a Memorandum of Understanding (MOU) seeking to lower existing barriers to weatherization for public and HUD-assisted multifamily housing. The MOU streamlined weatherization eligibility for approximately 2.3 million public housing units and privately owned federally assisted units in addition to 950,000 units financed by Low-Income Housing Tax Credits (LIHTC; HUD-DOE, 2010). Moreover, the MOU established requirements that prohibit rent increases for units being improved by weatherization measures, which is crucial to preserve affordable housing and prevent resident displacement. Most recently, WAP has received $3.5 billion through the Infrastructure Investment and Jobs Act (Alliance to Save Energy 2021). Despite the potential for leveraging WAP as a pathway to deep decarbonization in affordable housing, its effectiveness may be limited due to numerous barriers remaining for multifamily housing (Energy Futures Group 2020).

Community Development Block Grant (CDBG)

The CDBG program provides grant funding to local governments that can be used to meet a wide range of community development needs. This program requires that no less than 70% of the local government's allocation be directed to low- and moderate-income populations (EPA 2018). Grantees of these funds have been able to use them for energy efficiency upgrades. These flexible funds may be used by local governments to preserve affordable housing. The funds may help offset costs for retrofit projects and could also be tied to anti-displacement policies, helping to retain affordable housing in targeted areas.

HOME Investment Partnership Program

HUD's HOME block grant program provides funding to state and local governments to create or preserve affordable housing for low-income households. The funding can be used to fund the construction, buying, and/or rehabilitation of affordable housing (HUD 2021c). Participating jurisdictions are encouraged to use ENERGY STAR certified products and standards (EPA 2018).

Energy Performance Contracting (EPC)

HUD incentivizes state and local public housing agencies (PHAs) to use energy performance contracts (EPCs) as a financing technique to achieve energy savings (HUD Federal Register 2005). EPCs are a financing approach that uses "cost savings from reduced energy consumption to repay the cost of installing energy conservation measures" (HUD 2021d). EPCs are typically carried out with the help of Energy Service Companies (ESCOS), which support building owners and their staff with technical expertise to carry out energy efficiency projects. However, not all affordable housing owners or developers have the administrative capacity to undertake potentially lengthy and complicated processes with ESCOS.

Program Opportunities

Since most federal housing programs are funded by annual Congressional appropriations, they are subject to funding changes and fluctuations in priorities that can affect whether these programs (and ultimately the building owners) can pursue energy- or climate-related work. During the Obama administration, HUD leadership emphasized green building and supported the creation of policies that promoted energy efficiency, in line with the Obama administration's larger energy and climate-related goals. The American Recovery and Reinvestment Act (ARRA) of 2009 injected a large amount of funding into the preservation and improvement of distressed affordable housing. Many of these Obama era programs and policies are no longer active but are likely to be revived, improved, or replaced by different energy programs as the Biden administration continues to push its climate goals, with HUD one of many agencies creating policies in line with the Biden administration's larger climate goals.

HUD's 2021 climate action plan has outlined the agency's commitment to reducing the greenhouse gas emissions associated with its portfolio of approximately 4.5 million public and assisted housing units, which are estimated to produce 13.6 million metric tons of carbon emissions annually (HUD 2021a). HUD has requested $800 million in their 2022 budget specifically for increasing investments in energy efficiency upgrades and climate resilience measures (HUD 2021a). HUD's strategies to reduce emissions from their buildings will rely heavily on increasing investment in energy retrofits and incentivizing green building design for new buildings (HUD 2021a). Although HUD's climate action plan does not specifically call out strategies such as fuel switching or electrification, these strategies will be important for helping to decarbonize the affordable housing sector and can provide quantifiable health benefits to residents.

Benchmarking

Benchmarking has been used in many different building types to measure energy use performance. Benchmarking serves as an energy management strategy to compare similar building types and can encourage energy use improvements (Office of Energy Efficiency & Renewable Energy 2021). Currently, HUD does not have a comprehensive benchmarking initiative that covers all buildings in its portfolio due to data collection, regulatory, and organizational challenges (HUD 2021b), but the agency recognizes in its climate action plan that benchmarking is a critical step in setting its GHG reduction goals. HUD encourages but does not require subsidized affordable housing owners to participate in Energy Performance Contracting and energy use benchmarking through EPA's Energy Star Portfolio Manager tool. A draft notice issued by HUD in 2016, which would require HUD-supported multifamily affordable housing to participate in benchmarking, has not yet been finalized.

Benchmarking could encourage and assist energy management of HUD buildings and could capture benefits for the unsubsidized affordable housing multifamily sector as well (Ungar 2020). HUD's primary benchmarking initiative is the Department of Energy's (DOE) Better Buildings Challenge (BBC) Multifamily Sector program. DOE has partnered with HUD to help multifamily affordable housing owners and managers voluntarily achieve a 20% portfolio-wide energy reduction and offers support to navigate the unique challenges in the multifamily affordable housing rental market. The program offers a dedicated account manager, free technical assistance, and project recognition.

The BBC Management Add-On Fee Incentive is also available for HUD-assisted properties participating in the multifamily BBC. These fees help fund and continue implementation of energy efficiency measures (HUD Exchange 2022).

Although not an exhaustive list, table 4 lists several key federal programs that can help with the financing needed to undertake deep decarbonization upgrades to affordable housing.

Table 4. Programs that fund or incentivize energy efficiency in subsidized affordable housing

M2M GREEN INITIATIVE: This initiative focuses on HUD's section 8 portfolio and encourages owners and purchasers of section 8 housing to rehabilitate buildings using green building practices (HUD n.d.).
Green Mortgage Insurance Premium (MIP) Reduction Program: This voluntary financing program offers reduced insurance premiums for affordable green multifamily buildings. Benchmarking is required for BBC partners.
Fannie Mae's Green Preservation Plus: This partnership between the Federal Housing Authority (FHA) and Fannie Mae refinances energy efficiency and water upgrades in older affordable multifamily housing properties.
The Freddie Mac Multifamily Green Advantage: This program provides better pricing and additional funding for borrowers looking to improve the energy or water efficiency of their property.
Self-Help Homeownership Opportunity Program (SHOP): SHOP funds nonprofit organizations and consortia to purchase and develop or improve affordable housing. The funds are intended to provide homeownership opportunities to low-income populations that would otherwise be unable to purchase a home.
Community Development Block Grant (CDBG): CDBG provides grant funding to local governments that can be used to meet a wide range of community development needs. This program requires that no less than 70% of the local government's allocation be directed to low- and moderate-income populations (EPA 2018). Grantees of these funds have been able to use them for energy efficiency upgrades.
USDA: Multifamily Housing Direct and Guaranteed Loan Program: This program awards points to new construction and revitalization proposals that include energy efficiency improvements through the use of the ENERGY STAR program.

Source: Local Government Climate and Energy Strategy Series: Energy Efficiency in Affordable Housing: A Guide to Developing and Implementing Greenhouse Gas Reduction Programs (EPA 2018)

Despite the existence of federal programs and initiatives seeking to reduce energy use, there is not yet a unifying policy or program for reducing emissions in HUD-assisted buildings for either new construction or existing buildings. Most HUD policies and programs related to the environment and energy are focused on resource conservation rather than decarbonization. The pursuit of energy efficiency as a strategy to reduce environmental impact has historically enjoyed a great deal of acceptance due to its cost effectiveness. However, cost-effectiveness calculations must be adjusted to address climate change if these buildings are to achieve the emissions reductions necessary to decarbonize the building sector. Federal programs such as WAP focus on the savings benefits of energy use reductions for low-income households but do not necessarily highlight emission reductions. Quantifying carbon emission reductions due to weatherization, electrification, and other strategies that intentionally reduce a building's emissions should be considered a key benefit of the program; this would assist cities and states in continuing to track environmental justice and climate goals.

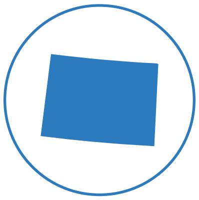
STATE POLICIES AND PROGRAMS

Because of the many areas in which states have influence and jurisdiction—including building codes, state climate goals and mandates, regional carbon markets, and taxpayer-funded programs—they are a uniquely powerful actor in advancing decarbonization in the affordable housing sector. States have led some of the most ambitious decarbonization efforts to date, such as in California and New York. However, decisions by states can sometimes have negative impacts on housing affordability and GHG emissions. The section below describes various policy levers states can employ to broaden or hinder decarbonization in affordable housing, as well as several examples of state-funded program approaches.

State Building Decarbonization Targets and Mandates

In a manner similar to an energy efficiency resource standard (EERS) and renewable portfolio standards (RPS), state governors and legislatures can enact building electrification goals and targets to serve a broad climate agenda. These can signal other market actors (manufacturers, builders, utilities, trade associations, homeowners, etc.) to invest in building decarbonization measures. The states with some of the most ambitious decarbonization efforts to date have enacted such policy targets and directives (Cohn and Esram 2022). Examples of states that have enacted building electrification policies and targets include

California: In addition to the state's target of reducing statewide GHG emissions to 40% below 1990 levels by 2030 and total decarbonization by 2050, the California Air Resources Board (CARB) is focused on reducing emissions in the buildings sector through distributed clean energy, energy efficiency improvements, and demand flexibility (CARB 2022). For affordable housing in particular, the California Energy Commission in 2018 laid forth its Clean Energy in Low Income Multifamily Buildings (CLIMB) action plan, directing various state agencies to increase access to energy efficiency and clean energy technology for this historically underserved sector (CEC 2018). One program that rose out of this effort, the *Low Income Weatherization Program for Multifamily*, is detailed in the section below.



Colorado: In 2021, Colorado became one of the first states to adopt legislation requiring its state-regulated utilities (including electric and gas utilities) to implement clean heat plans that reduce emissions 22% by 2030 relative to a 2015 baseline (Colorado Energy Office 2021). These solutions include energy efficiency, electrification, and financing for building upgrades. While the package of legislation includes expanded funding for the state's Weatherization Assistance Program, it does not contain specific carve-outs for affordable housing.

Massachusetts: Like New York, Massachusetts has mandated at least an 85% reduction in GHG emissions by 2050 with a goal of reaching net zero. The state's decarbonization roadmap, published in December 2020, lays out strategies for various sectors, including the buildings sector. The state's strategy highlights the importance of heat pump technologies, energy efficiency, and low- and zero-carbon fuels to decarbonize buildings (Edington et al. 2020). This technical potential analysis breaks out buildings by sector and type (single family, multifamily, and commercial) and recommends cost-effective pathways and measures for stakeholders to achieve decarbonization.

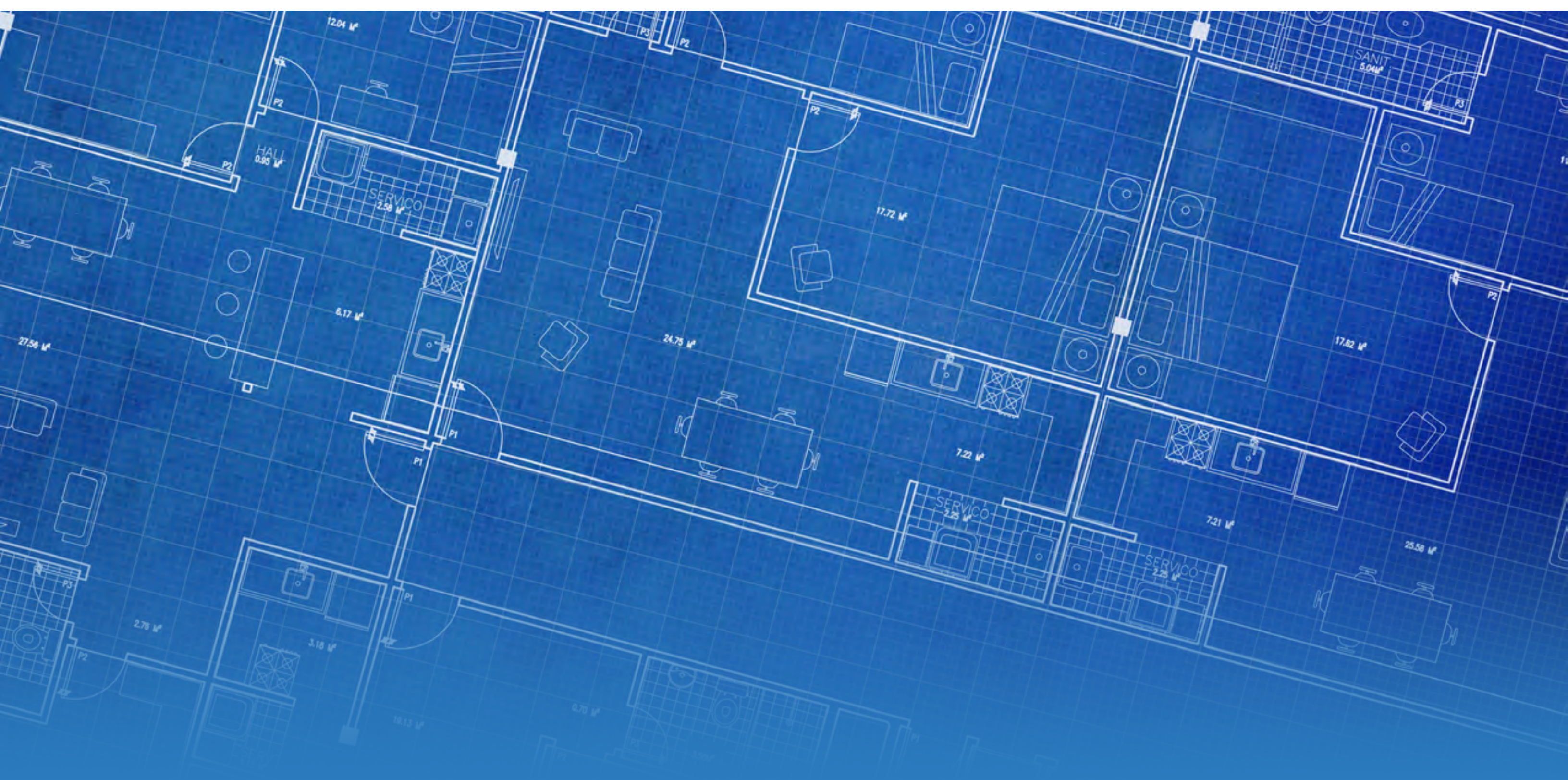
Minnesota: While Minnesota does not have a building decarbonization target in legislation or executive order, the Minnesota Center for Energy and Environment, a statewide, utility-funded, nonprofit program implementer, is highly concerned with advancing equitable decarbonization for the building sector (CEE 2021a). Their approach incorporates multiple angles: providing workforce and customer education, promoting flexible devices such as managed EV charging, and modernizing the natural gas industry to transition to low-carbon fuels.

New York: In December 2021, New York State governor, Kathy Hochul, announced a statewide initiative, the Building Better Homes initiative, to deliver decarbonization for single-family homes and neighborhoods in accordance with the state's goals of reducing GHG emissions by 85% by 2050 (Kavanagh 2021). This $30 million initiative will be administered by the New York State Energy Research and Development Authority (NYSERDA) and provide a network of builders and developers to supply training and technical support for net-zero home construction. While this effort is not specific to affordable housing, New York's Climate Act also requires that at least 35% of state clean energy investments are directed to disadvantaged communities.

Building Energy Codes

Building codes are one of the most effective ways to ensure buildings are built or retrofitted to standards that minimize GHG contributions. Cities and states adopt building codes that require specified levels of energy efficiency and building quality. These codes have steadily increased in stringency, with the result that newer buildings generally use significantly less energy than older buildings. In addition, states and cities in some areas are beginning to create policies and upgrade building codes to phase out the use of natural gas in new buildings. Through electrification requirements in building codes, states and cities are driving the transition to a low-carbon building sector. These codes, in addition to state and local GHG reduction targets, create a "clear link between achieving those targets and electrifying building stocks" (Lamm and Elkind 2021).

California's newest (2022) building code, for example, is accelerating decarbonization of the state's building stock. The state's new codes include requirements that complement the state and cities' GHG emission reduction goals. The new codes seek to shift buildings toward electrification and low-carbon technologies and include provisions requiring or encouraging photovoltaic systems, heat pumps, ventilation strategies to improve air quality, lighting controls and sensors, and other energy efficiency measures that target specific building types (CEC 2021). Likewise, the New York City Council recently approved a law to largely prohibit use of natural gas in new buildings. Although building codes are a strong policy lever to decarbonize buildings, it is important to note that building code stringency, compliance, and authority to amend building codes varies widely across the United States. Stretch codes, which are model codes municipalities are authorized to adopt in some states, are also an important compliance path that could help communities go beyond basic building codes.



State Program Examples

California: Low Income Weatherization Program (LIWP)

California's Low Income Weatherization Program (LIWP), administered by the Association for Energy Affordability, a state-funded nonprofit organization, is one of the largest building electrification efforts in the United States to date (Cohn and Esram 2022). This program is designed to deliver comprehensive building retrofits and decarbonization measures to multifamily properties with low-income residents, a historically underserved sector. This program has been operating since 2016 and to date has delivered more than $33 million in incentives for more than 8,100 low-income rental households. Building retrofits include measures such as insulation; air and duct sealing; space heating, hot water, and cooking electrification; and distributed energy resources including rooftop and community solar (Hill, Dirr, and Harrison 2020). It is the first low-income program in the state to focus on decarbonization specifically, as reflected in the incentives, which are provided based on total avoided GHG emissions instead of a per-measure basis.

This program is designed to address several roadblocks to decarbonization for low-income housing. One crucial barrier is the split incentive problem, which this program addresses by offering higher incentives to upgrade properties with individually metered units. By working from the ground up with property managers and residents alike to identify high-impact opportunities for upgrades, program administrators can deliver custom measures that lead to lower energy costs and GHG emissions. Every project starts with a free energy audit and assessment to provide whole-building recommendations. The flexible, technology-neutral incentive method allows for program implementers to recommend specific upgrades for a variety of building types and mechanical systems. This approach has demonstrated results: properties enrolled in the program average 37% site energy savings from efficiency measures alone and 43% when solar photovoltaic (PV) is pursued in tandem. These upgrades translate to savings for residents, with an estimated $830 in annual utility bill savings per year for residents where the building upgrades combined efficiency, electrification, and solar PV.

Funding for the LIWP has in the past come primarily from carbon emissions allowances purchased through California's cap-and-trade program. Because these funds are allocated annually by the California legislature, this creates a somewhat inconsistent annual funding stream which can lead to difficulties with retrofit projects that usually require 12–24 months to complete. As of June 2020, this program has completed 81 projects and served approximately 0.6% of the state's low-income multifamily housing stock, with more than 1,000 multifamily buildings currently on the program's waiting list. This unique program design, which addresses many of the barriers listed above and delivers lasting decarbonization and electrification, can serve as a model for other states and jurisdictions that are serious about addressing the issue of unequal access to decarbonization through whole-building holistic strategies.

In addition to the LIWP program, the California Public Utilities Commission in late 2021 launched two large-scale building decarbonization efforts: the CA Building Initiative for Low-Emissions Development (BUILD) program and TECH Clean California. TECH is an upstream program that aims to jump-start the market for heat pump space and water heaters by providing incentives and partnerships for manufacturers, distributors and vendors of these technologies. The BUILD program is dedicated to all-electric housing, with 75% of funds carved out for spending on low-income housing. The two projects have a combined budget of $200 million over four years, funded by cap-and-trade market revenues similarly to the LIWP (Borgeson 2020).

New York: Empire Building Challenge and Affordable Housing Decarb Pilot

Following the passage of the 2019 Climate Leadership and Community Protections Act (CLCPA), an ambitious state policy that mandates an economy-wide shift to carbon neutrality by 2040, New York State has become a national leader in building electrification efforts that leverage the combined interests and resources of state agencies, regulated utilities, and private sector businesses. New York City has "one of the largest retrofit markets in the country," which invites the interest of public organizations, utilities, and private capital to invest in repeatable methods that deliver carbon-reduction solutions for large commercial and multifamily buildings (Building Energy Exchange 2020). To attract private capital and promote innovation in building technology strategies—particularly in hard-to-reach sectors like affordable housing—the former governor announced in 2020 that the state would be embarking on the Empire Building Challenge, leveraging $50 million in public funding to develop scalable decarbonization strategies for large commercial and multifamily building retrofits.

The New York State Energy Research and Development Authority (NYSERDA), a state wide public benefit corporation that provides research, program administration and technical assistance, is responsible for implementing this and other building retrofit programs throughout the state. As a state-funded organization, NYSERDA has a mission to deliver equitable, climate justice–oriented solutions for New Yorkers, and views decarbonization for affordable multifamily housing as a high priority. In partnership with 10 real estate portfolio managers, the first cohort of the Empire Building Challenge has committed to developing capital plans to achieve carbon neutrality in 131 large commercial and multifamily buildings in New York City over the next 10–15 years (NYSERDA 2021a). By leveraging public dollars in combination with private funds, state leadership in New York aims to "pour fuel on the fire" and accelerate decarbonization practices in the private sector.

Alongside its efforts to develop and accelerate the market for decarbonization, NYSERDA administers additional programs specifically targeting the needs of affordable housing communities and property managers. In 2021 NYSERDA announced a forthcoming $24 million pilot program in partnership with the New York City Department of Housing Preservation and Development (HPD) to fund electrification in affordable housing in New York City (NYSERDA 2021b). This partnership aims to deliver all-electric retrofit upgrades to 1,200 units and benefits to more than 3,000 LMI residents. Critically, this program allows subsidy dollars from NYSERDA to be claimed by building owners as part of project financing in the predevelopment stage. This differs from past program models where clean energy subsidies were paid out during or after project completion in the form of a rebate. The new approach allows for decarbonization incentives to be baked into project financials and represents an innovation in terms of motivating housing developers to invest in clean energy, efficiency, and carbon-free solutions for affordable housing units.

By providing funding and financing for building managers to cover the incremental costs of electrifying existing HPD-regulated buildings, and by delivering efficiency and other building performance improvements such as building envelope upgrades and water-saving measures, the program administrators aim to deliver energy savings and reduced greenhouse gas emissions. As with the Empire Building Challenge, one of the goals of this program is to develop replicable methods for decarbonizing the state's existing building stock to reduce GHG emissions in service of the state's 2050 carbon neutrality goal.

UTILITY POLICIES AND PROGRAMS

Electric utilities have an important role to play in promoting and implementing electrification, especially for low-income customers. This role varies across states and jurisdictions based on policy mandates and market conditions. The following section describes some of the challenges utilities face in promoting decarbonization for affordable housing and highlights some examples of solutions leading utilities have implemented for low-income customers.

Because utilities have a direct relationship with their customers, they are uniquely positioned to deliver information, programs, and incentives for technologies like heat pumps and for energy efficiency measures. Utilities may also support other decarbonization efforts in less direct ways, such as by offering incentives to homebuilders to construct homes to higher efficiency standards or establishing partnerships with contractors and other trade allies to promote energy efficiency and electrification technologies.

Policy and regulatory changes are a major driver for utilities to adopt decarbonization programs and efforts. As of 2020, six states (California, Alaska, Tennessee, New York, Vermont, and Massachusetts) have established policies that allow utilities to promote fuel switching or substitution of fossil fuels with electric equivalents (Berg, Cooper, and Cortez 2020). More states are beginning to pass policies that look specifically to electrify fossil fuels in buildings to meet climate goals. In 2021 Colorado became one of the first states to require its investor-owned utilities to establish building electrification plans and meet targets related to emissions reduction (DiChristopher 2021). States and regulators across the United States will need to pass more policies and incentives to motivate utilities to develop comprehensive and inclusive programs for beneficial electrification in affordable housing.

Many utilities offer energy efficiency programs that are specifically targeted to low-income customers. In ACEEE's 2020 *Utility Scorecard*, approximately 11% of all energy efficiency spending by the nation's 52 largest utilities was on low-income programs (Relf et al. 2020). These programs include direct-install measures, as well as some more comprehensive programs offering critical measures such as insulation and air- and duct-sealing. Low-income programs are often less cost effective for utilities because they are offered at little to no cost to qualified customers. While most utility energy efficiency programs are required to pass a cost-effectiveness screen, many low-income programs are exempt from this requirement because they achieve other non-energy benefits as well as policy and equity-related goals. Adding decarbonization goals to existing programs and revising screening practices to account for non-energy benefits, such as carbon reductions and resilience from natural disasters, could expand the set of eligible measures offered to customers, such as building energy efficiency retrofits and incentives for various electrification technologies.

As prior sections of this report have discussed, there are additional complexities with reaching low-income customers for home energy upgrades. The following section provides several program approaches utilities are taking to incentivize electrification for affordable housing in states such as Illinois, Colorado, and Massachusetts. Following that, we profile several utilities that have particularly comprehensive strategies and/or success in delivering results.

Utility Program Approaches

New Builds and Code Support

Utilities can leverage building energy code compliance support—incentives paid out by utilities to homebuilders to construct homes and buildings that go beyond standard building energy codes—to achieve widespread, long-lasting energy savings and GHG emissions reductions on a market-wide scale (Stellberg et al. 2012). Certain states and jurisdictions have adopted zero energy (ZE) codes that go above International Energy Conservation Code (IECC) minimum requirements to construct highly efficient buildings that offset their energy footprint with distributed generation (i.e., rooftop or community solar). Some codes and programs promote "zero-energy-ready" homes that are highly efficient but do not yet offset their remaining energy footprint with distributed generation (Nadel 2020). By providing incentives for builders to construct new housing that goes above code and including incentives for installing all-electric or prewiring homes to make them "ready to electrify," utilities can lower the initial cost barrier to electrification and encourage homebuilders to pass down those savings to their customers.[20]

Utility incentives for above-code buildings are offered by Commonwealth Edison in Illinois (detailed below) and other utilities and utility-funded organizations such as NYSERDA, Mass Save, and National Grid Rhode Island (Nadel 2020). While building homes to meet this standard does come at a cost premium over standard code, utilities can assist homebuilders in addressing this difference by providing financial and logistical support for installation and certification. In addition, as the market grows for qualified professional designers and contractors, the cost to construct homes to this standard is likely to go down.

Incentives for Electrification Technologies

Another approach that is common across large and small utilities is providing technology rebates that may be claimed by individual homeowners, multifamily property owners, or directed to midstream contractors or distributors. This funding may support other programs run by third-party implementers, such as the City of Denver utilizing Xcel Energy's rebates to reduce up-front costs of all-electric new buildings (NBI 2021). Research by the Pacific Northwest National Laboratory (PNNL) identified over 850 air-source heat pump rebate programs and 240 heat pump water heater rebate programs offered by utilities in 2021 (PNNL, pers. comm.). A recent ACEEE report discusses 42 programs that specifically encourage electrification (Cohn and Esram 2022). Certain utilities may offer scaling rebates based on income qualifications, up to and including the full cost of the measure. However, low-income households (or property owners for multifamily units) may not be able to access rebate-based incentives due to lacking the up-front capital, having homes in need of repair beyond simply replacing inefficient appliances, and/or having limited control of their home energy use due to renting the property (see "Split Incentive" in the definitions section above).

[20] All electric appliances, such as heat pumps, water heaters, and induction cooktops, require dedicated circuitry and sufficient capacity on the home's electric panel. In electrification retrofits, the cost of wiring and panel upgrades can add an additional $2,000–5,000 to existing project costs.

Retrofits for Existing Buildings

To effectively combat GHG emissions and deliver electrification measures and benefits to most affordable housing units, utility programs need to target existing building retrofits in addition to new construction. Forty of the 52 utilities evaluated in the 2020 *Utility Scorecard* operated whole-home audit and/or retrofit programs for single-family and multifamily buildings. These programs represent a critical opportunity for utilities to deliver electrification measures for existing buildings.[21] By braiding electrification with existing energy efficiency program delivery, utilities can reach customers where they are most receptive and prescribe and deliver results that optimize electrification, weatherization, and energy efficiency.

Even with ambitious goals, however, electrification outcomes in existing buildings can often lag expectations. Massachusetts, with a stated goal of 100,000 conversions per year of fossil-fueled space and water heating, saw just 461 homes making the switch in 2021 (Shankman 2021). Although several utility-funded efforts exist for the affordable housing sector, these are largely conventional energy efficiency efforts—notably the Massachusetts Low-Income Energy Affordability Network (LEAN), which operates a direct-install energy efficiency program for multifamily where at least 50% of units are occupied by households at or below 60% Area Median Income (Mass Save 2019). This program, which has a whole-building approach, has recently expanded its criteria to include electrification upgrades, such as space heating and hot-water system replacements, alongside insulation and air sealing, lighting and appliance retrofits, water efficiency measures, and other energy-saving measures that meet the cost-effectiveness criteria. However, an equivalent type of whole-building approach does not yet appear to exist for market-rate units. Utility efforts will need to dramatically scale up in the coming years to meet state policy targets for electrification.

[21] On their own, home energy audits are often insufficient to deliver comprehensive impacts and energy savings. These must be paired with direct installation services or, at a minimum, incentives for installation of measures in order to result in substantial uptake of audit recommendations. Due to inconsistent reporting methods from utilities on home retrofit participation, the 2020 *Utility Scorecard* combines audit and retrofit programs into a single metric.

Utility Program Examples

The section below highlights a selection of utility programs that provide electrification and/or decarbonization for affordable housing and LMI households, including program delivery methods and strategies used to overcome barriers.

Sacramento Municipal Utility District (SMUD)

SMUD, the municipal utility for Sacramento, California, has one of the most ambitious decarbonization targets of any utility in the nation, with a goal of reaching 100% carbon-free power by 2030 (SMUD 2021). To attain that goal, the utility seeks to combine supply-side resource changes with demand-side solutions for customers. The utility offers several incentive programs and partnerships to address different segments of the affordable housing sector, including low-income single-family and multifamily as well as market-rate programs. In addition, SMUD's Sustainable Communities initiative involves partnerships with key community groups like Habitat for Humanity, the Sacramento Housing & Redevelopment Agency, and the Mutual Housing Fund. By combining resources and supplying funds to these initiatives, SMUD can more easily deliver incentives for electrification measures such as heat pumps, water heaters, and induction stoves to many low-income units in its service territory. The utility's various decarbonization program offerings and incentives for low-income and multifamily housing are detailed below.

Low-Income Electrification. To ensure low- and moderate-income customers are not left behind in the energy transition, SMUD embedded electrification incentives within its existing direct-install energy efficiency program. All customers enrolled in SMUD's energy assistance program are qualified for in-home energy audits and weatherization services. Electrification measures are combined with this service at no cost to the customer. Since including this component, SMUD has conducted fuel switching on more than 80% of homes receiving incentives and services through this program (Gerdes 2019). These conversions may additionally require upgrading 100-amp electrical service panels to a 200-amp unit. Full electrification project costs for low-income customers can range from $10,000–15,000 depending on the extent of upgrades required. SMUD pays the full cost.

Existing Multifamily. SMUD's Go Electric incentives are designed for existing multifamily properties with 5+ units to promote switching to electric space heating, water heating, and cooking appliances. This program also offers incentives for wiring and electrical panel upgrades, EV charging, and energy efficiency measures. Property managers can receive a per-appliance incentive and an additional 25% incentive for majority income-qualified apartment complexes. Project managers work with property owners to provide and deliver incentives but also engage directly with building residents to provide education and guidance through the upgrade process.

New Homes Electrification. This program targets housebuilders with incentives to construct all-electric and energy-efficient single-family and multifamily residential houses. SMUD provides a per-home incentive of $4,000 per single-family home and $1,250 per multifamily unit, with an additional bonus for including induction cooking appliances. To qualify for incentives, builders must construct homes with all-electric appliances and mechanical systems, with no gas service or infrastructure. The program also includes a demand response component in the form of an optional add-on incentive for connected heat pump water heaters.

DC Sustainable Energy Utility (DCSEU)—Low Income Decarbonization Pilot (LIDP)

This pilot program concluded its initial run with 10 total units receiving partial or full conversion to all-electric heating, hot water, and cooking, with distributed solar on the single-family units and a community solar subscription for the four-unit multifamily complex. These whole-home conversions were provided at no cost to income-qualified participants. Program managers noted high satisfaction rates among participants, with 9 out of 10 reporting entirely positive outcomes in surveys after the pilot concluded. Beyond energy savings, customers responding to these surveys indicated they experienced improved air quality and increased comfort levels in their homes because of electrification and weatherization measures. The program managers cited clear communication from the contractor as a key aspect of ensuring participants were well-informed and satisfied with the process.

Program administrators encountered some unexpected challenges and complexities as well. The COVID-19 pandemic created multiple obstacles and required reducing the planned participant group of 20+ households by more than half. Other barriers included the cost and complexity of wiring and panel upgrades. Additionally, the relatively short time frame for the project placed stress on the contractors, permitting processes, unit delivery, and other factors. Most projects were completed in under 45 days; a typical full-unit conversion takes upward of 4–6 months (Patti Boyd, DCSEU, pers. comm., July 9, 2021). Lastly, administrators emphasized the importance of clearly communicating program goals and outcomes up front. Some participants initially believed this was a whole-home renovation rather than an energy-oriented program. Once program administrators addressed participants' questions, the process proceeded smoothly.

Based on the success of the pilot, the DCSEU is moving forward with more building decarbonization incentives beginning in 2022. An HVAC replacement program provides for the installation of high-efficiency electric heat pumps, high-efficiency electric water heaters, and advanced thermostats in single-family homes owned or rented by low- and moderate-income District residents. The Affordable Housing Retrofit Accelerator is a comprehensive energy retrofit program that provides technical and financial assistance to affordable multifamily residential building owners who are required to comply with the District's Building Energy Performance Standards (BEPS).

Commonwealth Edison, Illinois—New Building Electrification

ComEd in Illinois has for several years run new construction programs that provide additional funding for energy efficiency in affordable housing and all-electric homes. In a recent pilot study comparing two multiunit dwellings of the same type built to different standards, ComEd found that building homes to meet the Passive House Institute U.S. (PHIUS+) criteria with all-electric heat and appliances would lead to 42% reduced kWh consumption and 60–70% lower GHG emissions compared with properties built to 2020 code (Slipstream 2021). Based on the success of this pilot, ComEd is recommending a PHIUS+ certification pathway be included in the existing affordable housing new construction program.

Efficiency Vermont—Targeted High Use (THU) Program for LMI

Efficiency Vermont, a statewide regulated energy efficiency utility, offers various programs, incentives, and rebates to encourage its customers to retrofit homes and buildings. The organization's THU program incentivizes direct-install of efficiency and electrification measures such as appliances, heat pumps, and heat pump water heaters to qualifying houses with high electricity use. This program was promoted to customers who were deemed likely to be income eligible and were (based on utility data) users of 10,000 kWh per year or more. Based on qualitative feedback from participants in the program, the Efficiency Vermont team aims to redesign this program to incorporate more diverse voices and representatives from marginalized communities at all stages of program management and delivery (Wentz et al. 2021).

CITY AND MUNICIPAL POLICIES AND PROGRAMS

Cities and local governments face compounding crises of increasing climate disruptions and affordable housing shortages. Most recently, Hurricane Ida, which caused extreme flooding in cities like New Orleans, Philadelphia, and New York City, highlighted the need for both climate resilience planning and strengthening a city's infrastructure, including the electric grid. Increasing extreme weather events pose a huge risk to affordable housing and its residents, typically low- and moderate-income families who are particularly vulnerable to the impacts of climate-related disasters as a result of historic divestment (Enterprise 2021).

A growing number of municipalities have adopted electrification policies, although they are still not widespread. Along with establishing decarbonization goals and supportive policies, local governments are collaborating with affordable housing advocates, developers, and community-based organizations to advance energy efficiency and electrification in affordable housing. Below are selected examples of local policies and programs designed to achieve both carbon and energy use reductions.

Building Performance Standards

Building energy performance standards (BPS or BEPS) are key policies that can accelerate the decarbonization of the affordable housing sector. Building Performance Standards are "mandatory performance-based standards that set limits on energy or GHG emissions intensity for certain building types" (RMI 2021). BPS crucially target existing buildings, many of which have equipment or building systems that are inefficient and nearing the end of their lifecycles. Using a whole-building approach to electrification offers the opportunity to size equipment in the most optimal way, reducing costs and improving performance and comfort. BEPS is currently a powerful and popular tool for multifamily housing. Home energy scores or similar disclosure efforts in single family are not yet commonplace but could offer similar energy management opportunities for single-family affordable housing.

Currently, St. Louis, Missouri; New York City, New York; Reno, Nevada; Boulder, Colorado; and the District of Columbia,[22] as well as Washington State have building performance standards (Nadel and Hinge 2020). Recently, Colorado and the cities of Boston and Denver have adopted such standards as well (Nadel 2022). Municipalities should take steps to ensure that owners of affordable housing have the financial and technical support needed to comply with the policies. For example, Washington, DC, has created the Affordable Housing Retrofit Accelerator program to help multifamily affordable housing building owners comply with the District's newly adopted BEPS. The District Government, DC Sustainable Energy Utility, and the DC Green Bank are collaborating in this effort to meet the city's sustainability goals. The accelerator offers financial and technical assistance to building owners in complying with the District's energy standards (DC DOEE 2021).

[22] For detailed information on how affordable housing stakeholders collaborated to make sure the affordable housing community in Washington, DC, would be able to comply with BEPS, see *Recommendations for Implementing the District's Building Energy Performance Standard in Affordable Multifamily Housing* (November 2019).

Local Program Examples

MINNEAPOLIS: 4D AFFORDABLE HOUSING INCENTIVE AND GREEN COST SHARE 4D ENERGY EFFICIENCY PROGRAMS

The 4d program was created to preserve unsubsidized affordable housing while also addressing energy efficiency and resident health and improving building owners' bottom line (City of Minneapolis 2018). The program also has a goal of incentivizing the development of new market-rate affordable housing in the city. Although deep decarbonization of these buildings is not the goal of the program, given the program's success, the 4d program has several key elements that should be considered when designing programs that do have decarbonization and the preservation of affordable housing as the primary goal.

This program takes advantage of the state's 4d 40% property tax reduction for low-income properties as an incentive for market-rate building owners to keep rents affordable. In exchange for committing to maintain affordable rents, the city helps property owners apply for the 40% tax abatement. Properties qualify for this program if at least 20% of units have current rents that are affordable (30% of gross income) to households earning at or below 60% of Area Median Income (AMI) and the property owners agree to keep these rents affordable for a period of 10 years. Other program offerings include a grant of up to $1,000 and, eligibility to participate in the Green Cost Share 4d Energy Efficiency program for additional incentives. If the property owner chooses to participate in the 4d Energy Efficiency program, they are eligible to receive funding of up to $50,000 per building and 90% of the project cost after applying for utility incentives and energy efficiency programs (Samarripas and Jarrah 2021). Furthermore, the program offers free energy assessments for energy efficiency upgrades and solar energy incentives up to $50,000 per project (City of Minneapolis 2018).

Initially, the city's Green Cost Share Energy Efficiency program received very little interest. To increase participation, the city combined the offerings of the 4d Efficiency program with the 4d Affordable Housing Incentive Program (Samarripas and Jarrah 2021). Combining both programs has proven to be a successful strategy, leveraging funds, administrative expertise, and historical knowledge from multiple funding streams and city departments. The program directly takes on the split incentive to remove barriers to participation in energy efficiency upgrades. This coordination has proven to be a key element of success for implementing and administering the program offerings.

Several other elements in the 4d program also contribute to the program's success. The state's 4d tax credit helped the city to meet its goals of preserving affordable housing and fostering energy efficiency. Renegotiation of the city's franchise agreement with local utilities included using part of the franchise fee for funding programs benefitting low-income residents and communities of color (Samarripas and Jarrah 2021).

Boston

Through an RFP in 2020, the city of Boston announced that almost $30 million would be available to affordable housing developers or owners seeking financial support from the city for the construction or rehabilitation of affordable housing. In addition to a commitment to serving extremely low-income Bostonians, unhoused populations, seniors, or special needs households, the developer must prove that their staff reflects the diversity of Boston's population. Moreover, the city requires that new construction comply with carbon neutral performance standards to support the city's climate impact reduction goals. Meeting these carbon neutral goals will require energy efficiency measures, electrification, and renewable energy.

Chicago

Chicago's building stock is responsible for 70% of the city's GHG emissions. Given their large contributions to emissions, the city has created a working group focused on equitable decarbonization of the city's building stock that features members of the city's affordable housing organizations. The city acknowledges its role in the creation of past policies that have widened racial and economic disparities in communities of color and is taking steps to undo those harms by creating intentional discussions around equitable decarbonization.

Ithaca, New York

Ithaca recently made national headlines when it became the nation's first city to begin decarbonizing 100% of its building sector. Through private funding, local government incentives, and working with organizations such as the energy startup BlocPower, the city plans to begin electrifying thousands of its commercial and residential buildings to meet its climate goals. The city plans to incorporate equity into their decarbonization efforts, which includes special considerations for the complicated financing cycles for affordable housing.

Denver

Denver has also passed legislation that seeks to regulate emissions in large multifamily and commercial buildings, requiring those "25,000 square feet or larger to achieve 30% energy savings by 2030, with interim goals set in 2024 and 2027" (Metzger 2021). Requirements such as the need to electrify building heating systems make the legislation a powerful tool for pushing electrification and decarbonization. The timeline for the requirements ensures a gradual uptake of these systems, which can often be cost-prohibitive if done at once along with other energy efficiency upgrades such as weatherization.

Decarbonization strategies are key to reducing a city's emissions from buildings. At the same time, access to and prevalence of affordable housing is a key issue that many cities are struggling to address; investing in the creation and preservation of affordable housing is essential to the well-being of communities across the country. Local governments wishing to design policies or programs that target their affordable housing for decarbonization should take steps to ensure they have relevant comprehensive housing and household data on target markets. Additionally, they should leverage existing programs, funding, or partnerships to create well-designed and robust policies or programs for affordable housing (Samarripas and Jarrah 2021). When created without centering equity considerations, programs or policies have the potential to deepen systemic injustices for communities of color, adversely impacting affordability or causing displacement. Intentional equity considerations help ensure that affordable housing, particularly unsubsidized affordable housing, continues to serve lower income populations. Fortunately, community-based organizations (CBOs) and organizations working closely with impacted communities have created resources and roadmaps[23] to help cities formulate strong programs and policies that address the need to decarbonize affordable housing while ensuring these buildings remain affordable.

[23] Although not an exhaustive list, see *Equity and Buildings: A Practical Framework for Local Government Decision Makers, 2021; Equitable Building Electrification A Framework for Powering Resilient Communities, 2019;* and *The Building Electrification Equity Project, 2020.*

NONPROFITS AND NONGOVERNMENTAL ORGANIZATIONS

New York City's Urban Homesteading Assistance Board

On the leading edge of decarbonizing their affordable housing stock, New York City has also taken direct steps to electrify it. Though these projects have not been completed, this development offers a promising outlook for other cities interested in electrifying their affordable housing. The lessons learned from these projects will undoubtedly be impactful for cities with similar housing stocks.

New York City's low-income housing cooperatives have also taken steps to decarbonize their building energy systems. The Urban Homesteading Assistance Board (UHAB) was created in the early 1970s during the self-help housing movement, precipitated by years of racist housing policies and intentional community divestment. The group's mission is to "empower low- to moderate-income residents to take control of their housing and enhance communities by creating strong tenant associations and lasting affordable co-ops" (UHAB 2021). As democratic, community- and tenant-centered housing entities, housing cooperatives often do not have to overcome split incentives or landlord indifference and are more likely to make decisions that are good for residents in the long term. Moreover, UHAB has been able to assist cooperatives in taking advantage of and implementing necessary measures to meet New York City's aggressive climate goals and policies such as Local Law 97[24] and Local Law 84.[25]

UHAB has partnered with Solar One and low-income HDFC[26] cooperatives to support the installation of rooftop solar PV systems that are owned by the cooperative, as well as to electrify their building's heating systems. The Co-ops Go Solar campaign also assists with virtual net metering arrangements for co-ops that may not be able to install rooftop PV systems. The campaign provides co-ops with free technical support and assists in identifying incentives such as rebates for installing PV systems to reduce overall project costs. UHAB also created the Clean Heat for Co-ops program to help buildings install heat pumps over oil or gas boilers. To engage and educate tenants on energy-related decisions for their buildings, UHAB has created educational materials and training for tenants to learn and make informed decisions about their building's energy use (UHAB 2021). In 2021 UHAB hosted 93 classes on environmental justice, solar power, and electrified heat, which complement their energy-related programs (UHAB 2021).

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[24] Local Law 97 requires most buildings over 25,000 square feet to meet new energy efficiency and greenhouse gas emissions limits by 2024. https://www1.nyc.gov/site/sustainablebuildings/ll97/local-law-97.page.

[25] Local Law 84 requires building owners to report water and energy use via the ENERGY STAR program from the U.S. Environmental Protection Agency. https://www1.nyc.gov/html/gbee/html/plan/ll84_about.shtml.

[26] In New York City, HDFC co-ops are affordable housing cooperatives. "In HDFC co-ops all shareholders own an equal number of shares, regardless of the size of their apartment. Shareholders elect a Board of Directors to make decisions about the co-op. The Board of Directors is legally obligated to act in the best interests of the HDFC and its shareholders….They are responsible for ensuring the financial well-being of the coop, as well as compliance with the law and regulatory restrictions placed on the property, including income, resale and subletting restrictions. HDFC co-ops are different from market-rate co-ops in that a shareholder's ability to gain a profit from selling a unit is limited to ensure the continued affordability of the unit to future low-income purchasers" (City of New York 2022).

Big Reach Initiative

Decarbonization initiatives for affordable housing at the local level can draw on the experience of successful national-level energy efficiency programs. The Big Reach initiative from Stewards of Affordable Housing for the Future (SAHF, a national nonprofit organization) demonstrated how affordable housing can exceed a 20% portfolio-wide reduction in energy and water use. The Big Reach initiative was developed contemporaneously with the DOE's Better Buildings Challenge (BBC) multifamily program. Taking advantage of the concurrent development of the BBC multifamily program, SAHF worked closely with HUD to overcome split incentives in affordable housing. SAHF's knowledge of the financial and administrative challenges associated with this sector made them a key stakeholder in the development of these incentives. The Big Reach initiative took place over the course of seven years, 2013–2020. In the years leading up to the launch, SAHF members (who are large, nonprofit affordable housing developers) undertook a series of pilot initiatives to assess the potential of strategies to reduce energy and water consumption, which led to the yearlong process of setting a reduction target for the initiative. At the conclusion of the initiative in 2020, participants were allowed to exceed their target and achieved a 29% energy savings against a 2010 baseline. These savings were achieved through carefully crafted strategies that considered the challenges faced by affordable housing owners, managers, and developers (Schaaf, Wongbuphanimitr, and Ponsor 2021).

Although the portfolio-wide strategies varied by participant and considered unique utility landscapes, operational necessities, and building priorities, many of the strategies pursued in the Big Reach initiative are outlined in LIHTC QAP requirements intended to incentivize energy efficiency. Among the most popular strategies utilized in the Big Reach to achieve a 20% portfolio-wide energy use reduction were pursuing third-party green building standards, discretionary retrofits, and the incorporation of renewable energy. Operations and maintenance as well as behavioral approaches like resident engagement were also key strategies. The Big Reach initiative additionally covers water efficiency, a need for many localities in increasingly water scarce areas.

Some of the main barriers raised in the Big Reach initiative included the ability to collect energy consumption data for benchmarking. Depending on the metering arrangement, data privacy concerns could be an impediment to a building's ability to use benchmarking as a strategy for energy efficiency. Access to better consumption data would also benefit affordable housing residents by allowing more accurate utility allowances. To date, overly simplistic and inaccurate methods are used to allocate utility allowances for residents in some subsidized buildings (A. Brindel, Midwest director of energy efficiency policy, National Housing Trust, pers. comm., August 12, 2021).

The outcomes of the Big Reach initiative are tremendously promising and show that these efforts can be scaled up to ensure that nationwide creation and preservation of affordable housing is energy efficient and eventually low/no carbon. However, these efforts are more feasible for owners of larger portfolios who may be able to hire staff to manage energy projects. Owners of affordable housing with smaller portfolios may find this more challenging. It is important to consider these differences when creating policies or advocating for programs, to ensure proper technical, administrative, and financial support. Cities and local governments can look to the Big Reach initiative to scale decarbonization work, as the foundational steps from energy efficiency to deep decarbonization of affordable housing have been tried and tested and demonstrated success through this initiative.

Conclusions and Recommendations

STATUS, OUTLOOK, AND PROMISING DEVELOPMENTS

Our research shows that efforts to achieve decarbonization of affordable housing through high energy efficiency and electrification are at early stages of development and implementation. We found relatively few examples of mature, full-scale programs serving large customer populations, although a growing number of cities, states, and utilities are establishing policies and programs for decarbonization that target affordable housing. Such efforts are mostly at early stages in a handful of states. Many of the examples we identify tend to be single demonstration projects or pilot programs. This reflects the relative newness of promoting less-familiar electric technologies, such as heat pumps and induction stoves, over well-established fossil fuel technologies, such as natural gas stoves and furnaces. As a result of limited program experience, there are gaps in proven approaches to address key barriers for decarbonizing affordable housing, such as reducing split incentives, reaching rental households, and procuring large amounts of capital to improve building stock and electrify existing fossil fuel technologies.

Despite the limited number of examples, local governments, utilities, statewide initiatives, affordable housing advocates and developers, and others are laying the foundations for decarbonizing affordable housing. Some of these initial efforts target new construction[27] as this can be the easiest market to affect, providing great opportunities for high efficiency and electrification. Restrictions or outright prohibitions on new natural gas hook-ups are controversial, but some cities are passing such ordinances, such as New York City, Berkeley, and San Francisco. Installing all-electric HVAC and major appliances typically can be done without increasing construction and total project costs. While some electric technologies may have a price premium, such extra costs can be offset by not requiring gas line extensions and hook-ups (Higbee et al. 2020; Armstrong et al. 2021); building all electric could save affordable housing developers thousands of dollars in avoided gas infrastructure costs. Environmental, health, and safety considerations add to the strong case for all-electric construction. Well-insulated and weatherized buildings also can provide resilience benefits during power outages for maintaining livable indoor temperatures for longer periods.

Higher costs for electrification technologies pose large barriers for affordable housing, particularly for building retrofits. As markets grow for electrification technologies, these costs are likely to decline. However, for LMI communities, policies and incentive programs will be necessary to support their transition to all electric. Out of all income groups, these communities have the most to gain from the health benefits and energy savings that are achievable through comprehensive energy efficiency retrofits and electrification. Moreover, they are at risk of experiencing a disproportionate future burden of funding the maintenance of fossil fuel infrastructure that may become stranded in the long term. They cannot afford to be among the last to switch to electric. If we depend on the market alone, they inevitably will be.

In terms of technological barriers, current research efforts provide a good outlook for advancements that will increasingly minimize those limitations and increase the equipment's flexibility to existing building conditions, especially in the affordable housing building stock. Innovative retrofit approaches, such as prefabricated insulation, make the prospect of an entire multifamily building retrofit more feasible.

[27] The embodied energy of building materials in new construction is another concern that is important to address as part of decarbonization strategies as they progress.

REACHING THE POTENTIAL FOR DECARBONIZATION OF AFFORDABLE HOUSING

Our review of decarbonization policies and programs targeting affordable housing reveals common keys to success. These include

- Setting specific carbon reduction goals
- Securing adequate funding and financing
- Establishing collaborations among affordable housing stakeholders
- Engaging with affordable housing residents
- Educating residents, building owners, contractors, and suppliers

Of these, securing adequate funding and financing is perhaps the biggest hurdle, particularly for retrofitting buildings to achieve high energy efficiency and to electrify existing fossil fuel technologies. Affordable housing providers generally cannot do substantial upgrades without financial and technical assistance. Many have limited staff and access to capital. Funding and requirements for energy efficiency in affordable housing do exist and measures have been implemented successfully in various climate zones in the United States. Many utilities are also able to provide low-income incentives; however, these offerings vary by locality. A push for more coordination and flexibility for taking advantage of and combining different programs and incentives is necessary for creating robust programs that can address housing affordability and decarbonization at the same time. As illustrated by the Big Reach initiative, having a dedicated sustainability staff for affordable housing developers is an effective approach to achieve these goals (Schaaf, Wongbuphanimitr, and Ponsor 2021).

To achieve decarbonization in affordable housing, we make the following recommendations.

For federal policymakers and agencies:

- Establish funding specifically for decarbonization of affordable housing retrofits through high energy efficiency and electrification, leveraging both existing programs and new ones emerging from infrastructure investments.
- Continue to provide and increase funding to states for community development via tax credits and block grants with flexibility for energy efficiency and electrification retrofits.
- Establish requirements for decarbonization and energy efficiency in housing supported or provided through federal programs.
- Prioritize equity in developing and implementing climate change policies and programs.

For state policymakers and agencies:

- Establish requirements or preferences for decarbonization in housing supported or provided through state programs or through federal programs administered at the state level.
- Revise building codes to align with decarbonization goals.
- Create and offer attractive financing options, such as green banks.
- Allow health and environmental funding to be used for decarbonization of existing affordable housing, braiding complementary funding streams together.

For utility regulators:

- Ensure that regulatory processes are structured to involve and incorporate feedback from affordable housing stakeholders, particularly low-income and marginalized communities.
- Encourage utilities to support electrification by setting annual targets and providing a financial incentive for meeting certain goals, including reaching LMI communities with electrification incentives and programs.
- Specify that electrification programs include requirements for building shell efficiency (and upgrades if necessary) to reduce the electrification installation and operation costs and help minimize the added electric supply costs.
- Review and revise as necessary existing regulations, policies, and procedures that may limit or work against decarbonization for affordable housing, such as existing restrictions for fuel switching and metering.

For cities:

- Examine existing program offerings to identify and implement changes that can be effective in reaching decarbonization goals and maximizing positive outcomes for LMI communities, incorporating emerging best practices.
- Establish building performance standards requiring decarbonization retrofits with support and flexibility for affordable housing, as is starting to happen in some cities.
- Develop and commit substantial new funding resources for upgrading buildings while keeping homes affordable, especially at critical times for new investment, such as refinancing and other planned building upgrades.
- Establish affordability requirements for building upgrades completed as the result of decarbonization programs and projects.

For program administrators (utilities or non-utility organizations):

- Establish collaborations and partnerships among the many organizations and stakeholders involved in affordable housing, including local governments, housing authorities, developers, financiers, utilities, community-based organizations, environmental justice organizations, building owners, and residents to leverage resources and create effective programs.
- Ensure that electrification programs include components for building shell efficiency upgrades, to reduce the electrification installation and operation costs, improve customer comfort, and help minimize the added costs to the electric system.
- Take advantage of multiple funding offerings, such as community development grants and various state and federal programs that address energy, environmental quality, and health to secure sufficient program funding, particularly for retrofitting affordable housing.
- Engage and involve residents in creating and implementing affordable housing programs to best meet their needs, interests, and abilities.
- Establish workforce training programs to increase the number of qualified electrification contractors (possibly with state agencies and other partners).

Pursuing decarbonization for affordable housing will require the coordinated implementation of building energy efficiency improvements as well as electrification. Methods for improving building energy efficiency are well-proven. The principal technologies necessary for electrification are newer and comprise a small share in most relevant markets but perform well and are remarkably efficient. To grow these markets will require innovative technical and business solutions to overcome barriers to adoption. Current barriers stem mostly from installation/technology complexities and limitations, lack of awareness, high up-front costs, and the uncertainty and variability of operating cost savings due to differences in climate, electricity rates, fossil fuel costs, and equipment efficiency (especially in retrofit applications). A variety of coordinated and complementary efforts at all levels of government along with active engagement and partnerships among utilities, community-based organizations, housing developers, building owners, and residents are necessary to accelerate the decarbonization of affordable housing.

Decarbonization for affordable housing is challenging. It will require some new approaches but can draw upon a strong legacy of policies, programs, and projects that address energy equity and sustainability through energy efficiency and other distributed energy resources, such as renewable energy systems. In this way, the clean energy transformation underway can also be equitable, reaching all types of households, regardless of income or race.

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Appendix A. Estimating Energy Use and GHG Emission Impacts

To estimate potential energy and GHG emission reductions, we primarily used data from the 2015 Residential Energy Consumption Survey (RECS) conducted by the U.S. Energy Information Administration (EIA) and the U.S. DOE's Low-Income Energy Affordability Data (LEAD) Tool.

The 2015 RECS contains energy usage information for over 5,000 representative households from different regions, income levels, family structures, and housing types. For the purposes of this analysis, we classify low- to moderate-income (LMI) households as those with a total annual income below 80% of the Area Median Income (AMI). The dataset from RECS does not provide AMI data, but rather income ranges in increments of $20,000. This makes it difficult to perfectly align the RECS sample with our target demographic. Nevertheless, it was important to attempt this distinction, as studies indicate that energy use can differ with socioeconomic status. To form a sample of LMI households' energy use, we calculated the income threshold that would classify a household as low-income (using 200% federal poverty level as a substitute for AMI data) and then matched this with the income ranges in RECS. We could thus exclude households who fell outside of this identified range—for example, four- and five-person households earning more than $60,000, six-person households earning more than $80,000, and so on. Table A1 shows the low-income threshold for each household size, as well as the closest corresponding income range limit in RECS. Although not exact, it is the closest approximation to a low- and moderate-income sample given the available parameters.

Table A1. Low-income thresholds by household size

No. of household members	200% FPL low-income threshold	Closest income limit in RECS
1	25,760	40,000
2	34,840	40,000
3	43,920	60,000
4	53,000	60,000
5	62,080	60,000
6	71,160	80,000
7	80,240	80,000
8	89,320	80,000
9	98,280	100,000
10	107,360	100,000
11	116,440	120,000
12	125,520	120,000
13	134,600	140,000
14	143,680	140,000

As energy use patterns vary based on housing type, we sorted the data by the following housing categories: mobile, single family, small multifamily (two to four units), and large multifamily (more than four units). Table A2 includes a breakdown of these LMI household units.

Table A2. Low- and moderate-income households living in each building type

Building type	No. of LMI families in this building type
Manufactured/mobile homes and trailers	3,661,380
Single family	28,143,902
Multifamily (2–4 units)	5,651,916
Multifamily (5+ units)	12,455,350

We created an energy usage profile for each housing type, noting the average electricity, natural gas, propane, and fuel oil/kerosene usage (measured in Btus) as provided in RECS. We then calculated two savings scenarios: 30% energy efficiency improvements through a moderate decarbonization retrofit, and 50% efficiency improvements through a deep decarbonization retrofit. Both scenarios assume full electrification (i.e., discontinued use of natural gas, propane, and fuel oil/kerosene). These savings percentages come from energy modeling done by ACEEE and are consistent with actual energy reductions from case studies presented in Stopwaste's *Accelerating Electrification in Multifamily Buildings* report (2019). A deep retrofit would include full envelope (i.e., wall and attic insulation, air sealing, window replacements, etc.) and full equipment upgrades (i.e., HVAC and DWH). A moderate retrofit might pursue priority envelope improvements, such as attic insulation and air sealing (but exclude costly wall insulation or window replacements), and either an HVAC or DWH upgrade. Using emissions factors from the EIA, we calculated the corresponding CO_2 emissions for each housing profile.

The LEAD tool provides a breakdown of LMI households by housing type, which we then used to aggregate energy and carbon emissions savings to the 49 million LMI households in the United States.

Due to data limitations, this methodology does not account for low-income households who already reside in energy-efficient housing.

Appendix B. A Primer on Electrification Technologies

Heat Pumps

Heat pumps for heating and cooling are significantly more efficient than any of their electric resistance or fossil fuel counterparts. In the winter, heat pumps transfer heat from the outside to indoors; in the summer, they reverse this cycle to remove heat from inside a home. Figure B1 shows the heat pump's vapor-compression cycle.

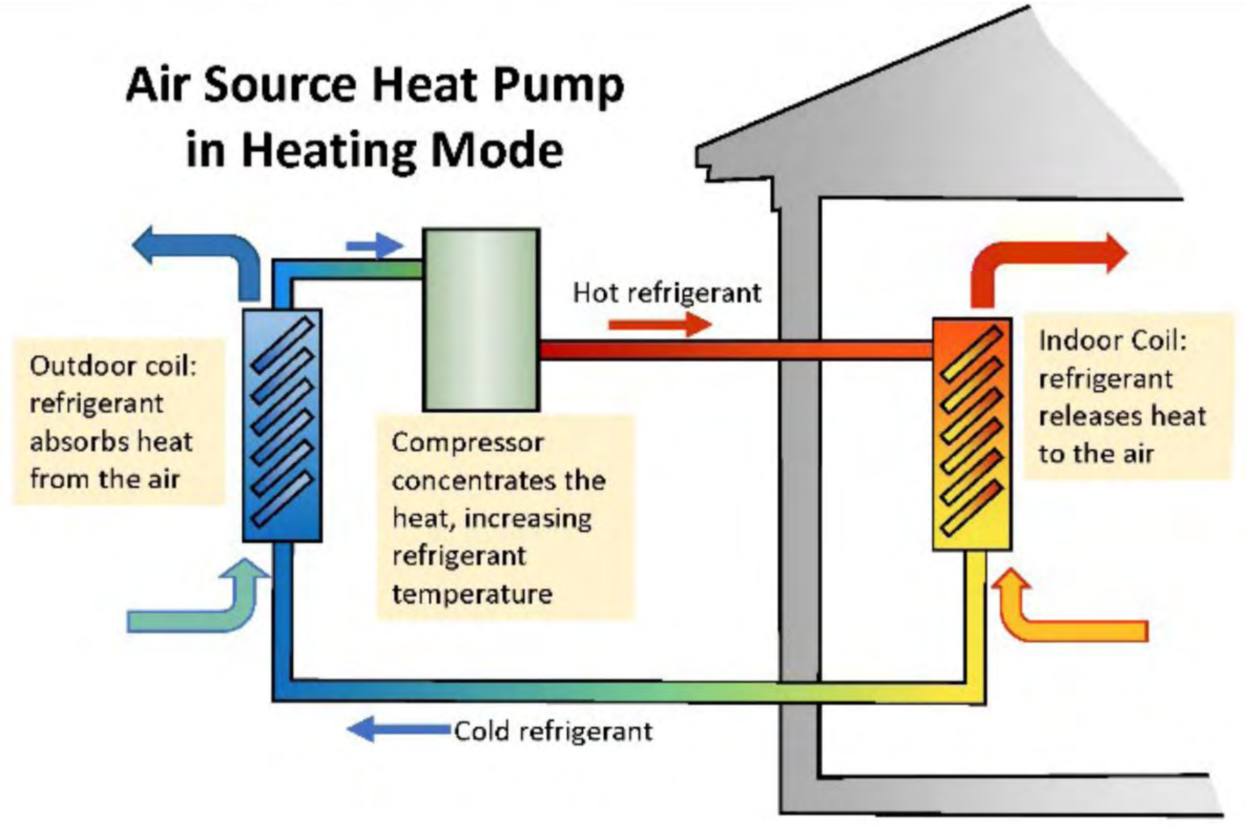

Figure B1. The heat pump cycle in heating mode. The cycle is reversed in cooling mode. *Sources*: NEEP 2020; original from David Pill, Pill-Maraham Architects.

Heat pumps are differentiated by how they source their energy. The three main types are air source, water source, and geothermal. Air-source heat pumps draw heat from the air; geothermal (ground source) from underground rocks or groundwater; and water source from a body of water such as a lake, a pond, or a well. Geothermal heat pumps are the most efficient of the three, especially in cold climates, but are expensive to install and are sometimes not cost effective (Levin 2018; Hopkins et al. 2018).

Air-Source Heat Pumps for Space Heating and Cooling

Air-source heat pumps (ASHPs) come in different configurations. They can be a ducted, mini-split, or packaged unit. Ducted heat pumps are split systems that rely on ductwork and can therefore make use of existing central distribution systems to distribute hot or cold air throughout the home. In homes or apartments without existing ductwork, ductless mini-splits may be a suitable option. They are smaller, in-unit systems that provide enough heating and cooling for a specific zone of the house (1–5 rooms), similar to window AC units. Ductless heat pumps are easier and less expensive to install, and usually more efficient than ducted models. They are most practical in climates that require both heating and cooling (SWA 2019). Another configuration is a packaged terminal heat pump (PTHP). These heat pumps have all the necessary components in a single unit and are often used in individual hotel rooms and apartments (Hopkins et al. 2018). Figure B2 shows models of these three heat pump configurations.

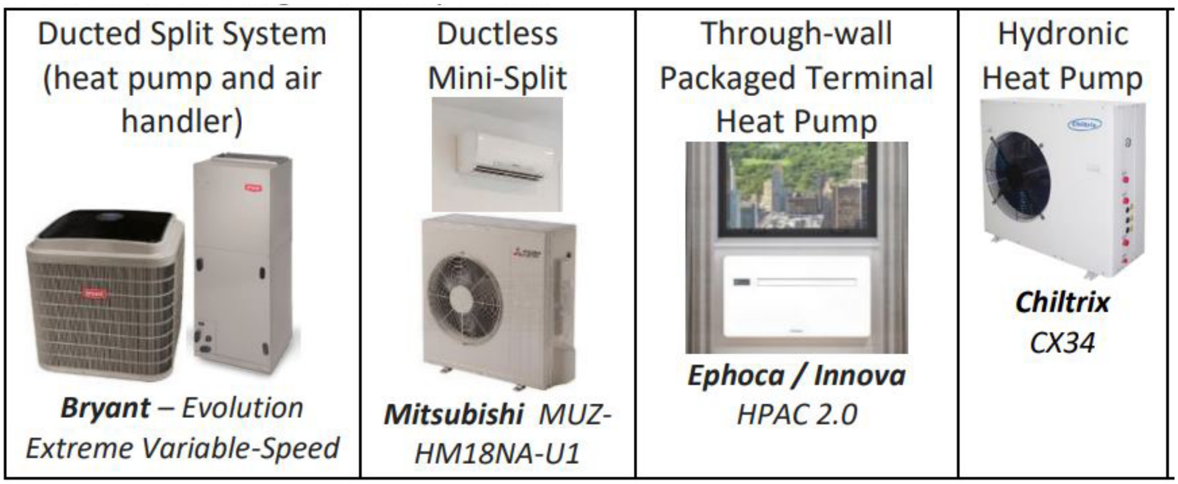

Figure B2. Heat pump models in different configurations. From left to right: ducted, ductless mini-split, and packaged terminal heat pump. ***Source***: Armstrong et al. 2021.

Replacing a central fuel-fired furnace with ducted mini-splits in a low-rise building and replacing packaged gas room heaters with PTHPs are both retrofits that carry a low level of difficulty (SWA 2019). This is due to favorable existing conditions (e.g., existing ductwork from the furnace can be used for the mini-splits; a packaged gas heater's location, required electrical service, and existing wall penetration all fulfill a PTHP's installation requirements); relative simplicity; and minimal disturbance to space and residents. In contrast, upgrading a steam or hot-water central system to mini-splits may be disruptive to all spaces and may pose difficulties for large buildings without appropriate spaces for the outside unit. Retrofitting steam or hot water in a high-rise to a central heat pump is also disruptive because of the new refrigerant lines that must be installed. Buildings that use hot water for space heating may benefit from water-source heat pumps that can reuse existing hot-water distribution systems, although attention must be paid to distribution water temperatures as many older buildings are designed for hotter water than many heat pumps can provide.[28]

[28] This problem can be addressed by weatherizing apartments so that cooler distribution water provides adequate heat or by using special heat pumps that can generate high-temperature water.

Since transferring heat requires significantly less energy than generating it, heat pumps are 2–5 times as efficient as traditional heating technologies (Levin 2018). Although they share similar refrigeration cycles, heat pumps are also nearly twice as efficient as air conditioners (Hopkins et al. 2018). Figure B3 shows the difference in efficiency between ASHPs and conventional heating and cooling technologies.

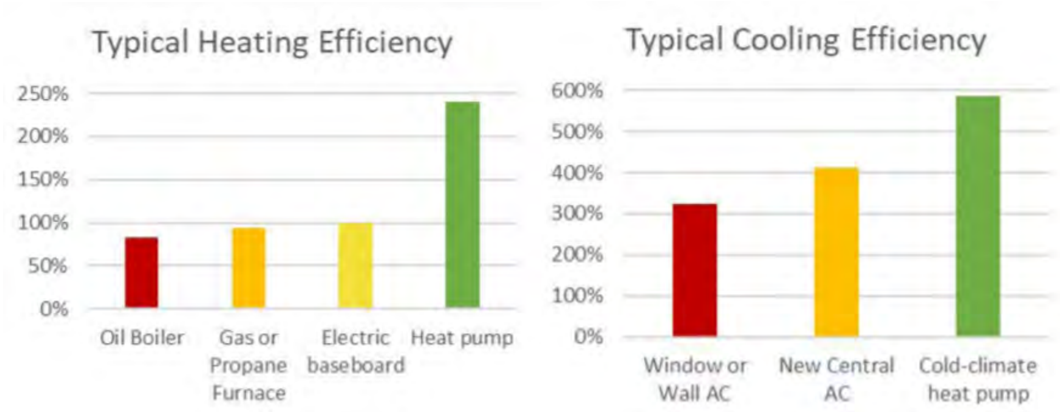

Figure B3. The typical efficiencies of air-source heat pumps compared to those of conventional heaters and air conditioners. ***Source***: NEEP 2020.

Cost effectiveness can vary, however. When replacing electric resistance, heat pumps almost always lead to significant utility bill savings. This is also the case when replacing oil heaters. Switching from natural gas heaters is not as straightforward. Gas heaters are much less efficient than ASHPs, but because electricity rates are higher than natural gas rates in most of the country, the retrofit may not lead to significant savings. To optimize the ASHP's efficiency and maximize utility bill savings, measures to reduce the heating and cooling demand—such as building envelope reinforcement—should precede a retrofit.

Heat Pump Water Heaters

Heat pump water heaters (HPWHs) come in unitary (also called integrated or packaged) and split models. Unitary HPWHs have all the needed components (air-source heat pump and storage tank) in a single unit, whereas split models consist of indoor storage tanks connected to outdoor heat pump systems. Figure B4 shows the components of both systems. Unitary HPWHs cool the area around them as they draw heat from the air. This can reduce cooling loads in the summer (or year round in some climates), but inversely, can add heating demand in the winter (Alstone et al. 2021). A possible workaround is installing ductwork leading to an attic, a closed-off hallway, a closet, or the outdoors where the heater can draw heat. Another possible solution is placing the unit where other systems (e.g., elevator equipment in multifamily buildings) produce waste heat they can repurpose (Eversource 2018).

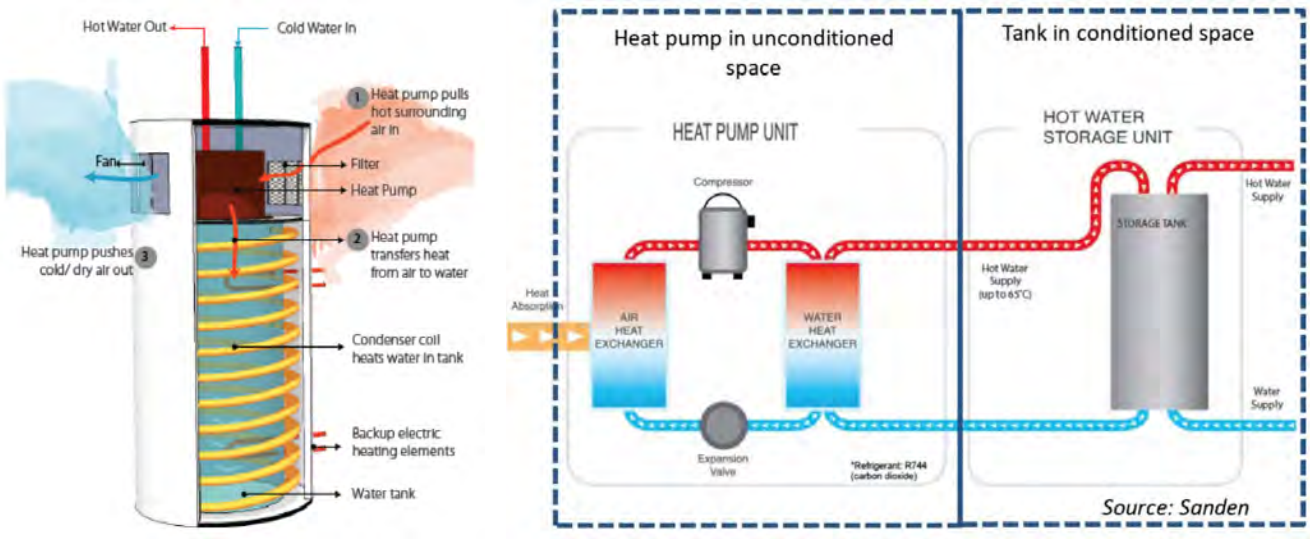

Figure B4. A unitary (integrated) HPWH (left) and a split HPWH (right).
Source: Shapiro and Puttagunta 2016; SWA 2019.

HPWHs can be used as central, in-unit, or multi-central systems. Central water heaters provide hot water to an entire building via a recirculation system. In multifamily buildings, they save space, facilitate maintenance, and reduce design coordination. They also minimize installation costs, but increase operating costs, as piping heat losses can make them half as efficient as individual systems (Gartman and Armstrong 2020). Individual in-unit systems provide hot water to a single unit or home. They are more efficient than central water heaters due to minimal heat loss, but their per-unit installation cost is much higher. Multi-central systems are hybrids and use individual water heaters to service several units (2–8). This results in minimal heat loss compared to the central system and reduced space requirements and installation costs compared to the in-unit models.

Induction stoves

Compared to both gas and electric resistance, induction ranges are generally the better option for performance, health, and safety considerations. Through its electromagnetic process (illustrated in figure B5), no heat is produced without cookware present, and the cooktop's surface itself is not heated. Once the hot pot or pan is removed, the surface cools very quickly, reducing the risk of accidental fires or of burn injuries. This immediate temperature response also offers remarkable precision and control over the cooking process, the lack of which is a common complaint about electric resistance stoves. The lack of heat waste can also reduce a home's cooling load in warm climates. Moreover, induction cooktops avoid the harmful emissions of gas stoves. These emissions and particles significantly impact occupants' health, leading to increased risk of respiratory illnesses, fatal carbon monoxide poisoning, and emergency room visits (Lin, Brunekreef, and Gehring 2013; EPA 2009).

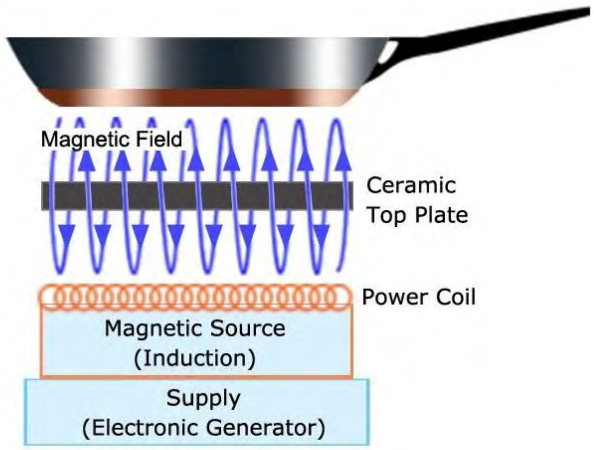

Figure B5. The induction cooking process. ***Source***: City of San Jose.

Due to induction's unique mechanism, nearly 90% of the energy input is transferred directly to the cookware, making this technology more efficient than gas or electric resistance ranges. A Frontier Energy report tested the performance of six cooktops—three induction, two resistance, and one gas—with comparable specifications (Livchak, Hedrick, and Young 2019). The performance metrics tested for heat-up time, temperature response, energy efficiency, and energy consumption. The induction stoves had a better performance than their gas and electric counterparts in most metrics. The incremental efficiency is less pronounced compared to electric than to gas but is nonetheless present. Table B1 shows a results overview of the different tests.

Table B1. Performance results of three induction cooktops, two resistance cooktops, and one gas burner.

Cooktop	Induction A (Frigidaire)	Induction B (GE)	Induction C (Samsung)	Resistance ceramic (Whirlpool)	Resistance coil (Frigidaire)	Gas burner (Samsung)
12-lb water heat-up time (min)	9.8	9.3	11.6	17.8	15.5	18.6
Heat-up efficiency*	85.2%	86.1%	83%	75.5%	79.3%	31.9%
Large pot 200°F overshoot*	0.8	0.8	0.8	7.1	4.9	1.7
Large pot cooldown to 190°F (min)	18.8	20.6	18.8	38.1	26.5	23.9
Sauté efficiency	52.5%	47.8%	54%	54.8%	38%	22.8%

*Key terms—Heat-up efficiency: percentage of the heat input that the cookware and its contents receive. Overshoot: the highest recorded temperature over the target (in this case, 200°F) after the cooktop is turned off. ***Source***: Livchak, Hedrick, and Young 2019.

Redwood Energy conducted a similar three-trial study comparing the performance of stovetops and other appliances (i.e., pressure cookers) while cooking one cup of dried chickpeas. When using the same type of cookware, the induction stovetop performed better than the electric. It was on average 40 minutes faster and used 22% less energy (Hueckel and Brandi 2020). Figure B6 shows the average energy use and cooking times of both stovetops.

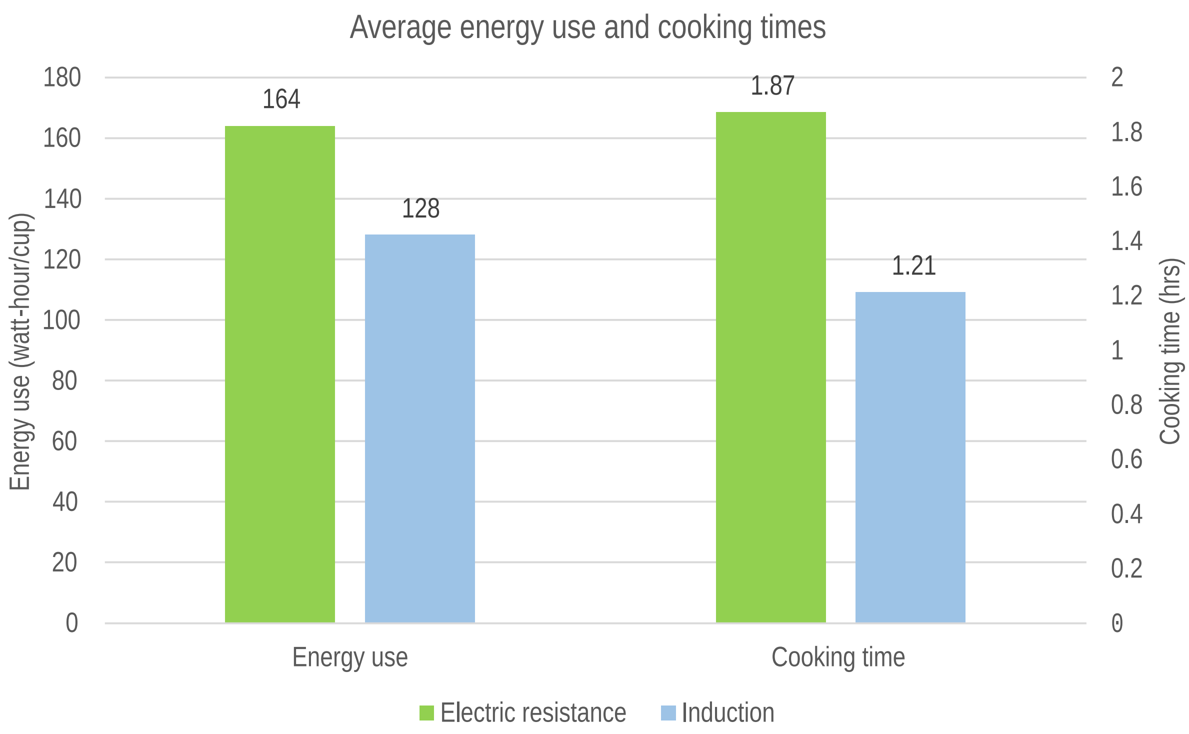

Figure B6. Average energy use (left) and cooking times (right) resulting from the trials. *Source*: Hueckel and Brandi 2020.

Appendix C. Use of Electric Heating by Region and Building Type

Region and building type	Total (in millions)	Electricity (in millions)	% using electric heating
U.S. Total	122,802,904	48,468,896	28%
Northeast Total	21,665,127	3,415,636	14%
Mobile Home or Trailer	489,292	47,010	9%
Single Family	13,034,718	1,248,379	9%
Small MF	3,103,383	505,295	14%
Large MF	5,031,790	1,613,785	24%
Midwest Total	27,105,867	5,939,238	18%
Mobile Home or Trailer	965,641	253,340	21%
Single Family	19,967,330	2,991,827	13%
Small MF	1,952,350	576,713	23%
Large MF	4,207,947	2,113,682	33%
South Total	46,381,669	29,634,107	39%
Mobile Home or Trailer	3,803,702	3,114,202	45%
Single Family	32,458,487	18,093,207	36%
Small MF	2,335,229	1,812,242	44%
Large MF	7,717,912	6,574,732	46%
West Total	27,650,241	9,479,915	26%
Mobile Home or Trailer	1,420,176	562,940	28%
Single Family	18,610,695	4,815,416	21%
Small MF	1,881,757	825,004	30%
Large MF	5,687,308	3,256,537	36%

Source: Pecan Street 2021