DECARBONIZING THE U.S. ECONOMY BY 2050

A National Blueprint for the Buildings Sector

April 2024

EXECUTIVE SUMMARY

Residential and commercial buildings are among the largest sources of carbon dioxide and other greenhouse gas (GHG) emissions in the United States, responsible for more than one-third of total U.S. GHG emissions. There are nearly 130 million existing buildings in the United States, with 40 million new homes and 60 billion square feet of commercial floorspace expected to be constructed between now and 2050. Today, most buildings consume large amounts of energy and cause significant climate pollution to meet our basic needs. Buildings account for 74% of U.S. electricity use and building heating and cooling drives peak electricity demand. Moreover, buildings are where electric vehicles (EVs), solar, storage, heat pumps, water heaters, and other distributed energy resources integrate with the electricity system. Consequently, the buildings sector will play a key role in achieving economy-wide net-zero emissions by 2050.

People spend 90% of their time in buildings and expend substantial sums of money on building energy costs—upwards of $370 billion annually. One in five American households is behind on energy bill payments, with people in economically marginalized communities more likely to face energy insecurity due to high energy costs. Such communities also bear the brunt of health-harming pollution emitted from burning fossil fuels and safety risks from substandard building conditions. Transitioning buildings to clean energy sources and reducing overall energy consumption will therefore address not just climate risks but also the physical and financial well-being of all Americans.

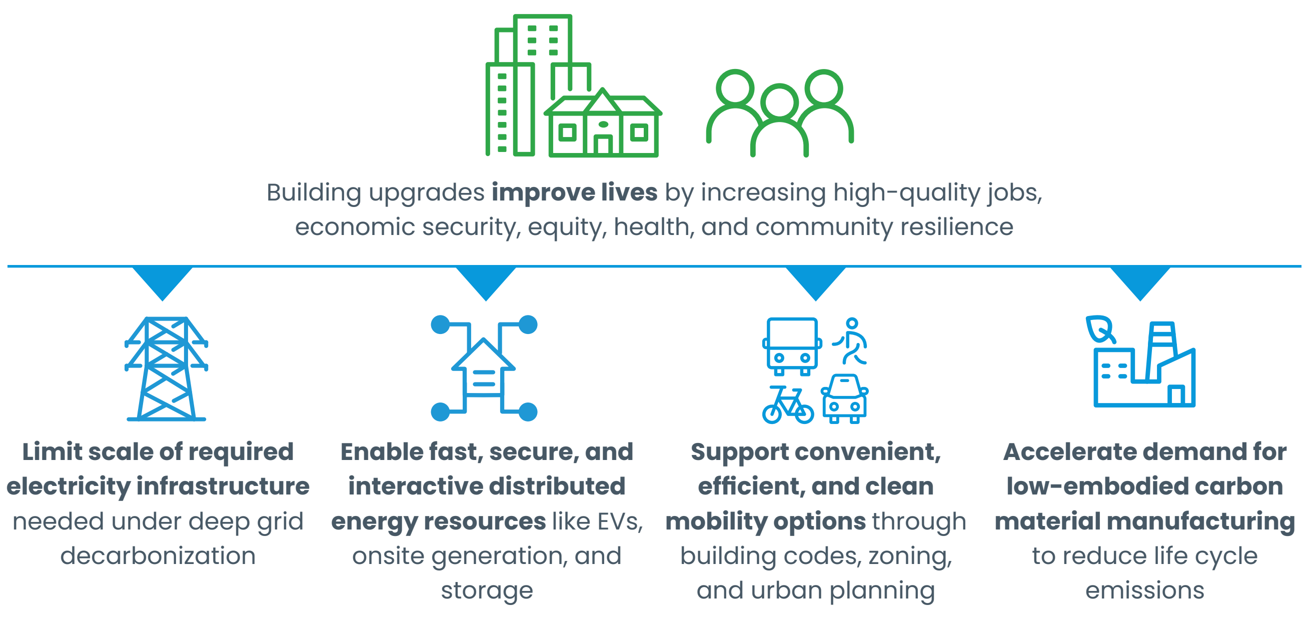


Figure ES-1. Buildings engage multiple critical pillars of economy-wide decarbonization.

Reduce U.S. building emissions 65% by 2035 and 90% by 2050 vs. 2005 while enabling net-zero emissions economy wide and centering equity and benefits to communities

CROSS-CUTTING GOALS

Equity – Advance energy justice and benefits to disadvantaged communities

Affordability – Reduce energy burden and technology costs so all can benefit

Resilience – Increase the ability of communities to withstand and recover from stresses

STRATEGIC OBJECTIVES

Increase building energy efficiency
Reduce on-site energy use intensity in buildings 35% by 2035 and 50% by 2050 vs. 2005

Accelerate on-site emissions reductions
Reduce on-site GHG emissions in buildings 25% by 2035 and 75% by 2050 vs. 2005

Transform the grid edge
Reduce electrical infrastructure costs by tripling demand flexibility potential by 2050 vs. 2020

Minimize embodied life cycle emissions
Reduce embodied emissions from building materials and construction 90% by 2050 vs. 2005

Figure ES-2. Rapid decarbonization of the buildings sector by 2050 is marked by the achievement of three cross-cutting goals and four strategic objectives. The Appendix includes documentation of how quantitative performance targets were determined.

THE VISION

Deep and equitable decarbonization of U.S. buildings to meet national climate targets

This Blueprint outlines a strategy to reduce GHG emissions from U.S. buildings 65% by 2035 and 90% by 2050 compared with 2005, while enabling net-zero emissions economy wide. Although the strategy focuses on federal actions that can drive change, it aligns with several state-level decarbonization roadmaps and notes key opportunities for collaboration among federal, state, and local agencies. It highlights how building decarbonization enables the decarbonization of other sectors—for example, by supporting more convenient, efficient, and clean transportation options; accelerating demand for low-carbon manufacturing; and limiting the scale and cost of electricity infrastructure needed for a 100% clean power sector (Figure ES-1). And it identifies solutions that benefit all Americans through outcomes such as energy justice and security, improved health, good jobs, and American prosperity.

Building decarbonization pathways centered in equity, affordability, and resilience

Any pathway to decarbonization of the buildings sector must be centered in the cross-cutting goals of equity, affordability, and resilience to ensure that the low-carbon buildings transition benefits disadvantaged communities, reduces energy costs, and increases the ability of communities to withstand stresses. Alongside those three cross-cutting goals, the Blueprint identifies four strategic objectives necessary for decarbonization:

1. **Increase building energy efficiency** to reduce overall building energy demand while delivering customer energy bill savings and strengthening building resilience.
2. **Accelerate on-site emissions reductions** by electrifying space and water heating and reducing fugitive equipment refrigerant emissions.
3. **Transform the grid edge** where building efficiency and electrification solutions, EV charging, and on-site renewable energy

generation and storage connect to the power grid to shrink the scale of electrical infrastructure required for a 100% clean electricity system.

4. **Minimize embodied life cycle emissions** from the construction of every new building and renovation.

Each strategic objective is tied to specific performance targets that achieve the overall emissions reductions, as summarized in Figure ES-2.

Far-reaching impacts on GHG emissions, energy use, and other outcomes

Combined with a 100% clean electricity sector, meeting the Blueprint's 2050 targets will result in far-reaching benefits to American families and businesses, including:

- reducing building GHG emissions to within reach of net zero to avoid catastrophic climate disruptions,
- reducing annual building energy use by one-third to unlock billions of dollars in energy and power system cost savings, and
- avoiding billions of dollars in annual health costs and spurring up to $1 trillion in buildings sector job investments.

ACHIEVING THE VISION

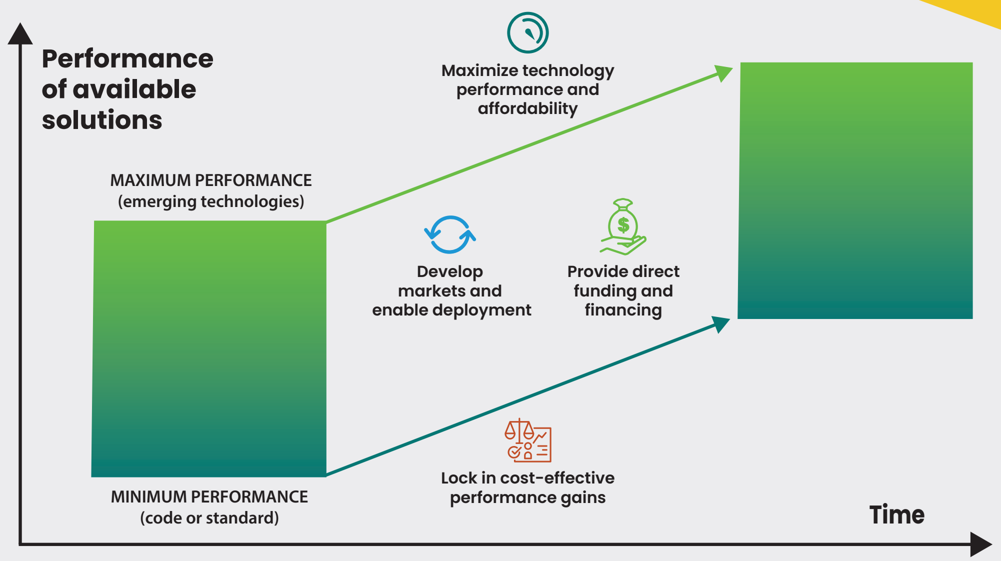
A diverse sector with a range of technical solutions for decarbonization

The scale and complexity of the buildings sector make decarbonization a significant challenge despite major advances in energy efficiency and electricity decarbonization in the last two decades. The 130 million existing buildings in the United States include many different energy uses and GHG emissions sources. Meanwhile, the long lifetimes of buildings and their components mean that today's buildings will still comprise the majority of the U.S. building stock in 2050. Thus, to achieve this Blueprint's vision, it is critical to accelerate deployment of low-carbon solutions in both new construction and in existing buildings—particularly in disadvantaged communities, where building upgrades are most needed.

The Blueprint identifies five categories of technical solutions for building decarbonization and evaluates their potential impacts:

- energy efficiency,
- efficient electrification,
- grid edge resource management,
- low global warming potential refrigerants, and
- low embodied carbon construction

Each of the solution categories can support multiple goals and objectives outlined in Figure ES-2. For example, energy efficiency upgrades like insulation and air sealing reduce overall energy demand, while also making it easier to reduce on-site emissions through electrification. Such efficiency solutions can also: support grid edge transformation by reducing peak demand and enabling flexibility to reduce power system costs; increase building resilience during extreme weather; improve affordability by lowering energy costs; and promote equity by improving health, creating high-quality jobs, and advancing energy justice in communities that have been historically marginalized.



Maximize technology performance and affordability

- Foundational science
- Early-stage R&D funding
- Solutions for hard-to-decarbonize segments
- Pilot demonstrations

Provide direct funding and financing

- Point-of-sale rebates
- Tax credits and deductions
- Facilitate financing

Develop markets and enable deployment

- Enabling tools, partnerships, and market-facing resources
- Contractor/consumer outreach
- Workforce development
- Technical assistance/validation

Lock in cost-effective performance gains

- Appliance efficiency standards
- Support building energy code development and adoption
- Support other state/local regulatory actions

Figure ES-3. Four types of federal actions can accelerate building decarbonization using existing authority and available funding. Early-stage research and development raises the ceiling on maximum technology performance and cost reduction. Market development activities enable deployment by dismantling market barriers while direct funding and financing increases adoption of ready and emerging technologies. Proven cost-effective technologies are locked in for mainstream adoption with efficiency standards and building codes that raise the floor of minimum performance. Strategic coordination of actions increases their potential to accelerate deployment over time.

Coordinated federal action can accelerate widespread adoption of building solutions

The Blueprint outlines four types of federal action to increase the speed and scale of building decarbonization, such as funding research and development to develop lower-cost technologies, expanding markets for low-carbon technologies and approaches, providing direct funding and financing, and supporting the development and implementation of emissions-reducing building codes and appliance standards (Figure ES-3). It also outlines ways that federal agencies can support state, local, and Tribal decarbonization efforts, such as by providing technical assistance and decision-making tools and leading by example with performance standards and procurement requirements for federally owned or operated buildings.

CALL TO ACTION

Three stages of action to reach 2050 goals

Looking ahead, the Blueprint identifies three stages of federal activities to reach buildings sector decarbonization by 2050. Before 2030, federal action must focus on catalyzing the transition. Examples include reducing the cost of heat pumps, improving public awareness of low-carbon solutions and their benefits, providing technical assistance and workforce training, and leading by example with federal facility decarbonization. The next stage from 2030 to 2040, focuses on adapting and scaling, with efforts to update market integration support, incentives, and training resources for high-impact technologies and to expand federal facility upgrades consistent with Administration goals. The final stage, from 2040 to 2050, will complete the transition through activities such as enabling technology adoption and prioritizing retrofits in lagging segments and addressing remaining emissions from combustion and material life cycles. The Blueprint specifies technical, market, and policy milestones for judging success; identifies key data sources available to track progress toward the listed milestones and performance targets; and recommends a regular review and revision process.

Achieving the vision that this Blueprint sets out to decarbonize U.S. buildings in just a few decades requires bold and coordinated action to address how buildings are sited, designed, built, operated, and retrofitted.

Achieving the vision that this Blueprint sets out to decarbonize U.S. buildings in just a few decades requires bold and coordinated action to address how buildings are sited, designed, built, operated, and retrofitted. The vision and approach presented in the Blueprint reflect the current thinking and efforts of the U.S. Department of Energy (DOE) in coordination with other federal agencies. DOE intends to continue to vet these recommendations with a wide range of stakeholders, track progress on their implementation, and amend the document in the future to ensure federal support for building decarbonization remains relevant and useful to key decision makers, even as the buildings landscape evolves.

CONTENTS

1 INTRODUCTION

"In the United States and around the world, we are already feeling the impacts of a changing climate. Here at home, in 2021 alone we have seen historic droughts and wildfires in the West, unprecedented storms and flooding in the Southeast, and record heatwaves across the country. We see the same devastating evidence around the world in places like the fire-ravaged Amazon, the sweltering urban center of Delhi, and the shrinking coastlines of island nations like Tuvalu. The science is clear: we are headed toward climate disaster unless we achieve net-zero global emissions by midcentury. We also know this crisis presents vast opportunities to build a better economy, create millions of good-paying jobs, clean our waters and air, and ensure all Americans can live healthier, safer, stronger lives."

THE LONG-TERM STRATEGY OF THE UNITED STATES: PATHWAYS TO NET-ZERO GREENHOUSE GAS EMISSIONS BY 2050, NOVEMBER 2021

Recognizing the need for federal leadership to address the threat of climate change, the Biden-Harris Administration set multiple goals for the equitable mitigation of greenhouse gas (GHG) emissions—including carbon dioxide (CO_2) and other climate pollutants—in the United States (Figure 1):[1]

- Reduce U.S. GHG emissions 50–52% below 2005 levels by 2030.
- Reach 100% clean electricity by 2035.
- Achieve a net-zero[2] emissions economy by 2050.
- Deliver 40% of the benefits from federal investments in climate and clean energy to disadvantaged communities.[3]

Achieving these goals will require rapid acceleration in the adoption of climate change mitigation solutions across every sector of the U.S. economy. This includes residential and commercial buildings, which are among the largest sources of U.S. GHG emissions and constitute a key focus of the *Long-Term Strategy (LTS) of the United States*,[4] which lays out pathways for reaching net-zero greenhouse gas emissions by 2050. In 2023, the United States set the target of making zero-emission building renovations and zero-emission new construction common practice by 2030 and joined the United Nations (U.N.) Buildings Breakthrough with the goal of normalizing "near-zero emission and resilient buildings" by 2030.[5] In 2024, the U.S. proposed a National Definition for a Zero Emissions Building to standardize and

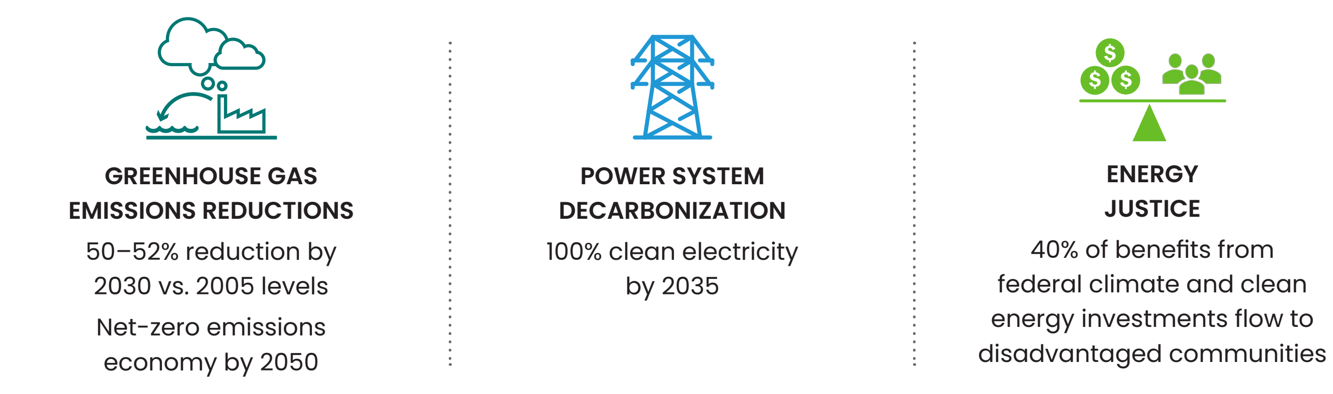


Figure 1. The U.S. National Climate Task Force is working toward multiple ambitious goals to mitigate the risks of climate change while delivering health and economic benefits to communities and businesses.

Figure 2. Improving people's lives must be at the core of developing and deploying solutions that benefit all Americans and achieve our ambitious climate goals.

verify the transition toward zero-emission buildings.[*] The United States has also joined the U.N. Global Cooling Pledge to advance sustainable cooling[6] and set a goal to transition the federally owned building portfolio to net-zero emissions by 2045.[7] These commitments underscore the need for a comprehensive plan to decarbonize the U.S. buildings sector—that is, to reduce residential and commercial building emissions of CO_2 and other GHG gases to near-zero by 2050—to meet the scale and urgency of national climate ambitions.

Buildings are central to the quality of our day-to-day experiences and the health of our communities (Figure 2). We spend 90% of our time in buildings,[8] where we live, work, play, gather, and make memories. Buildings provide shelter and keep us safe during extreme weather events. Buildings can also be the source of great economic opportunity: there are an estimated 2.2 million people in the United States employed in jobs related to building energy efficiency.[9] Americans spend $374 billion annually on building energy costs,[10], [11], [12] and lowering these costs will improve the financial stability for many households and spur further investment into local communities and businesses. This is a pivotal opportunity to target economically marginalized communities, who bear the highest energy burdens.[13] For these reasons, transitioning to a low-carbon buildings sector to meet climate targets presents an unprecedented opportunity to deliver meaningful improvements for communities while reducing GHG emissions.

* The definition stipulates that a zero-emission building is: (1) highly efficient, (2) free of on-site emissions from energy use, and (3) powered solely from clean energy. U.S. Department of Energy. 2024. "National Definition for a Zero Emissions Building." https://www.energy.gov/eere/buildings/national-definition-zero-emissions-building.

There are nearly 6 million commercial buildings and 124 million occupied homes in the United States.,[14], [15] with 40 million new homes and 60 billion square feet of commercial floorspace expected to be constructed between now and 2050.[16] Today, most buildings consume large amounts of energy and cause significant climate pollution—over one-third of the nation's total—to meet our basic needs. Moreover, many of today's buildings will continue to exist in 2050: 75% of projected homes and 51% of projected commercial square feet in 2050 have already been constructed.[17] The most energy- and carbon-intensive buildings are aging and in need of repairs, and marginalized communities bear the brunt of these deficiencies, as their members disproportionally live or work in buildings with poor indoor air quality, structural deficiencies, or additional health and safety concerns.[18]

However, it doesn't have to be that way. In the past two decades, the buildings industry has made major advances in energy efficiency, flexible and low-carbon space and water heating, installation of on-site clean electricity generation, lower embodied carbon materials, and equipment refrigerants with low global warming potential (GWP), putting near-zero emissions well within reach for new construction and retrofits. Buildings can be constructed and retrofitted to use a fraction of the energy they once required, meaning occupants are less susceptible to volatile energy prices. Investments in demand-side solutions in the buildings sector—particularly high performance building envelopes (elements of the building shell, such as windows and walls), efficient low-carbon heating, and smart control systems—have the potential to dramatically reduce the need to expand the power grid as it transitions to clean energy sources, saving billions of dollars annually and offsetting a large portion of the cost of grid decarbonization.[19] These buildings sector innovations and investments can be focused toward disadvantaged communities, ensuring that the benefits of transitioning to a low-carbon buildings sector are equitably shared.

As we recognize the existential risk that climate change poses to our society and individual well-being, the United States needs a fundamental shift in how we site, design, construct, operate, and retrofit our buildings to align with decarbonization goals, while providing healthy and enriching environments in which all Americans can thrive. The transition to a low-carbon buildings sector can't wait. To meet ambitious climate targets over the long term, we must start significantly reducing the energy use and climate pollution of our homes and businesses now while readying them to support a power grid that is rapidly becoming cleaner. But immediate and widespread progress won't materialize without a comprehensive and well-coordinated strategy to affect change across the full spectrum of geographies, end uses, and technologies that the buildings sector encompasses.

This document presents a Blueprint for catalyzing and scaling U.S. buildings sector decarbonization at the national level. It outlines a broad and complementary range of actions that the federal government can take now and in the coming decades to **support rapid decarbonization of the U.S. residential and commercial building stock in line with achieving economy-wide net-zero emissions by 2050**. In charting a course to decarbonize our nation's building stock, the strategy centers equity, affordability, and resilience to ensure that the solutions are grounded in communities and people (Figure 2). These people-centered outcomes—additional economic growth and high-quality jobs, energy justice, climate resilience, improved public health, and reduced energy costs and energy burden, among others—must be at the core of developing and deploying solutions that benefit all Americans and achieve our ambitious climate goals. Although this Blueprint focuses on federal-level programmatic, regulatory, and market levers that will drive change in the buildings sector, action at state and local levels will also be critical for success. The Blueprint therefore emphasizes federal, state, and local coordination as a top

implementation priority and aligns its strategic approaches with those of state-level roadmaps.[20] The Blueprint also highlights opportunities for building decarbonization solutions to facilitate the decarbonization of other energy sectors, such as transportation and electricity. Overall, the Blueprint establishes a common strategic reference point for decarbonization actions that can collectively accelerate deep reductions in building GHG emissions to meet the urgency of the climate crisis.

The remainder of the Blueprint is structured as follows: Section 2 discusses why buildings are an important focus for energy and emissions reductions, for the decarbonization of other sectors, and for delivering benefits to people and communities. Section 3 introduces the Blueprint's 2050 vision for building decarbonization, outlines the strategic framework that underpins the vision's achievement, and discusses the scale and urgency of the challenge the vision initiates. Section 4 details how the vision can be achieved by further contextualizing the strategic framework and key challenges, highlighting key building decarbonization solutions and federal levers to accelerate their deployment, and identifying critical areas of state, local, and Tribal action where federal support can bolster progress. Section 5 concludes with a call to action that walks through three stages of Blueprint implementation over the coming decades, shows how progress will be tracked, and discusses follow-on program planning and execution work that will translate Blueprint guidance into day-to-day practice.

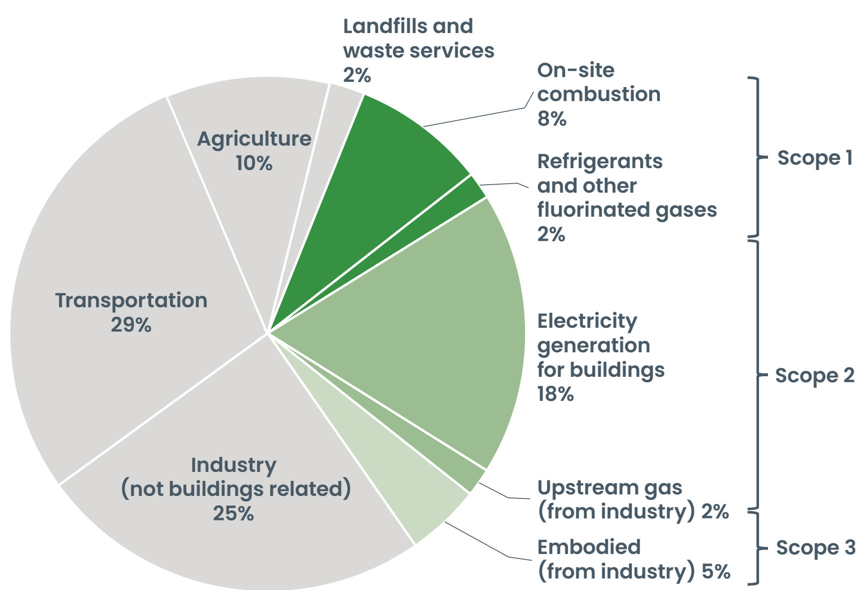
2 THE IMPORTANCE OF BUILDINGS

2.1 • Contributions to U.S. Greenhouse Gas Emissions

In 2021, the buildings sector (residential and commercial buildings) contributed more than one-third of total U.S. GHG emissions (Figure 3). Building GHG emissions span three "scopes": direct emissions from on-site building sources (scope 1), indirect emissions from generation of purchased electricity (scope 2), and other indirect emissions (scope 3).[21] The majority of building GHG contributions are indirect emissions from electricity generation for buildings (18% of total U.S. GHG; 52% of buildings sector GHG); these indirect emissions are expected to decrease as the U.S. progresses toward the goal of 100% carbon-free electricity by 2035. The second largest portion of building GHG emissions comes from the on-site combustion of fossil fuels (8% of total U.S. GHG; 24% of buildings sector GHG). Smaller contributions are attributed to the use of fluorinated gases as refrigerants in building equipment, foam blowing-agents, and fire suppressants (2% of total U.S. GHG; 5% of buildings sector GHG). The buildings-related emissions from the production and distribution of natural gas and from the embodied carbon of materials and construction (i.e., the emissions from producing, transporting, installing, and disposing of building materials) contribute an estimated 2% and 5% of total U.S. GHG emissions, respectively (5% and 14% of buildings sector GHG), though there is high uncertainty in the estimates for these two categories.[22]

Operational energy emissions from buildings—including from on-site combustion of fuel and from purchased electricity—can be broken down further by fuel and end-use category: space

Figure 3. The buildings sector contributed an estimated 35% of total GHG emissions in 2021, including estimated portions of the industrial sector for embodied building life cycle emissions and the buildings sector share of emissions from natural gas production and distribution.[*] Buildings sector emissions span three "scopes" of GHG emissions—direct emissions from on-site building sources (scope 1), indirect emissions from generation of purchased electricity and upstream emissions from gas production and delivery (scope 2), and embodied life cycle emissions (scope 3).[**] Percentages do not add to 100% because of rounding.



* Primary source: U.S. Environmental Protection Agency. 2023. "Inventory of U.S. GHG Emissions and Sinks: 1990-2021." EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021. See endnote 140 for how the embodied emissions portion was estimated.

** World Business Council for Sustainable Development and World Resources Institute. The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard, Revised Edition. https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

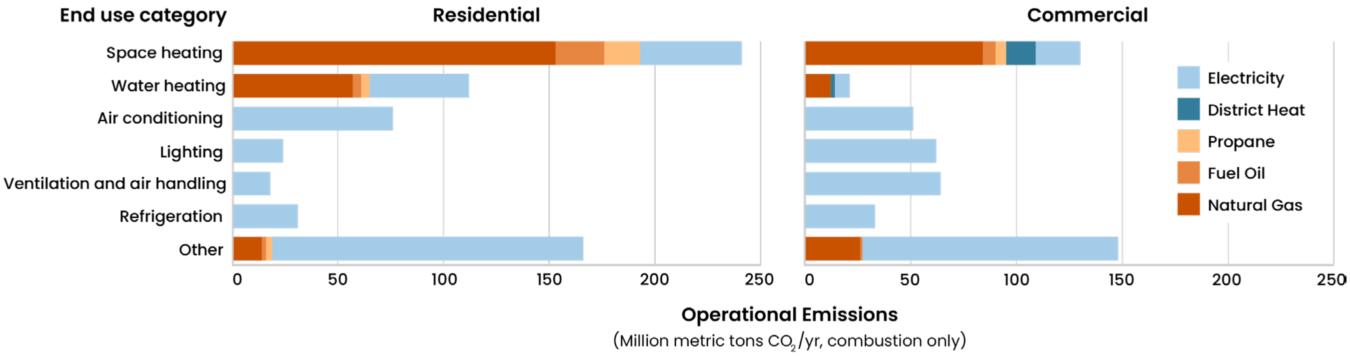


*Figure 4. Residential and commercial end-use contributions to operational energy-related emissions.**

heating, water heating, cooling, lighting, and so on (Figure 4). Together, space and water heating make up half of building site energy use and 90% of on-site emissions, so addressing these end uses is critical to decarbonize the buildings sector.[23]

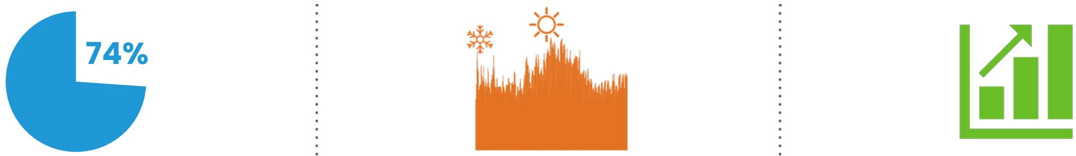
The next four largest end uses—space cooling (air conditioning), lighting, ventilation, and refrigeration—almost always use electricity.[24] Electricity also powers the substantial building emissions from miscellaneous or "other" end uses that are individually small or are otherwise difficult to measure and characterize. Electric end uses will likely contribute progressively less to building operational emissions in the coming years as the emissions intensity of electricity continues to decline (Figure 6). District steam and hot water systems are estimated to contribute around 1% of the operational end-use emissions shown in Figure 4,[25] though this does not include district chilled water systems and may underestimate the total emissions from all district systems.

In addition to end-use segmentation, operational energy emissions from buildings can be segmented by building type (see *Appendix, Additional Segmentation of Building Emissions*). Single-family homes are by far the largest source of current building emissions when segmented by building type. Commercial building type emissions contributions are most notable for their heterogeneity. Education, offices, public assembly, and retail building types have the largest impacts on commercial building emissions.

2.2 • Demand for Electricity and Fossil Fuels

Buildings are the largest energy consumer among the three major end-use sectors (residential and commercial buildings, industry, and transportation), having consumed 38% of total energy across all primary sources (petroleum, natural gas, coal, renewable energy, and nuclear power) in 2022.[26] Buildings are also the top consumer of the electricity generated from primary energy sources (74% of electricity

* Site energy use data by fuel: U.S. Energy Information Administration (EIA). 2020. Residential Energy Consumption Survey. https://www.eia.gov/consumption/residential/data/2020/; EIA. 2022. "2018 CBECS Survey Data." Commercial Buildings Energy Consumption Survey. https://www.eia.gov/consumption/commercial/data/2018/, with U.S. Department of Energy analysis of emissions; 2018 CBECS does not directly estimate site energy use for propane, so propane usage was estimated based on the ranges of propane use reported by survey respondents in field PRAMTC (100 was used for the "Less than 100" response, 5000 used for the "1,000 or more" response and the range midpoint used for other responses); Emissions factors for natural gas (0.053 Mt/TBtu), propane (0.063 Mt/TBtu), and fuel oil (0.073 Mt/TBtu): EIA. "Carbon Dioxide Emissions Coefficients." https://www.eia.gov/environment/emissions/co2_vol_mass.php; Emission factor for electricity (0.088 Mt/TBtu): National Renewable Energy Laboratory. 2022. Cambium full data sets. https://www.nrel.gov/analysis/cambium.html; Average emissions rate from the midcase scenario for the year 2024 and carbon dioxide are from combustion only. Contributions from specific types of residential and commercial buildings are summarized in the Appendix, Figure 16.



Buildings account for about 74% of U.S. electricity use

Building heating and air conditioning drive peak demand, and therefore grid infrastructure costs

As heating electrification accelerates, peak demand from buildings could increase significantly in some regions

*Figure 5. Illustration of the relationship between buildings and the power sector.**

consumption), and building heating and air conditioning drive peaks in electricity demand on the electric grid (Figure 5).[27] The high degree of interdependence between the buildings and power sectors presents an opportunity for strategic investment in building energy efficiency and demand flexibility in buildings to reduce the cost of decarbonizing the power system, which may require a five-fold increase in clean generation capacity by 2050 (Figure 6).[28]

Residential and commercial buildings are also responsible for about 29% of total U.S. natural gas consumption and 42% of end-use sector gas consumption.[29] The overwhelming majority of the 77.7 million natural gas customers in the United States are in residential and commercial buildings, which are connected to production areas and storage facilities by about 3 million miles of pipeline.[30] While the majority of buildings' on-site fuel use is natural gas (83%), distillate fuel oil (7%), propane (6%), and gasoline used in commercial buildings (4%) make up the remainder.[31]

Burning fossil fuels for building space heating, water heating, and cooling emits substantial health-harming pollutants (see *Building Decarbonization Improves People's Lives*). Moreover, the production, transmission, processing, and distribution of oil and natural gas for buildings and other end uses contributes 30% of total U.S. emissions of methane, a significant contributor to climate change and the focus of the recent Global Methane Pledge[32] and U.S. Methane Action Plan.[33] Such harmful health and climate pollution can be reduced by solutions such as load electrification and envelope efficiency that reduce the need for on-site fossil fuel combustion in buildings. While electrification and efficiency can reduce some of the upstream oil and gas emissions, methane leakage from distribution pipes and meters would require more significant infrastructure changes, such as replacing or decomissioning pipes.

* Source for middle icon: National Renewable Energy Laboratory. 2018. "Electrification Futures Study Load Profiles." https://data.nrel.gov/submissions/126.

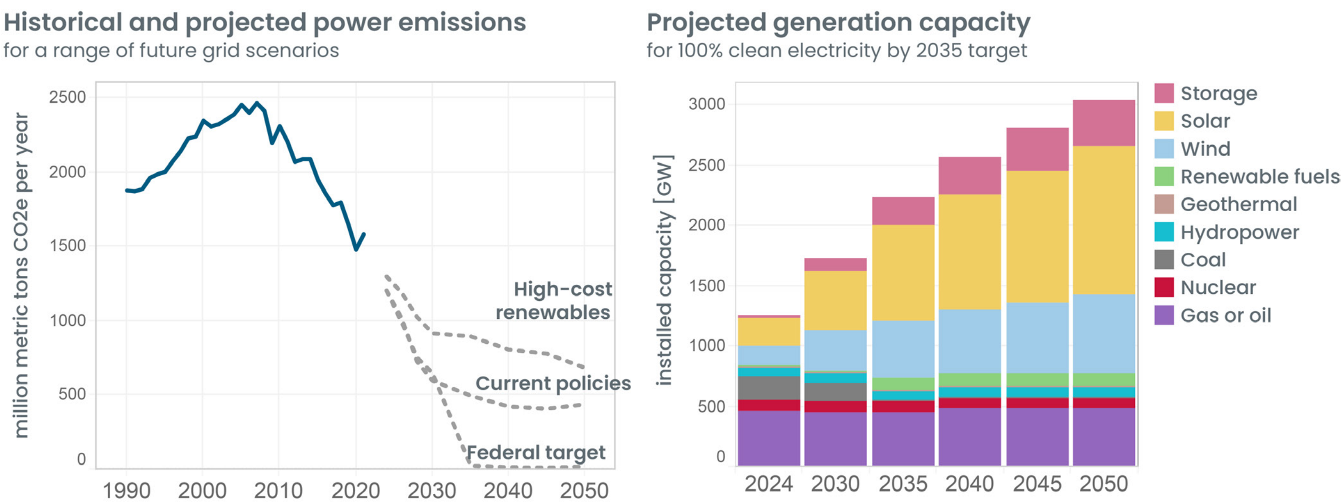


*Figure 6. The context for buildings sector decarbonization includes a power sector that is rapidly changing. The scale and cost of new generation, transmission, and distribution infrastructure will be determined in large part by the demand from buildings and other sectors.**

2.3 • Buildings Play an Essential Role in Decarbonizing Other Sectors

Measures taken to decarbonize buildings can benefit the decarbonization of all other sectors of the energy system, as illustrated in Figure 7. Energy efficiency and demand flexibility in buildings reduce the peak demand on the grid, thus reducing the investment in grid infrastructure needed to achieve a 100% clean electricity sector.[34] These benefits accrue at both the grid edge—the "last mile" of distribution networks and behind-the-meter infrastructure that is closest to a utility's end-use customers—and for the bulk power generation and transmission system.

Furthermore, buildings can enable integration of distributed energy resources (DERs) like EVs, on-site solar generation, and battery storage, which can be coordinated with flexible building loads to improve grid reliability and facilitate power sector decarbonization.[35] From a planning perspective, a high-density built environment that integrates public transit, bicycle amenities, and EV charging infrastructure supports increased use of more convenient, efficient, and clean modes of transportation.[36] Finally, efforts to reduce embodied building life cycle emissions increase demand for low embodied carbon material manufacturing, supporting a key component of industrial sector decarbonization.

2.4 • Building Decarbonization Improves People's Lives

Of all the components of our nation's energy system, the buildings sector has the most immediate connection to people's lives. From the bills we pay to keep the lights, heating, and air conditioning on in our homes and businesses, to how the temperature and air quality in buildings affect learning in schools, worker safety and productivity, and our short-term and long-term health, our everyday experiences are impacted through the buildings we inhabit. Building decarbonization can therefore offer significant benefits to people and communities alongside its impacts on energy and emissions. Here we

*U.S. Environmental Protection Agency. 2023. "Inventory of U.S. GHG Emissions and Sinks: 1990-2021." EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021; National Renewable Energy Laboratory. 2022. Cambium full data sets. https://www.nrel.gov/analysis/cambium.html; HighRECost, MidCase, and MidCase100by2035 scenarios and includes combustion emissions only.

Figure 7. Buildings engage multiple critical pillars of economy-wide decarbonization.

summarize four areas of potential people-centered benefits of building decarbonization:

- **Economic growth and high-quality jobs**: In 2022, there were an estimated 2.2 million people in the U.S. employed in jobs related to energy efficiency,[37] up 7.4% since 2020.[38] By industry, most of these jobs were in construction (54%), followed by professional services (22%) and clean manufacturing (14%). By occupation group, the majority of energy efficiency jobs are installation or repair (33%). These efficiency jobs can be found in 99.8% of U.S. counties. Eight in 10 employers in energy efficiency are small businesses with fewer than 20 employees. This provides a unique opportunity for building wealth in disadvantaged communities.[39] However, these employment opportunities have not been equally distributed: women and Black workers are underrepresented relative to the overall U.S. workforce.[40]

  The need to dramatically increase the pace of building retrofits and heat pump conversions to decarbonize buildings has the potential to increase the number of high-quality energy efficiency jobs, which also offers an opportunity

to train underrepresented individuals for these jobs. Jobs in building construction; renovation; and heating, ventilation, and air conditioning (HVAC) tend to have low educational barriers-to-entry[41] and are likely to be resistant to outsourcing and automation, so they represent an opportunity for long-term, high-quality employment, as defined by the Department of Commerce and Department of Labor Good Jobs Principles. These principles include family-sustaining wages, health and retirement benefits, a free and fair right to organize, job security and predictability, and the opportunity for career advancement.[42]

- **Energy affordability, security, and resilience:** The U.S. Energy Information Administration (EIA) estimates that 27% of U.S. households are experiencing energy insecurity, meaning they are unable to adequately meet their energy needs. This is disproportionately true for households with low incomes.[43] Federal agencies can work to develop and deploy low-carbon building technologies and programs that reduce the cost of providing comfortable and safe buildings for people in the U.S. and internationally.

  Beyond improving energy affordability and providing energy security, increasing the energy efficiency of existing and new buildings can significantly enhance their resilience, which is defined here as the capacity to withstand or recover from chronic and acute stresses such as disasters, power outages, and extreme weather. Building energy codes, and energy efficiency in general, can improve the durability, moisture management, fire safety, thermal safety, and economic vitality of our buildings in the face of disasters or other adverse events. Specific to buildings, *thermal resilience* is the ability of buildings to maintain comfortable indoor temperatures under normal operation and during power or fuel outages. Lack of access to air conditioning is one of the most important factors in heat-related deaths; lack of air conditioning is most prevalent in low-income and renter households.[44] *Electrical resilience* is the ability of buildings to maintain service to critical electric loads during power outages using batteries or microgrids. Greater demand flexibility and integrated deployment of distributed energy resources such as on-site solar generation and battery storage with smart controls further improve the ability of buildings to maintain essential services for longer in the face of such events.

  More broadly, efforts to decarbonize buildings can support *community resilience*: the ability of communities to prepare for hazards, adapt to changing conditions, and withstand and recover from disruptions.[45] Upgrading buildings can provide high-quality local jobs that can't be outsourced, with wages and energy bill savings also indirectly stimulating local economies. Reducing energy costs for local businesses, schools, places of worship, and other buildings that serve as hubs for community needs strengthens resilience against economic hardship and disasters. Improving the safety and durability of these buildings can also promote neighborhood stability and social connectedness. Access to resilient buildings is something that everyone deserves, and it is therefore a priority to ensure that resilience efforts benefit communities of all income levels.

- **Health and air quality**: Emissions of fine particulate matter, sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), and volatile organic compounds (VOCs) from fuel combustion in buildings contribute to the tens of thousands of annual deaths and disabilities associated with these pollutants in the United States.[46] Gas appliances in U.S. buildings emit over twice as much NO_x pollution as gas power plants, despite burning less gas.[47] While both sources are significant, pollutants emitted by buildings at or near ground level typically have worse health impacts than elevated smokestack emissions from power plants and factories.[48] Additionally, lack of appropriate kitchen and bathroom ventilation in buildings precludes removal of indoor pollutants and moisture. Effective building ventilation is critical for reducing the spread of respiratory infections.

Many older buildings contain lead, asbestos, and other hazards, including water leaks with the potential for mold and moisture damage. Furthermore, substandard conditions such as broken heating systems and air conditioners, drafts, and cold surfaces can negatively impact the physical and mental well-being of occupants, burdening our economy with lower productivity and poorer educational outcomes. The negative health impacts of building emissions disproportionately affect people of color, who, for example, are exposed to 90% higher rates of ambient particulate matter ($PM_{2.5}$) resulting from residential gas combustion compared to white people.[49] Upgrades to the building stock that reduce ambient pollution and address buildings' health and air quality issues can be targeted to disproportionately impacted groups to help reduce these inequities.

- **Energy justice and equity**: As described above, the job opportunities, energy cost burden, and health impacts related to the buildings sector have historically not been equitably distributed. In total, the federal Climate and Economic Justice Screening Tool (CEJST) shows that one in three Americans (109 million people) live in a community identified as disadvantaged because it faces one or more climate, socioeconomic, and health-related burdens.[50] Federal research, development/demonstration, and deployment programs can be directed to support the specific needs and opportunities facing historically underserved and overburdened communities. Through meaningful engagement, programs can be co-designed to deliver targeted decarbonization solutions that are more in line with community priorities. Building decarbonization strategies should uphold the core tenets of energy justice: distributive, procedural, recognition, and restorative justice.

Federal, state, and local programs can impact *distributive justice* by addressing historical injustices in how the benefits and negative impacts of our energy system are distributed across people and communities. Just as importantly, energy planners and program administrators can directly incorporate *procedural justice* into plans, programs, and policies by ensuring that fair and inclusive processes are established for planning, designing, and implementing programs. They can also integrate *recognition justice* by ensuring that human dignity and differences in experiences and needs are recognized in all interactions. By integrating all these concepts, the agencies, companies, and people planning and implementing the energy transition can work toward *restorative justice* that addresses historical harms and injustices through the restoration of trust and collaboration in social relationships.[51]

3 THE 2050 VISION

The buildings sector, with its strong influence on GHG emissions, energy consumption, and people's everyday experiences, is a critical focal point for broader efforts to achieve the economy-wide goals of net-zero emissions, zero-carbon electricity, and benefits to disadvantaged communities. Consistent with these broader ambitions, **the strategies and actions in this Blueprint aim to reduce U.S. residential and commercial building GHG emissions 65% by 2035 and 90% by 2050 vs. 2005, while enabling net-zero emissions economy wide and centering equity and benefits to communities**. These deep levels of building emissions reductions cover all sources of GHG emissions across the full building life cycle and assume the power grid is fully decarbonized by 2035, consistent with the Biden-Harris Administration's goals. By 2050, 10% of total building emissions remain—a level that multiple cross-sectoral modeling studies show could be offset by natural carbon sinks and carbon removal technologies to achieve the economy-wide net-zero emissions goal.[52]

Figure 8 puts targeted building GHG emissions reductions into historical context and illustrates recent trends in the sources of these emissions.[53] Emissions reduction targets for 2035 and 2050 are benchmarked against a 2005 peak, when annual buildings sector GHG emissions reached more than 2.7 gigatons CO_2 equivalent (Gt CO_2e). Since 2005, annual buildings sector GHG emissions have declined more than 20% to a present-day level that is comparable with that of 1990. This decline has been driven largely by reductions in the carbon intensity of electricity generation (Figure 6) and by increases in building energy efficiency that have kept demand flat even as the number of buildings—and the equipment and devices within them—has grown.

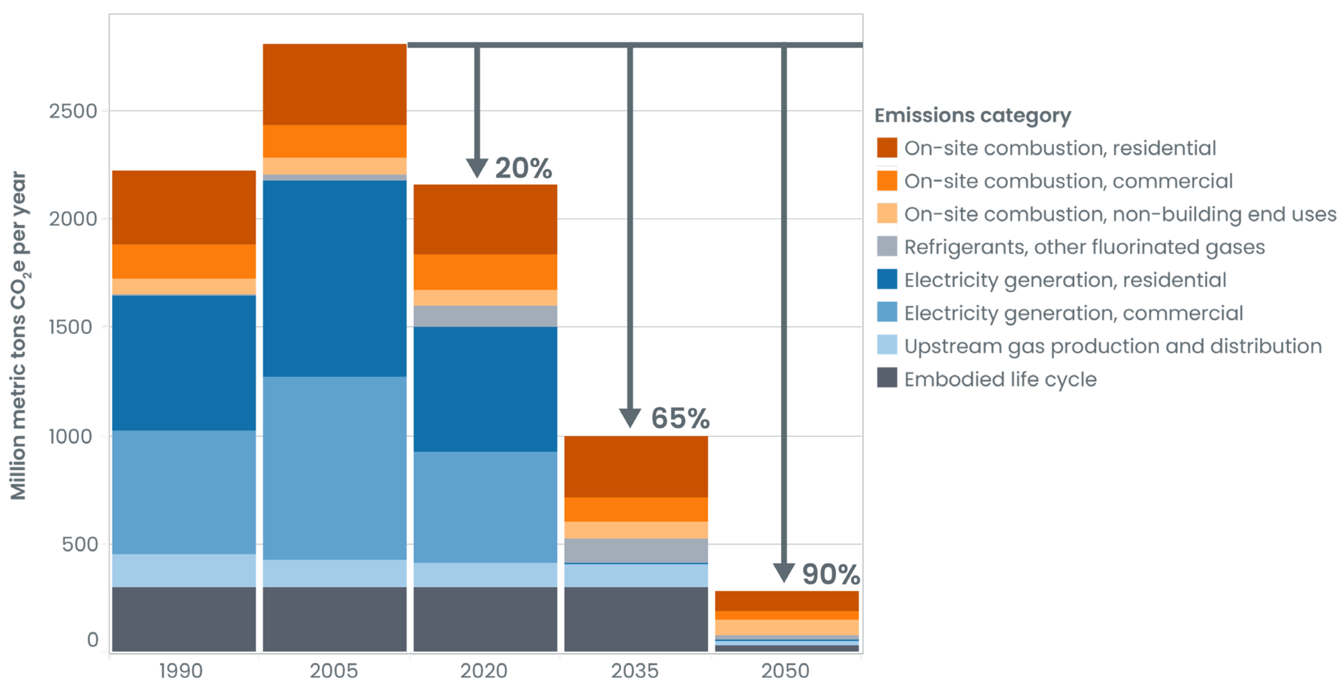


*Figure 8. This Blueprint outlines a vision for achieving a 65% reduction in buildings-related emissions by 2035 and a 90% reduction by 2050, relative to the peak in building emissions in 2005. This figure shows the historical and target emissions by category, split into commercial and residential sectors.**

* Historical emissions values: U.S. Environmental Protection Agency. 2023. "Inventory of U.S. GHG Emissions and Sinks: 1990-2021." EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021. Values for 2035 and 2050 are based on the strategic objective performance targets set in this Blueprint.

Reduce U.S. building emissions 65% by 2035 and 90% by 2050 vs. 2005 while enabling net-zero emissions economy wide and centering equity and benefits to communities

CROSS-CUTTING GOALS

Equity – Advance energy justice and benefits to disadvantaged communities

Affordability – Reduce energy burden and technology costs so all can benefit

Resilience – Increase the ability of communities to withstand and recover from stresses

STRATEGIC OBJECTIVES

Increase building energy efficiency
Reduce on-site energy use intensity in buildings 35% by 2035 and 50% by 2050 vs. 2005

Accelerate on-site emissions reductions
Reduce on-site GHG emissions in buildings 25% by 2035 and 75% by 2050 vs. 2005

Transform the grid edge
Reduce electrical infrastructure costs by tripling demand flexibility potential by 2050 vs. 2020

Minimize embodied life cycle emissions
Reduce embodied emissions from building materials and construction 90% by 2050 vs. 2005

Figure 9. Rapid decarbonization of the buildings sector by 2050 is marked by the achievement of three cross-cutting goals and four strategic objectives. The Appendix includes documentation of how quantitative performance targets were determined.

Meeting this Blueprint's targeted emissions reduction levels will require advancing and accelerating these historical improvements in building energy efficiency and power sector emissions. The coming decades will also need to see unprecedented reductions in direct building emissions from on-site fossil fuel combustion, which have remained largely unchanged since 1990 (Figure 8). Finally, the strategy's targeted emissions reductions nearly eliminate fluorinated gas and embodied material emissions by 2050, the former of which has grown notably since the nineties and the latter of which lacks comprehensive historical data.

3.1 • Strategic Framework

The overall 2050 vision in this Blueprint is framed through three cross-cutting goals and four strategic objectives, which are shown in Figure 9 and further detailed in section 4 (see *Strategic Opportunities and Challenges*). The cross-cutting goals—equity, affordability, and resilience—establish three overarching priorities that guide the pursuit of specific pathways to achieving the 2050 vision. The four strategic objectives—increase efficiency, accelerate on-site emissions reductions, transform the grid edge, and minimize embodied life cycle emissions—define supporting performance targets that roll up into the overall building emissions reduction targets while ensuring that low-carbon buildings have low energy demand and high value to the power grid. The Appendix includes additional context for the selection of these performance targets.

The impacts of achieving the performance targets in Figure 9 will be far reaching (Figure 10). In addition to reducing building GHG emissions to near zero by 2050, meeting all the targets in combination with a 100% clean electricity sector could reduce annual building energy use by one-third, unlock billions of dollars in energy and health cost savings, and spur up to $1 trillion in new clean energy job investments. These benefits would be in addition to avoiding up to more than $100 billion in potential power system decarbonization costs annually in 2050,[54] as well as the wider spectrum of people-centered benefits that could follow from a rapid transition to low-carbon buildings.

The Blueprint's strategic framework seeks to catalyze widespread deployment of building equipment and controls infrastructure that will maximize the benefits that behind-the-meter DERs, such as on-site generation and battery storage, can provide; however, specific DER performance targets are outside the Blueprint's scope, as are clean electricity targets, which are covered extensively in the *LTS and Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035*.[55] The strategic framework also limits focus on land use and planning opportunities for buildings, which are covered extensively in the *U.S. National Blueprint for Transportation Decarbonization*.[56] Approaches for cutting building emissions should not stop at the building boundary, however. Investing in buildings in walkable and transit-oriented communities, as well as in buildings with EV infrastructure, cuts emissions that are accounted for in other sectors, particularly transportation. Investing in well-sited buildings can also benefit Americans with lower incomes by cutting transportation costs, while also improving quality of life for all.

3.2 • Scale and Urgency of the Challenge

Meeting the grand ambition of decarbonizing the buildings sector by 2050 will require immediate and unprecedented acceleration in the deployment of solutions in homes and businesses across every region of the United States. As discussed, significant gains have already been made over the past two decades in improving building efficiency. Moreover, the Infrastructure Investment and Jobs Act[57], commonly known as the Bipartisan Infrastructure Law (BIL), and the Inflation Reduction Act (IRA)[58] of 2022 include robust federal and state incentives to increase these gains. However, the current scale and speed

Reduce **90% of total GHG emissions*** from the buildings sector

Avoid **7 quads of annual energy use**** while converting many building loads to clean electricity

Save consumers more than **$100 billion in annual energy costs**** through efficiency improvements

Avoid **$17 billion in annual health costs**† and add **$1 trillion of investment in high-quality jobs****

Figure 10. The impact of achieving the 2050 vision is far-reaching and includes significant greenhouse gas, energy use, cost savings, health, and high-quality jobs impacts.

* Based on achieving the performance targets in strategic framework plus 100% power sector decarbonization, consistent with the Biden-Harris Administration's goal.

** Based on Langevin et al. "aggressive" decarbonization benchmark, which maps most closely to the targeted pathway ["Demand-Side Solutions in the US Building Sector Could Achieve Deep Emissions Reductions and Avoid Over $100 Billion in Power Sector Costs." One Earth 6, 1005-1031 (2023). https://doi.org/10.1016/j.oneear.2023.07.008.]

† Based on U.S. Environmental Protection Agency CO-Benefits Risk Assessment (COBRA, https://cobra.epa.gov/) of avoided health costs of 75% reduction in residential and commercial fossil combustion in contiguous United States (range $10 billion–$23 billion).

Example: Residential space heating

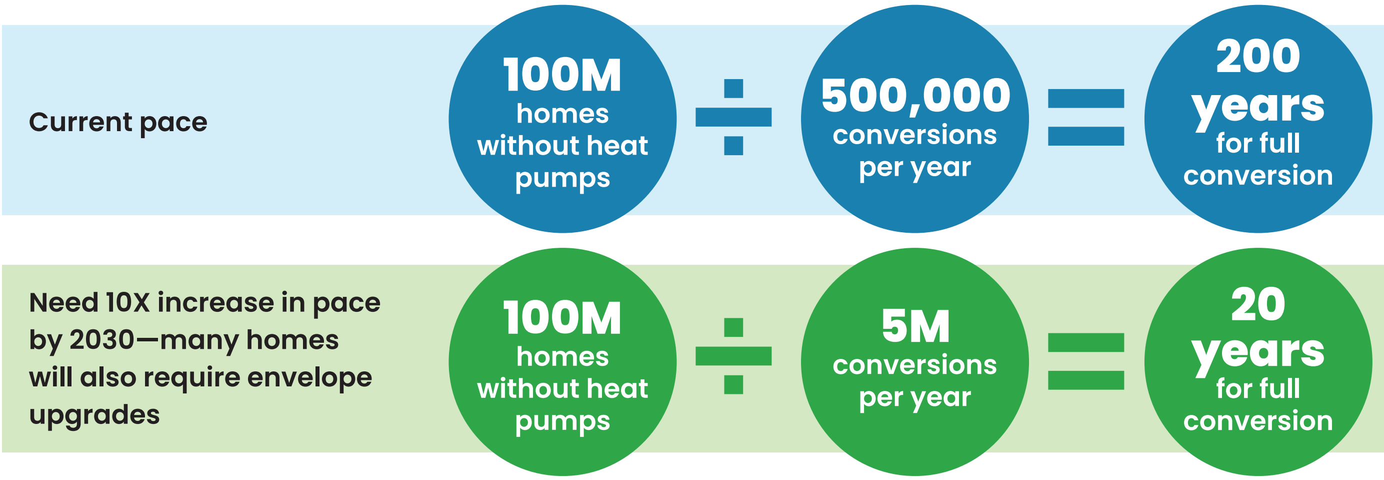


Figure 11. To convert 100 million existing homes to heat pumps by 2050, the current pace of conversion—including envelope upgrades where needed—needs to increase tenfold from 500,000 conversions per year to 5,000,000 conversions per year by 2030. Current conversion rate estimated based on U.S. Energy Information Administration Residential Energy Consumption Survey 2015 and 2020 data.

of progress must increase dramatically in the coming years to reach the aggressive building decarbonization targets set forth in this Blueprint.[59]

Rapidly expanding energy efficiency retrofits to sharply reduce building energy use intensity is among the most pressing challenges to meeting the Blueprint's 2050 vision. Upgrades to the building envelope are one of the most impactful building efficiency measures, yet they are infrequent. At current retrofit rates, upgrading all residential windows would take at least 30 years, while increasing the insulation of all homes would take at least 90 years; retrofitting commercial building envelope components would take longer—up to 250 years for commercial insulation.[60] Comprehensive, high-performance envelope retrofits occur at an even slower pace that could extend full replacement timelines for certain envelope components.[61] To meet the 2050 vision of a highly efficient, net-zero emissions buildings sector, this retrofit rate would need to increase up to 25X by 2030.

Converting inefficient fossil fuel-fired or electric heating equipment to efficient electric air- or ground-source heat pumps will also require a significant break from historical equipment adoption trends, as Figure 11 illustrates. Data from the past decade suggests that just 500,000 of the 100 million homes in the United States that do not currently use a heat pump for heating can be expected to make this conversion each year.[62] At that rate, it would take 200 years to fully convert the residential heating stock to heat pumps. Recent market trends are encouraging—last year alone Americans purchased 4 million heat pumps, eclipsing gas furnace sales for the first time,[63] and heat pump incentives in the IRA are expected to galvanize further growth in the market.[64] However, this progress is still not enough to meet the massive scale of the deployment challenge for this critical decarbonization pathway, which will require up to a 10X increase in the current rate of residential heat pump conversions by 2030.

Such large gaps between current status and net-zero emissions ambitions are a particular challenge for the buildings sector given the slow rate of retirement for building components and equipment, which limits installation opportunities for low-carbon technologies between now and

2050. Given the long lives of buildings and their systems, it is crucial that new buildings are constructed as efficiently as possible with low-carbon technologies and that whenever an existing building is upgraded or components are replaced, high-efficiency investments and low-carbon technologies are prioritized. Failure to deploy efficient, low-carbon solutions in new buildings and to existing buildings for components and equipment that wear out between now and 2030 increases the need to retrofit building components and equipment before wear-out in subsequent years, dramatically increasing the incremental cost of the transition. For example, to avoid early replacements, efficient and clean technologies must achieve nearly 100% market share by 2029 for typical space heating equipment and by 2037 for typical water heating equipment.[65] It is imperative that the United States makes significant progress on accelerating uptake of these technologies within the next decade to meet the 2050 targets.

Rapidly expanding energy efficiency retrofits to sharply reduce building energy use intensity is among the most pressing challenges to meeting the Blueprint's 2050 vision.

4 ACHIEVING THE 2050 VISION

To achieve the ambitious vision of reducing U.S. residential and commercial building emissions 65% by 2035 and 90% by 2050 vs. 2005 while enabling net-zero emissions economy wide and centering equity and benefits to communities, this Blueprint outlines a framework of three cross-cutting goals—equity, affordability, and resilience—and four strategic objectives: increase efficiency, accelerate on-site emissions reductions, transform the grid edge, and minimize embodied life cycle emissions. The following sections describe the strategic framework's key components, the technical solutions and policy tools available to support the framework's implementation, and key implementation milestones.

4.1 • Strategic Opportunities and Challenges

Cross-Cutting Goal 1: Equity – Deliver Benefits to Disadvantaged Communities

Buildings impact our physical and economic well-being every day, from the bills that we pay to heat and power our homes and businesses, to the air that we breathe and our ability to stay comfortable and safe. Historically the benefits and harms of the built environment have not been equally distributed. For example, outdoor fine particulate matter ($PM_{2.5}$) is responsible for 26,000 to 72,000 excess deaths in the United States.[66] People of color are exposed to 90% higher rates of $PM_{2.5}$ resulting from residential gas combustion. Residential gas combustion and commercial cooking are the two sources of $PM_{2.5}$ pollution with the greatest racial-ethnic disparities—greater than highways, power plants, and industrial facilities.[67] Pollution from residential fossil fuel combustion is highest in neighborhoods with a history of systematic discrimination under federal housing policies.[68]

Every state and U.S. territory has disadvantaged communities, which are home to 55 million people.[69] Disadvantaged communities span a diverse set of urban, suburban, and rural settings and may each have unique needs and decarbonization challenges.[70] There are also approximately 576 federally recognized American Indian Tribes and Alaska Native villages, with many more state-recognized or unrecognized Tribes.[71] These Tribes and villages may have a variety of needs and concerns related to environmental justice. Policymakers must

recognize and engage with these communities to co-create building decarbonization technology and deployment solutions that best serve each community's unique perspective. Recognition and engagement are critical to ensure communities embrace and take pride in the transition to a low-carbon buildings sector.

The Biden-Harris Administration made a national commitment to environmental justice through the Justice40 Initiative,[72] which sets a goal that 40 percent of the overall benefits of certain federal investments flow to disadvantaged communities that are marginalized, underserved, and overburdened by pollution. The benefits that buildings sector funding programs deliver to disadvantaged communities can be tracked and reported using federal Justice40 implementation guidance[73] and screening tools.[74] Federal programs for the buildings sector can

ENSURING DECARBONIZATION IS EQUITABLE, AFFORDABLE, AND RESILIENT

The Role of the Affordable Home Energy Shot™

The three cross-cutting goals presented here—to advance equity, affordability, and resilience—serve as people-centered lenses through which the direction and outcomes of federal actions for this Blueprint must be continually evaluated. While equity, affordability, and resilience are interrelated, each involves a distinct set of opportunities and challenges. Together these goals speak to the federal role in creating a more equitable future by accounting for the particular conditions and needs of communities across the country. For example:

- In 2023, one in five American adults lived in a household that was behind on energy bill payments by at least one month.[*] While electrification brings benefits including air conditioning, improved indoor air quality, and significant bill savings, the high cost of electricity in some locations has the potential to exacerbate the already high energy cost burden if homes are electrified with inefficient equipment and without addressing inefficient building envelopes.[**]
- Additionally, tenants and building owners in low-income and marginalized communities may not be able to afford the higher upfront cost of efficient equipment and efficiency upgrades and could face escalating gas rates as fewer customers remain to pay for legacy gas distribution infrastructure.
- Due to historical housing discrimination, low-income and marginalized communities are often more vulnerable to power interruptions caused by extreme weather events like hurricanes and flooding, making resilience a critical aspect of equitable building decarbonization.[†]
- Most people with low incomes live in unsubsidized housing, which remains affordable due in part to the lack of property-owner investment. Significant new investment in energy efficiency upgrades and electrification could risk exacerbating displacement in high-demand and high-cost areas.

The Affordable Home Energy Shot announced by the Department of Energy in October 2023 is an initiative that aims to reduce the cost of decarbonization technology for affordable housing by at least 50% while lowering energy bills by at least 20% within a decade. Achieving these goals will require advancing solutions that meet the needs of every household, which reinforces this Blueprint's cross-cutting focus on ensuring that building decarbonization is equitable, affordable, and resilient for all Americans.

* U.S. Census Bureau. 2024. "Phase 4.0 Cycle 01 Household Pulse Survey: January 9 – February 5." February 22, 2024. https://www.census.gov/data-tools/demo/hhp/#/?measures=ENERGYBILL&areaSelector=040

** Wilson, E., P. Munankarmi, B. D. Less, J. Reyna, and S. Rothgeb. "Heat pumps for all? Distributions of the costs and benefits of residential air-source heat pumps in the United States." *Joule*. https://doi.org/10.1016/j.joule.2024.01.02

† U.S. Environmental Protection Agency. 2021. Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. EPA 430-R-21-003. https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf.

also make broader contributions to the Justice40 Initiative by increasing clean energy enterprise creation, improving contracting opportunities in disadvantaged communities, and strengthening the clean energy jobs and training pipeline for underrepresented populations.

Key Barriers to Progress

HISTORICAL INEQUITIES IN THE DISTRIBUTION OF BENEFITS

Technology development and deployment has typically benefitted wealthier building owners who can afford higher upfront investments. For example, low-income households are less likely to have installed a solar photovoltaic system.[75] More than half of low-income households are renters, compared to less than a quarter of higher income households, making it difficult for low-to-moderate income (LMI) households to invest in and benefit from new technologies.[76] Similar barriers apply to small businesses, nonprofit organizations, and community groups that rent space in commercial buildings. Renters and LMI households are more likely to live in buildings that have substandard conditions that prevent them from participating in traditional energy efficiency programs, weatherizing, or taking advantage of financial incentives. For example, households with incomes below the federal poverty line are more than twice as likely to have mold, a hole in the roof, and/or boarded up windows compared to all other households.[77]

HIGH ENERGY BURDEN FOR LOW-INCOME HOUSEHOLDS

Energy burden is the percentage of gross household income spent on housing energy costs. An estimated 30 million U.S. households have a high energy burden (greater than 6%) and 16 million have a severe energy burden (greater than 10%). In some areas, the average energy burden can be as high as 30%. The energy burden metric does not capture other types of energy poverty, such as households that forgo heating, cooling, and other energy services to reduce their energy bills, putting themselves at risk of heat-, cold-, and moisture-related illnesses.[78] In 2020, 27% of all U.S. households had trouble meeting their energy needs, including 20% that were forced to spend less on food, medical, or other basic necessities to pay their energy bills.[79] Factoring in additional housing and transportation costs, such households have little opportunity to invest in and benefit from new technologies that would reduce their energy burden. An additional challenge is that upgrading buildings in low-income neighborhoods could increase rents for tenants if preventative measures are not in place, further increasing the burden of housing costs.

Community Benefit Plans in DOE programs

The U.S. Department of Energy is taking steps to embed equity and energy justice priorities across its programming and funding opportunities made available through the Infrastructure Investment and Jobs Act and the Inflation Reduction Act of 2022. DOE requires applicants for funding to submit Community Benefit Plans that address how priorities such as Justice40; workforce, community, and labor engagement; and diversity, equity, inclusion, and accessibility (DEIA) are incorporated into projects. Community Benefit Plans help ensure that DOE investments deliver meaningful impacts for disadvantaged communities, generating shared prosperity in the clean energy transition.

*U.S. Department of Energy. "About Community Benefit Plans." https://www.energy.gov/infrastructure/about-community-benefits-plans

Cross-Cutting Goal 2: Affordability – Reduce Energy-Related Costs

With proper planning and contractor training, the incremental cost of constructing highly energy efficient zero-emissions new buildings can be minimal.[80] However, existing building retrofits present unique affordability challenges. The high cost of retrofitting key building decarbonization solutions continues to limit their widespread adoption, particularly in households with low-to-moderate incomes and for small businesses with less ability to pay the upfront cost or qualify for financing for these solutions. For example, high-efficiency heating and cooling equipment is critical to decarbonizing buildings, but equipment prices increased 40% between 2020 and 2023, outpacing inflation and putting upfront equipment costs beyond the reach of many consumers.[81] Equipment prices remain high, as do the costs of necessary upgrades to electrical infrastructure such as wiring and panels. Soft costs, including the cost of finding customers, managing the sales process, and mitigating the risk of service calls, also add to the upfront cost barrier. For envelope upgrades like insulation, windows, and air sealing, unforeseen building conditions such as structure or moisture issues, asbestos/lead abatement, and knob-and-tube wiring can require expensive remediation measures.[82]

Near-term deployment incentives, building contractor training, and other means of reducing the cost of building decarbonization solutions are critical for ensuring that the transition to a low-carbon buildings sector is affordable for all Americans. At the same time, building decarbonization solutions must deliver lower energy bills to consumers once installed. In areas with high electricity rates, there could be a strong focus on improving energy efficiency when switching to electric technologies to limit the risk of increasing energy bills and exacerbating energy burdens. In areas with good solar resources and supportive compensation policies, on-site solar energy systems can be an effective means of reducing energy bills alongside electrification.

Efforts to make low-carbon building solutions more affordable must prioritize underserved communities; the previously highlighted Affordable Home Energy Shot is one example of how this can be done. The IRA, the largest investment in clean energy and climate action in U.S. history,[83] is also providing rebates, tax credits, and financing to cut energy costs and emissions in buildings with enhanced incentives for underserved communities and a commitment to Justice40.

Key Barriers to Progress

CONSUMERS LACK CAPITAL

Housing costs soared relative to wages between 2019 and 2023.[84] As mentioned, one in five American adults lives in a household that was behind on energy bill payments for at least one month in 2023.[85] Three in five Americans live paycheck to paycheck.[86] Under these conditions, investing in low-emissions building equipment, high-performance envelope components, and on-site renewables is often a challenge for these Americans based on first cost. Heating and water heating equipment is often replaced only when it fails. Because replacement is on an emergency basis, it is common for the most readily available and least expensive equipment to be installed. Building owners, especially in underserved communities, may not have access to low-cost financing options that could enable investing in higher efficiency equipment and other building upgrades.

HIGH SOFT COSTS

Both envelope and equipment upgrades have high soft costs that include customer acquisition, customer management, project customization, and risk; a recent survey found that gross margins for deep energy retrofits are higher than remodeling industry averages.[87] Some installers may be unfamiliar with sizing heat pump equipment or rely on sizing rules of thumb as opposed to detailed load calculations, which could lead to oversized equipment, unnecessary backup equipment, unnecessary electrical upgrades (see subsequent barrier), or uncomfortable occupants. If not guarded against, high demand from wealthy building owners could lead to price gouging. These challenges are especially acute in regions with relatively immature markets for key low-carbon technologies, such as cold climates with high current penetration of gas heating, though success stories in Maine and Minnesota demonstrate potential pathways forward.[88], [89] While the IRA is helping to offset consumer costs with rebates, tax credits, and financing, further innovation is needed to ensure the drivers of these costs are addressed directly.

ELECTRICAL UPGRADES

Electrifying building end uses may require consumers to cover the cost of upgrades to behind-the-meter electrical infrastructure and at the edge of the distribution grid, such as electrical panels, service wires, and transformers. These costs can be a significant barrier for building owners seeking to electrify. In states where utilities pay for these upgrades, electricity rates could increase if the additional revenue from increased electricity sales is not sufficient to pay for the upgrades over time. New, lower-power electric heat pumps, water heaters, appliances, and smart controls that could reduce the need for such infrastructure upgrades are beginning to enter the market but require further demonstration and policy support to accelerate near-term market penetration.

UTILITY RATE STRUCTURES

Some regions of the country have energy rates and rate structures that may be a barrier to reducing energy costs while pursuing building decarbonization that is equitable, efficient, and makes full use of clean electricity supply. As generation transitions to higher shares of variable renewable energy and as fixed costs such as plant construction and delivery infrastructure grow in importance, there is an opportunity to better align electricity rate structures with policy goals. For example, revised electricity rate structures might support greater adoption of heating electrification while distributing grid costs more equitably across income groups. Increased gas rates could also present an affordability challenge under high electrification without parallel evolution in gas utility business models, as a declining customer base could be saddled with the burden of maintaining legacy gas distribution costs.

Cross-Cutting Goal 3: Resilience – Increase the Resilience of Communities

With a cross-cutting emphasis on resilience, solutions for decarbonizing buildings can also improve the ability of the building stock to withstand operational stresses from extreme weather or grid disruptions. Climate-driven stresses on the built environment will increase over the next few decades,[90] with larger extreme weather events and longer, more frequent heatwaves and cold snaps. Extreme temperature events are particularly damaging to areas that are not accustomed to or prepared for these types of conditions, and cities are at greater risk of impacts from heat waves than non-urban areas due to heat island effects.[91] Human-made hazards such as cyberattacks or physical attacks on energy infrastructure also threaten the provision of vital building energy services.[92] A more resilient built environment can avoid a wide range of adverse impacts from such threats, including harm to building residents (e.g., injury from severe weather events or even loss of life), building property damage (e.g., burst pipes, buckling floors, mold growth, etc.) that can cause loss of housing or business bankruptcy, and other economic losses (e.g., refrigerated products). Since these outcomes will disproportionately affect low-income and disadvantaged communities,[93] achieving a more resilient building stock also helps advance the cross-cutting priority on equitable decarbonization.

Key building resilience measures include increasing the passive efficiency of building structures by upgrading existing envelopes to current code or beyond-code energy performance levels. This improves structural durability and thermal resilience, extends the habitability of structures during extreme heat and cold events with power outages, and decreases excess mortality.[94] In urban locations, measures such as cool roofs and pavements and increased vegetation can reduce heat islands make cities less vulnerable to extreme heat impacts. Such measures also decrease buildings' need for energy services and peak electricity demand and can be deployed alongside strategies that improve building load flexibility, maximize the use of distributed energy resources (e.g., on-site generation, battery backup), and coordinate operations across building clusters to alleviate stress on the power grid and improve the grid's operational resilience.[95] The goal of increasing the resilience of buildings and communities is therefore deeply intertwined with this strategy's parallel strategic objectives to increase the energy efficiency of building operations and transform the flexibility of buildings as a grid edge resource.

Key Barriers to Progress

LACK OF ACCESS TO COOLING

Heat is the leading cause of weather-related deaths in the United States.[96] While the number of homes with air conditioning continues to rise, there are still 14 million households without any air conditioning or evaporative cooling equipment.[97] In 2020, over 5 million households could not afford to fix or replace broken cooling equipment.[98] Additionally, half a million people in the United States are unhoused and lack the basic necessity of permanent shelter.[99] This lack of access to cooling presents a key obstacle to ensuring the safety of all Americans in the face of increasing extreme heat events caused by climate change.

POORLY INSULATED, AIR-SEALED, AND SHADED BUILDING STOCK

About half of all U.S. buildings were built before energy codes started to become common in 1980.[100, 101] Many of these buildings have not been insulated or air sealed and have no way of controlling solar heat gain through shading, cool roofs, or other passive design approaches and materials. These buildings are particularly susceptible to extreme hot and cold weather events, especially if the events coincide with power disruptions.

ELECTRIFICATION INCREASES CRITICAL ELECTRIC LOADS

While most U.S. buildings are susceptible to power outages, 14% of homes and 25% of commercial floor space have access to fuel-fired backup generators[102, 103] and behind-the-meter battery storage is on the rise. Electrifying end uses in buildings could make it more difficult to operate critical building loads on a generator or battery. Such challenges are magnified by climate risks and grid reliability issues. Measures such as envelope upgrades, on-site generation, bi-directional EV charging, and smart control systems that manage multiple DERs can collectively minimize building load requirements under electrification and improve buildings' thermal and electrical resilience relative to today.

A more resilient built environment can avoid a wide range of adverse impacts, including harm to building residents, building property damage that can cause loss of housing or business bankruptcy, and other economic losses.

Strategic Objective 1: Increase Building Energy Efficiency

Performance Target: Reduce on-site energy use intensity in buildings 35% by 2035 and 50% by 2050 vs. 2005

Energy efficient buildings are critical for ensuring affordable, healthy, comfortable, and resilient indoor environments for occupants while reducing emissions, energy use, and electricity demand. As noted previously, buildings are currently responsible for 74% of electricity use, with space conditioning driving both summer and winter peak demand—and therefore grid infrastructure costs—in many regions. Without persistent reductions in demand from improved efficiency, these grid costs could increase dramatically in the coming decades as wind, solar, and other clean electricity technologies are deployed at an unprecedented rate—at least four times the historical pace—to achieve 2035 and 2050 clean electricity goals.[104]

Ensuring that buildings continue to become more efficient, particularly for heating and cooling end uses, will reduce peak demand and increase the economic benefits of grid decarbonization by saving Americans money. Efficiency delivers other benefits, such as healthier and more comfortable indoor environments and the ability to maintain safe indoor temperatures during power outages. It is essential that these affordability and resilience benefits are equitably experienced by disadvantaged communities to mitigate further disparities in the societal impacts of climate change.

To meet the objective of increasing energy efficiency, the Blueprint targets a 35% reduction in building energy use intensity (EUI) per unit of floor area by 2035 and a 50% reduction by 2050, both vs. 2005 levels. These targets are based on necessary reductions in building EUI across several existing net-zero emissions studies. The efficiency targets are generally consistent with scenarios that assume widespread, but not universal, conversion from fossil-fired equipment

to efficient heat pumps by 2050, along with deep improvements in envelope and appliance efficiency. The timing of conversions to fossil-fired equipment is constrained by regular rates of building retrofitting and equipment stock turnover cycles. (see *Appendix, Development of Performance Targets*).

Targeted EUI reductions are ambitious. As of 2022, the building sector's EUI was just 16% lower than 2005 levels, and the targeted EUI reduction from 2022-2050 is more than double that of the U.S. Energy Information Administration (EIA) Annual Energy Outlook (AEO) Reference Case projection.[105] The targeted level of reduction during this period is also greater than that of the preceding 42-year period dating back to 1980 (31%), which saw the introduction of the first building energy codes and equipment standards.[106]

The efficiency target works in tandem with the subsequent performance targets related to on-site emissions reductions and grid edge objectives (strategic objectives 2 and 3, respectively). Efficient envelopes and ventilation will make it easier to electrify heating loads by enabling smaller equipment and fewer electrical upgrades. Converting heating and water heating to heat pumps inherently increases the efficiency of on-site energy use. Moreover, efficient envelopes make it easier to store thermal energy by pre-heating or pre-cooling

Energy efficient buildings are critical for ensuring affordable, healthy, comfortable, and resilient indoor environments for occupants while reducing emissions, energy use, and electricity demand.

buildings to coast through periods of peak demand. This improvement in thermal inertia supports increased building demand flexibility, a transformed grid edge at buildings,[107] and the broader goal of 100% clean electricity.

Key Barriers to Progress

LIMITED TOOLS TO ACCELERATE EFFICIENCY RETROFITS

While energy codes will continue to drive down the energy use intensity of the overall U.S. building stock by improving the energy efficiency of new construction, 75% of the current residential building stock and 51% of existing commercial stock are expected to remain in 2050 and energy codes generally do not apply to existing buildings or only apply to major renovation projects.[108] While federal appliance and equipment efficiency standards require regular improvements to minimum appliance and equipment efficiency, these efficiency standards do not address the main drivers of heating and cooling loads: envelope in residential buildings and ventilation in commercial buildings.[109] Building performance standards (BPS) are an emerging regulatory tool for accelerating efficiency improvements—including envelope and ventilation efficiency—in existing buildings, but have only been enacted in a limited number of states and jurisdictions and typically only apply to larger multifamily and commercial buildings.[110] Programs and incentives authorized by the Bipartisan Infrastructure Law and Inflation Reduction Act also have the potential to help transform the market for energy efficient retrofits.

LACK OF TRANSPARENT VALUATION OF EFFICIENCY IN THE MARKET

There is an opportunity to better recognize the value of energy efficiency in residential real estate transactions, dramatically improving the market and financing opportunities for a wide range of efficiency measures. Similarly, commercial and multifamily building energy benchmarking, transparency, and labeling requirements can increase the real estate valuation of energy efficient properties while delivering substantial energy savings.[111] Energy benchmarking also serves as a foundation for innovative leasing agreements that prioritize energy efficiency and address the issue of split incentives for operating efficiency between commercial landlords and tenants.[112] While many cities and some states have enacted policies to increase energy benchmarking and transparency for existing buildings,[113] the reach of these policies must continue to expand to spur widespread building efficiency improvements across the country.

SUBSTANDARD BUILDING CONDITIONS

Many buildings have deferred maintenance or other conditions such as mold, asbestos, lead paint, and structural issues that prevent their owners from participating in traditional energy efficiency and weatherization programs or benefitting from related financial incentives. In Connecticut, for example, between 10% and 35% of all weatherization jobs are canceled because of health and safety problems posed by existing building conditions.[114] Nationally, in the past year, over 11 million homes have had water leak through the roof, basement, walls, windows, or doors and almost 4 million homes have had mold.[115] There is an opportunity to dramatically expand the number of weatherization programs that braid funding sources to address health and safety barriers. While health, safety, and cost savings benefits are significant, addressing substandard building conditions can also increase people's dignity and community pride.

Strategic Objective 2: Accelerate On-site Emissions Reductions

Performance Target: Reduce on-site GHG emissions in buildings 25% by 2035 and 75% by 2050 vs. 2005

On-site GHG emissions from buildings, which come mostly from combustion of fossil fuels (83% of on-site emissions), will comprise an increasing share of building emissions as the power grid is decarbonized. Reducing on-site fossil-fired building emissions is often cited as a key component of economy-wide decarbonization, and building electrification with heat pumps is a primary strategy for doing so.[116] The potential benefits of building electrification go beyond emissions reductions and include improved indoor air quality, reduced construction costs, new jobs creation, and less exposure to increases in fossil fuel prices.[117]

To meet the objective of reducing on-site building emissions, the Blueprint targets a 25% reduction in these emissions by 2035 and a 75% reduction by 2050, both vs. 2005 levels. Targeted reductions in building emissions from on-site fossil fuel combustion are based on the same net-zero emissions studies that informed the preceding energy efficiency target and are similarly consistent with scenarios that assume high, but not universal, conversion of fossil-fired equipment to efficient heat pumps by 2050, constrained by regular rates of retrofitting and stock turnover cycles (see *Appendix, Development of Performance Targets*). The broad framing of this target as an on-site emissions objective recognizes the possibility of reducing fossil-based emissions through solutions other than direct electrification, such as thermal energy networks that can take advantage of multiple sources of carbon-free heat.

Meeting the targeted reductions in on-site emissions will require aggressive change and significant improvement in the current trajectory for this metric. As of 2022, building on-site emissions from fossil combustion had increased about 1% vs. the 2005 benchmark.[118] Looking at business-as-usual trends, the AEO 2023 Reference Case projects only a 9% decrease in building on-site fossil combustion emissions vs. 2005 levels between 2022 and 2050, far less than the Blueprint target of a 75% reduction.

The on-site emissions target also encompasses reductions in the 17%[119] of on-site building GHG emissions that come from fluorinated gas, including equipment refrigerant leakage, foam blowing agents, and fire suppressants. Specifically, the target assumes an 85% reduction in buildings sector fluorinated gas emissions pursuant to the American Innovation and Manufacturing (AIM) Act of 2020,[120] which authorized EPA to address hydrofluorocarbons (HFCs)—of which building equipment refrigerants are a primary source—by phasing down their production and consumption, maximizing reclamation and minimizing releases from equipment, and facilitating the transition to next-generation technologies through sector-based restrictions.[121] The AIM Act is the primary legislative means of implementing the Kigali Amendment to the Montreal Protocol, which was ratified by the U.S. in 2022 and requires reductions in HFC use.[122] In addition to reducing GHG emissions, the Kigali Amendment and AIM Act are expected to create domestic jobs to design, manufacture, and install new equipment that can operate with low-GWP refrigerants and ultimately strengthen U.S. manufacturing competitiveness in global markets.

Key Barriers to Progress

INSUFFICIENT LOCAL ELECTRICAL CAPACITY

Switching building equipment to run on clean electricity may require expensive electrical infrastructure and service upgrades for consumers at the grid edge. Equipment replacements tend to occur on an emergency basis, and consumers can ill afford to expend the substantial time and effort it takes to find an electrician to upgrade wiring, circuits, and/or breaker panels, or to coordinate with the electric utility on a service upgrade if necessary.[123] New, lower-power electric heat pumps, water heaters, appliances, and smart controls entering the market provide a potential pathway for reducing the need for infrastructure upgrades. However, consumers are not familiar with many of these, so further policy support is needed to accelerate their near-term market penetration.

COLD CLIMATE PERFORMANCE

Depending on equipment specifications and approach to sizing, low-efficiency electric resistance may back up air-source heat pumps to meet peak heating loads, particularly in buildings in cold climates, large commercial buildings, or other buildings with high heating demands. Such inefficiency could significantly increase demand on the electric grid, potentially doubling or tripling peak demand from buildings in some regions and shifting net system peaks from summer to winter.[124] Inefficient conversion of fossil-fired equipment to heat pumps that require resistance backup also increases the likelihood of electrical upgrade requirements for customers and at the grid edge. Air-source heat pumps installed with fossil-fired backup heat have less impact on peak electric demand and grid edge infrastructure, but they may not reduce methane leakage from pressurized gas pipes in buildings and from the greater gas distribution network and thus prove a challenge in the long-term for getting to a near-zero emissions buildings sector. Thus, for full building decarbonization with all-electric technology, it is essential to reduce peak heating demand with efficiency measures that reduce the need for backup heat sources.

UPFRONT COSTS FOR HIGHLY EFFICIENT EQUIPMENT

Switching to inefficient electric equipment may lead to higher consumer energy costs in markets where electric rates are considerably higher than gas rates and where electrification equipment is not paired with energy efficiency and/or on-site renewables. Higher efficiency cold climate air-source heat pumps and highly efficient ground-source (geothermal) heat pumps can mitigate the potential energy cost increases, but this equipment often costs much more than standard efficiency equipment. Limitations posed by lack of available space for equipment, existing ductwork size, and commercial equipment roof curbs may also increase the cost of installing larger heat pump equipment.

FRAGMENTED MARKET AND RISK-AVERSE PRACTITIONERS

The 124,000 independent HVAC contractor businesses in the United States compose a fragmented market.[125] Installers are often risk-averse because of industry challenges. Customer call-backs can eat into slim profit margins and the lack of common equipment sizing standards and guidelines exacerbates installer risks. Many existing HVAC installers lack the familiarity and experience in heat pump sizing and installation needed to support accelerated deployment into new markets. In larger multifamily and commercial buildings, the HVAC market runs through millions of contractors, architects, engineers, maintenance workers, lenders, investors, owners, and renters, all with different priorities and needs. Lack of communication, training, and market alignment among these diverse actors will lead to higher costs until low-carbon design and retrofit practices are normalized and collective learning-by-doing begins to level out the incremental costs of installing low-carbon HVAC technologies.

LACK OF CONSUMER PRODUCT AWARENESS AND FAMILIARITY

Heat pumps are not extensively marketed to consumers in regions where they are currently less common and the decarbonization potential is greatest, such as the Northeast, Mid-Atlantic and Great Lakes. Without greater consumer outreach and education that leverages evidence from real-world testing, concerns about heat pump system complexity, cold climate performance, resilience to power outages, and increased maintenance costs will constrain adoption in markets currently dominated by fossil-fired heating.

The potential benefits of building electrification extend beyond emissions reductions and include improved indoor air quality, reduced construction costs, new jobs creation, and less exposure to increases in fossil fuel prices.

UNCERTAINTY ABOUT ULTRA-LOW GWP REFRIGERANT APPLICATION AND PERFORMANCE

Several of the lowest-GWP refrigerant options for electric heating and water heating equipment have higher flammability or toxicity ratings, may require updated state and local building codes to enable usage, and/or may require system architecture redesign and new HVAC technician tools.[126] Moreover, the efficiency performance of emerging ultra-low GWP refrigerants requires further characterization, and as with newer types of heat pumps, consumer adoption of unconventional refrigerants could be limited by lack of familiarity with the use and performance of ultra-low GWP options. There is a need to more comprehensively understand the barriers to transition to ultra-low GWP refrigerants for different applications, along with the opportunities to overcome those barriers.

Strategic Objective 3: Transform the Grid Edge

Performance Target: Reduce electricity infrastructure costs by tripling demand flexibility potential by 2050 vs. 2020

Decarbonizing the electricity supply by 2035 without a parallel focus on managing end-use electricity demand at the grid edge—the "last mile" of distribution networks and behind-the-meter infrastructure that is closest to a utility's end-use customers—would require a significant build-out of new infrastructure for clean power generation, transmission, and distribution.[127] Transforming the grid edge by increasing buildings' energy efficiency, demand flexibility, and capacity to coordinate other DERs can reduce peak electricity demand, moderate the rate at which power generation must be ramped up or down, and alleviate other operational challenges. Collectively, these measures reduce the cost and scale of bulk power and distribution system decarbonization. Moreover, to the extent that building measures reduce the need for new grid infrastructure while load electrification adds to

utility revenue for financing new investments, such measures can also put downward pressure on retail rates.

Assets for transforming the grid edge include energy efficient technologies and operational approaches as well as additional hardware and software that enable smart management

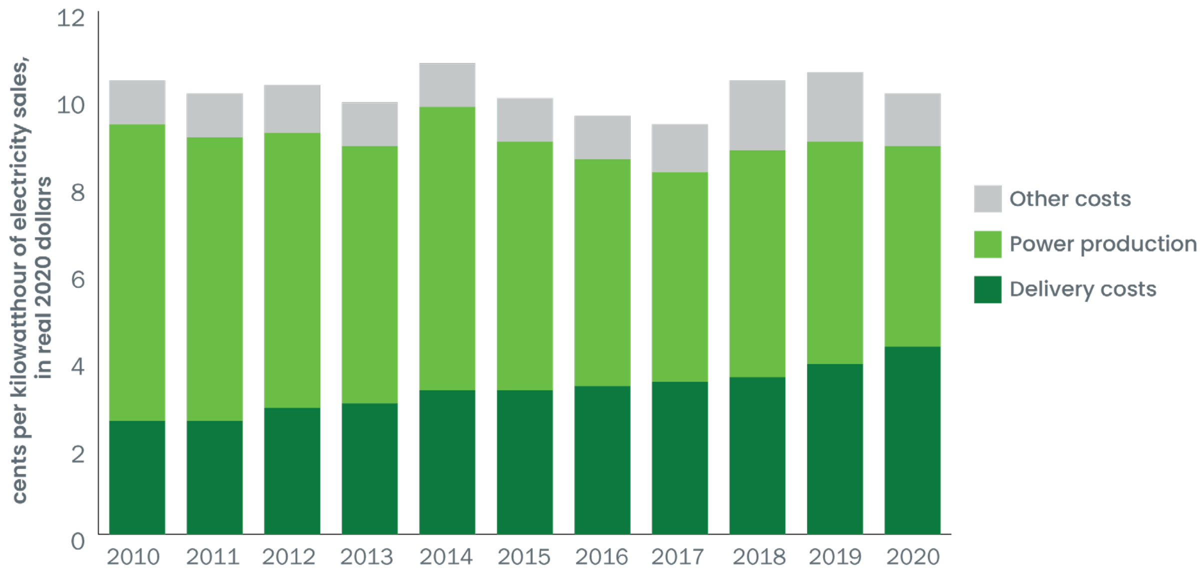


*Figure 12. U.S. Energy Information Administration data show that utility spending on electricity delivery has grown over the last decade while spending on power production has declined over the same period. During the same period, utility spending on electricity delivery increased by 65%, from 2.6 cents per kilowatt-hour (kWh) in 2010 (using 2020 dollars) to 4.3 cents per kWh in 2020.**

of customer electricity demand, such as: distribution system equipment and electrical service conductors; advanced distribution system management systems, distributed energy resource management systems, and supporting data management tools; customer electrical panels, breakers, voltage controls, and wiring; on-site renewable energy generation; charging/discharging of EV batteries and other on-site thermal or battery storage; and management of conventional building electric loads, including space conditioning or water heating via smart thermostats, smart appliances, and whole building controls and sensing networks.

Emerging business models are creating value for the use of these grid edge assets, including through virtual power plants (VPPs), which aggregate DERs to balance electrical loads and provide grid services.[128] Coordination of demand-side assets in buildings can smooth out electricity usage and reduce the scale of peak power generation capacity, including high-emission fossil-based generation plants that tend to operate at times of peak demand. It can also relieve pressure on transmission and distribution networks to counter the steadily increasing cost of delivering each kilowatt-hour (kWh) of electricity (Figure 12). In turn, these benefits can flow back to consumers through lower energy bills and reduced cost burdens, which can be directed toward disadvantaged communities to ensure more equitable outcomes.

To transform the grid edge and reduce electrical infrastructure costs, the Blueprint targets a threefold increase in building demand flexibility potential by 2050 compared to 2020 potential. This target was established through the related but more narrowly defined concept of building demand response (DR), which utilities, load aggregators, and grid operators have used for decades to encourage end-use customers to change power consumption via financial or other incentives.[129] Traditionally, DR programs and related studies and datasets have focused primarily on peak load reductions, but in recent years the concept of DR has begun to address the

*U.S. Energy Information Administration. "Today in Energy." 2021. https://www.eia.gov/todayinenergy/detail.php?id=50456. Based on data from Federal Energy Regulatory Commission Financial Reports, as accessed by Ventyx Velocity Suite.

broader concepts of building demand flexibility and integrated management of DERs.[130, 131] While the quantitative goal of increasing building flexibility threefold by 2050 is benchmarked by the existing estimates of DR peak load reduction potential (see *Appendix, Development of Performance Targets*), achieving that increase would require a broader grid edge transformation with the deployment of next-generation DR programs and incentives that encompass both traditional building loads and emerging loads such as stationary and vehicle battery charging, and can overcome recent stagnation in traditional DR markets, which have grown just 9% in the past decade. Such a transformation in buildings is expected to put downward pressure on electrical infrastructure costs, though changes in these costs cannot be attributed specifically to buildings given their dependence on a variety of other factors.

Key Barriers to Progress

LACK OF VALUATION AND INSUFFICIENT INCENTIVES FOR GRID EDGE RESOURCES

Demand-side measures at the grid edge are often excluded or undervalued in power markets, resource planning, and distribution planning. The ability of grid edge assets to access wholesale power markets remains uneven, despite recent regulatory progress.[132] Moreover, most utility customers remain on flat electricity rates that do not assign time-varying value to their electricity consumption or motivate the adoption of technologies that would enable sophisticated load management to meet grid needs. There is limited understanding of load adjustment motivations, preferences, and constraints across heterogeneous customer types.

LACK OF DISTRIBUTED RESOURCE INTEGRATION

Building end-use demand management measures are not typically coordinated with other behind-the-meter DERs, such as on-site photovoltaics (PV), EVs, or batteries. Such assets are typically marketed, installed, and valued in power markets separately (when they are valued in these markets at all) despite their potential to serve as complementary packages for distributed load management. Moreover, market rules may differ by asset type, making it challenging to coordinate value across DERs and reducing the potential for aggregation. Unmanaged deployment of these assets turns a potential demand-side resource into an additional grid challenge. For example, concurrent loads from EV charging and electric space heating could overload transformers, and distributed solar generation may be sent back to the grid during times of system-wide generation surpluses. New approaches such as VPPs can help address such barriers, but are not yet widely deployed.[133]

Strategic Objective 4: Minimize Embodied Life Cycle Emissions

Performance Target: Reduce embodied emissions from building materials and construction 90% by 2050 vs. 2005

As building operational emissions are reduced through progress on the preceding targets and complementary electric sector decarbonization, a greater portion of total building GHG emissions will come from the non-operational life cycle emissions "embodied" in building materials and equipment, including from resource extraction, manufacturing, transportation, construction, replacement/renovation, reuse, demolition, and material recycling or disposal. This category of building emissions is designated as Scope 3 emissions under the GHG Protocol Corporate Accounting and Reporting Standard.[134] The majority of embodied emissions are associated with decisions made during building design and construction.[135]

Strategies to reduce embodied building emissions can be divided into four categories. The first category reduces the quantity of building materials needed by repurposing existing buildings. The second involves choosing construction methods—for example, industrialized construction[136]— that waste fewer materials and use building materials with lower or net-negative embodied emissions intensity and/or longer lifespans. The third category involves reducing the embodied emissions intensity of existing materials like concrete and steel, including the circular use of materials salvaged or recycled from building demolition as well as designing for deconstruction and reuse. The final category focuses on reducing the carbon intensity of construction materials used in building construction and renovation.

Accurate estimates of embodied emissions from the national buildings sector are not currently available. A value of 11% of global emissions is commonly reported,[137] but more recent estimates are lower—around 4% of global emissions (2,200 Mt CO_2e per year).[138] The percentage is estimated to be smaller still in the United States, where construction rates are lower than in other regions.[139] It's estimated that embodied emissions from building construction, renovation, and material production are in the 200–400 Mt CO_2e per year range, based on the available literature.[140]

To meet the objective of minimizing embodied life cycle emissions from buildings, the Blueprint targets a 90% reduction in embodied building emissions by 2050 compared to 2005 levels. Given the uncertainty about the scale of embodied emissions from buildings and the potential for reductions, this target is based on a rough constraint of drawing down building emissions to no more than 10% of 2005 levels by 2050. As noted earlier, this magnitude of remaining building emissions is consistent with the level of remaining emissions levels for the broader energy system—including industrial and transportation—found in multiple modeling studies. These studies show that this level of remaining emissions could be offset by natural carbon sinks and carbon removal technologies to achieve the economy-wide net-zero emissions goal (see endnote 52).

Key Barriers to Progress

LACK OF HIGH-QUALITY DATA AND ACCOUNTING METHODS

There is a lack of quality data on embodied material life cycle emissions at the national or whole-building scales or for individual products. Manufacturers are developing environmental product declarations (EPDs) that standardize industry measurement and reporting for products and materials. EPDs have the potential to facilitate market signals for lower-emissions materials and products, and the IRA included a $250 million investment in enhancing the transparency, standardization, and development of EPDs and $100 million to develop an embodied carbon label for construction materials. At present, however, the quality of EPDs varies widely. This is particularly true for imported products that may not have the same reporting standards as domestically produced materials.

In addition to data and reporting issues, there is a lack of consensus on standardized whole building life cycle assessment (WBLCA) methods that can compare the embodied carbon of buildings designed with conventional building materials (e.g., steel and concrete) with that of buildings designed with new and innovative materials (e.g., bio-based materials such as engineered wood or wood fiber insulation). Such comparative WBLCA studies are needed to give confidence that sustainable building designs and retrofits minimize embodied carbon emissions relative to status quo approaches.

LACK OF MARKET INCENTIVES

There is a range of no-cost and low-cost ways to reduce embodied carbon in building construction.[141] However, additional steps may come at a cost premium. Unlike energy efficiency investments, this cost premium does not typically result in a return on investment. Thus, these decisions must be driven by government or corporate procurement policies (such as the Federal Buy Clean Initiative), or by voluntary standards like the Leadership in Energy and Environmental Design (LEED) rating system.

4.2 • Primary Technical Solutions

There is no one-size-fits-all solution for addressing buildings sector emissions. Rather, a full suite of design strategies, technologies, and operational approaches is needed to address the multitude of building energy end uses and GHG emissions sources. Table 1 groups these solutions into five categories and indicates the relative potential of each to reduce building GHG emissions:

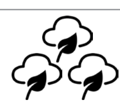
- **Energy efficiency** reduces waste in building energy operations and overall building energy demand. Efficiency can significantly reduce existing electricity use (52% of buildings emissions in 2021) and offset growth in electric demand from electrification.[142]
- **Efficient electrification** converts on-site fuel combustion to efficiently use clean electricity. This is the primary solution for reducing building emissions from on-site fuel combustion (24% of buildings emissions in 2021).
- **Grid edge resource management** uses building controls, sensor networks, and internet-connected equipment to enable demand flexibility and grid-responsiveness, reduce grid edge infrastructure costs, and coordinate DERs such as on-site solar generation and battery storage. Together with efficiency, strategic load flexibility and coordination of DERs at the grid edge facilitates electrification by reducing heating loads and avoiding electrical upgrades, while also significantly lowering the cost of decarbonizing the power grid and thus indirectly reducing electricity emissions (again, 52% of buildings emissions in 2021).
- **Low global warming potential (GWP) refrigerants and other HFCs** reduce the warming potential of equipment refrigerants, blowing agents for insulation and air sealing foams, and HFC fire suppression systems (5% of buildings emissions in 2021).
- **Low embodied carbon construction** reduces the embodied emissions associated with

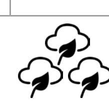
new construction and major renovations, including material manufacturing, transport, construction, and disposal (estimated to be around 14% of buildings emissions in 2021).

The context for buildings sector decarbonization includes a power sector that is rapidly decarbonizing through the deployment of a wide variety of generation and storage resources—both centralized and distributed (see Figure 6). While purchased carbon-free electricity and on-site renewables are not listed above as *buildings sector* solutions, they are a critical part of the economy-wide transition. Buildings can be designed and retrofitted to facilitate electricity decarbonization by hosting distributed generation and storage; integrating flexible building load and EV charging resources; and making efficient use of carbon-free generation, storage, transmission, and distribution infrastructure.

Table 2 further details each of the solution categories introduced in Table 1, summarizing the specific measures in each category, the role of each solution in the low-carbon building transition, and the benefits different solution types can unlock for people and communities. Measures in Table 2 range from equipment improvements and improved design and upgrades to building envelope and materials and advanced operational controls with distributed storage and generation. These approaches are not mutually exclusive and

Table 1. Five primary solution types are mapped to show how they address the sources of emissions introduced in Figure 3, with icons indicating the relative scale of reduction potential. Emissions scopes follow Greenhouse Gas Protocol definitions. HFCs = hydrofluorocarbons, GWP = global warming potential.

Emissions scope and source (% buildings emissions)		Energy efficiency	Efficient electrification	Grid edge resource managment	Low GWP refrigerants	Low embodied carbon construction
1	On-site fuel combustion (24%)					
	Refrigerants, other HFCs (5%)					
2	Electricity generation (52%)					
	Upstream gas*(~5%)					
3	Embodied life cycle (~14%)					

 Lower emissions reductions potential
 Moderate emissions reduction potential
 Higher emissions reduction potential

*Upstream methane emissions from the production and distribution of natural gas (~5% of buildings emissions) is partially addressed through efficiency and electrification solutions that reduce gas consumption, though fully addressing methane leakage from distribution pipes and meters would require more significant infrastructure changes, such as pipe replacement or decommissioning.

can be deployed beneficially in an integrated fashion, for example:

- Design a building to maximize use of passive heating and cooling while simultaneously increasing envelope insulation using carbon-storing materials and air sealing to reduce the required capacity and cost of upgraded HVAC equipment.
- Transition a fossil-based gas furnace or boiler to a high-performance cold climate heat pump that uses ultra-low GWP refrigerants and is grid interactive.
- Control the electric equipment—along with other DERs such as on-site solar, backup storage, and EV charging—with a grid-connected smart thermostat or building automation system that efficiently manages HVAC load schedules alongside load profiles for the other DERs, benefitting both the consumer and the grid.

Table 2. Solution category and key measures for building decarbonization and their roles and benefits.

Energy efficiency		
Key measures	**Role in economy-wide decarbonization**	**Benefits to people**
• High-performance building envelopes (e.g., highly insulating windows, insulation, air and duct sealing) and passive building design and retrofit approaches. • High-performance electric equipment and appliances (e.g., air- and ground-source heat pumps, ENERGY STAR appliances). • Technologies for optimizing ventilation rates and thermal loads (e.g., energy recovery, demand-controlled ventilation, occupant sensing).	• Delivers persistent reductions in building energy use and emissions by reducing waste in the provision of those services. • Reduces peak demand to limit the scale of clean generation, storage, and grid infrastructure, potentially lowering electric rates for consumers and facilitating economy-wide decarbonization. • Enables electrification by reducing required equipment capacities and avoiding electrical infrastructure upgrades.	• Saves consumers money on energy bills to lower energy burdens (directly and indirectly by reducing peak demand, which lowers electricity rates); reduces consumer exposure to volatile energy prices. • Delivers multiple other co-benefits (e.g., improved thermal resilience, comfort, health, and productivity).
Efficient electrification		
Key measures	**Role in economy-wide decarbonization**	**Benefits to people**
• Air-source heat pumps, including products optimized for cold climate performance with refrigerants that have low global warming potential. • Ground-source (geothermal) heat pumps. • Heat pump water heaters.	• Converts fossil-based building loads to clean electric service while prioritizing electric equipment that offers superior energy performance to fossil-based alternatives.	• Provides air quality and health and safety co-benefits. • Reduces exposure to heating fuel price volatility. • Improves energy security for locations that rely on fossil fuel transportation by truck. • Emphasis on high energy performance minimizes added burdens on the electric grid and the risk of bill increases for consumers.

Grid edge resource management		
Key measures	**Role in economy-wide decarbonization**	**Benefits to people**
• Grid-responsive smart thermostats and building automation systems with sensing hardware. • Grid-responsive water heaters and appliances. • Smart panels. • Thermal storage integrated with equipment or envelope materials. • Behind-the-meter battery storage. • On-site zero-emissions generation. • Managed EV charging and bi-directional EV charging infrastructure.	• Reduces grid expansion even as loads grow from building and vehicle electrification. • Enables coordination of on-site distributed energy resources and provides demand flexibility via targeted load shedding and/or shifting in response to bulk power system conditions, while maintaining occupant comfort.	• Facilitates the operation of a decarbonized power grid by reducing peak demand and shifting loads to times of abundant renewable power generation while avoiding behind-the-meter electrical upgrades and maximizing utilization of distribution grid infrastructure. • Improves resilience, lowers electric rates, and creates opportunities for consumer bill savings when paired with time-varying electricity rates or compensation for program participation.

Low global warming potential (GWP) refrigerants and other fluorinated gases		
Key measures	**Role in economy-wide decarbonization**	**Benefits to people**
• Development and adoption of low-GWP (<150 GWP) refrigerant, foam blowing agent, and fire suppressant alternatives and compatible equipment. • Development of non-vapor compression, refrigerant-free HVAC equipment. • Improved refrigerant leak detection methods and operation and maintenance practices. • Refrigerant recycling. • Building design that minimizes refrigerant lines.	• Reduces the global warming potential of refrigerants that leak from building equipment, countering potential growth in emissions from refrigerant leakage as more space and water heating equipment is transitioned to electric heat pumps that use refrigerants.	• Ensures that reductions in energy emissions from electrification are not offset by additional emissions from production of refrigerant and increased refrigerant leakage. • Creates domestic jobs to design, manufacture, and install new equipment that can operate with low-GWP refrigerants. • Strengthens U.S. manufacturing competitiveness in global markets.

Low embodied carbon construction		
Key measures	**Role in economy-wide decarbonization**	**Benefits to people**
• Invest in existing buildings to reduce the need for new buildings and materials. • Maximize efficiency of structural design and design buildings and retrofits to use fewer materials. • Use of recycled, low-carbon, and/or carbon-storing building materials. • Standardized embodied carbon calculation and reporting methods.	• Minimizes the need for and/or reduces the life cycle (nonoperational) carbon content of building materials. • Life cycle greenhouse gas emissions associated with building material manufacturing, transport, installation, maintenance, and end-of-use disposal will grow in relative proportion as operation-phase emissions are drawn down.	• Creates new material design, manufacturing, and construction jobs and potentially improves the quality and structural resilience of building designs and retrofits. • Improves construction site air quality for workers and neighbors. • Strengthens U.S. manufacturing competitiveness in global markets.

SPOTLIGHT ON FEDERALLY OWNED AND FUNDED BUILDINGS

The federal government can ensure that every dollar spent on buildings advances the trajectory to zero emissions.

Federally owned buildings – As the nation's largest building owner and property manager, the federal government is already leading by example in the federally owned building portfolio. Executive Order 14057 transitions the federally owned building portfolio to zero emissions by 2045, including cutting emissions in half by 2032 and constructing only zero-emission new buildings by 2030. U.S. government-funded projects contributed about 32% of construction-related embodied carbon in the United States. As the world's largest buyer of goods and services (more than $650 billion per year), the federal government has the opportunity to use its vast procurement power to move the market toward solutions that reduce embodied emissions from the buildings sector.

Federally funded buildings – In addition to its owned portfolio, the federal government also invests approximately $450 billion per year in the construction and renovation of non-federally owned buildings, or federally funded buildings, which do not fall under Executive Order 14057. There is an opportunity for deeper energy savings and emissions savings for non-federally owned buildings.

Additional types of solutions may be necessary to meet hard-to-electrify heating needs. For example, thermal energy networks (TENs) use pipes to share thermal energy for heating, cooling, or other end uses between buildings. Existing district energy systems (serving around 8% of commercial building floor area)[143] commonly use underground steam, hot water, and/or chilled water pipes to distribute thermal energy made by fossil fuel combustion. These systems could instead use a variety of carbon-free heat sources, such as hydrogen fuel cells, solar thermal, nuclear, other low-carbon fuels, carbon-free grid electricity, or even off-grid renewable electricity stored as heat, to make steam or chilled water.

The potential of TENs may go beyond the decarbonization of existing district systems, however. Legislation supporting the creation of thermal utilities in a growing number of states could dramatically expand the potential for new TENs that leverage the skilled workforce, existing rights-of-way, customer relationships, and access to capital of gas utilities.[144] This new wave of emerging TENs is often designed as ambient-loop systems that distribute water at temperatures closer to ambient air or ground temperatures and thus support electrification of buildings by enabling water-source heat pumps that are smaller and less power intensive than individual air-source or ground-source heat pumps. Ambient-loop TENs, whether newly deployed or converted district steam or chilled water systems, can use the sources of low-carbon heat listed above and can make use of lower-temperature heat, such as waste heat from building air conditioning or refrigeration and geothermal heat exchangers. Thus, TENs can reduce the peak demand impacts of electrification and, when using geothermal wells, can provide seasonal storage of thermal energy to smooth out seasonal differences in energy demand.

On-site use of low-carbon fuels in individual building boilers, furnaces, or fuel cells provides an additional opportunity to reduce on-site emissions but may be challenged by upstream emissions from production and pipeline leakage, neighborhood air quality concerns, and competing demands from hard-to-electrify transportation and industrial applications.

4.3 • Federal Actions and Implementation Tools

The federal government can increase the speed and scale at which decarbonization solutions are developed and deployed through a wide spectrum of actions that range from advancing foundational science to incentivizing broader adoption of low-carbon building technologies—all while promoting equitable, affordable, and resilient outcomes. Figure 13 groups federal actions to accelerate building decarbonization into four categories, described further here. All of the actions can be pursued through existing federal authority and available funding.

- **Maximize technology performance and affordability** by funding and piloting early-stage research and development (R&D) to develop low-carbon technologies with breakthrough cost reductions and performance characteristics that raise the energy and emissions performance "ceiling" for, and lower the cost of, market-available building technologies.
- **Develop markets and enable deployment** for low-carbon building technologies through voluntary efficiency and electrification standards, public-private partnerships, and leadership of federally funded construction and renovation practices. Remove key deployment barriers by providing supporting analysis, tools, and data; developing a skilled building decarbonization workforce and installer networks; and improve the ease of low-carbon technology installation for consumers and businesses.
- **Provide direct funding and financing** to improve the economic attractiveness of low-carbon technologies for consumers and businesses by lowering first costs (e.g., via tax credits and rebates) and/or spreading them over a longer

Maximize technology performance and affordability

- Foundational science
- Early-stage R&D funding
- Solutions for hard-to-decarbonize segments
- Pilot demonstrations

Provide direct funding and financing

- Point-of-sale rebates
- Tax credits and deductions
- Facilitate financing

Develop markets and enable deployment

- Enabling tools, partnerships, and market-facing resources
- Contractor/consumer outreach
- Workforce development
- Technical assistance/validation

Lock-in cost-effective performance gains

- Appliance efficiency standards
- Support building energy code development and adoption
- Support other state/local regulatory actions

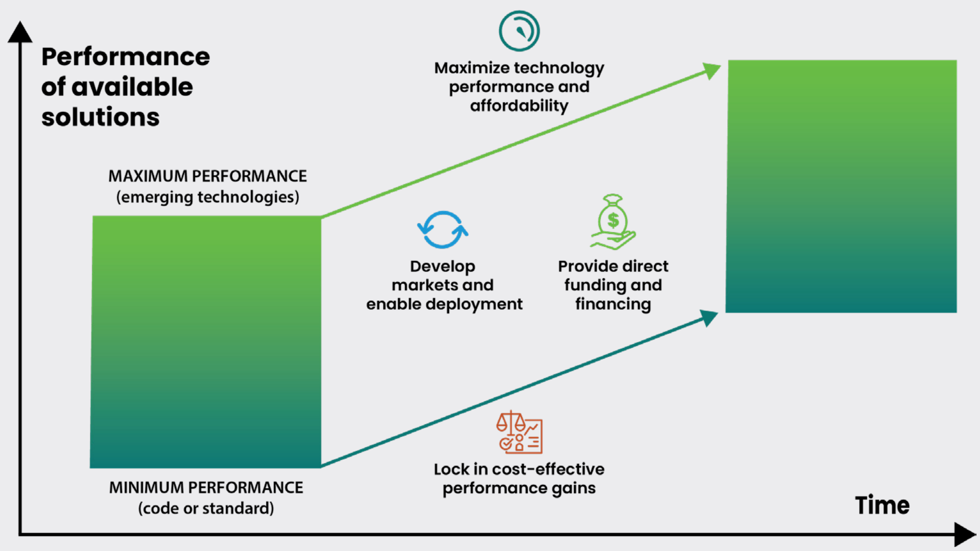


Figure 13. Federal activities to accelerate building decarbonization are grouped into four categories. Early-stage research and development raises the ceiling on maximum technology performance and cost reduction. U.S. Department of Energy. 2021. Opaque Envelopes: Pathway to Building Energy Efficiency and Demand Flexibility. https://www1.eere.energy.gov/buildings/pdfs/80170.pdf. Proven cost-effective technologies are locked in for mainstream adoption with efficiency standards and building codes that raise the floor of minimum performance. Strategic coordination across the categories increases potential to accelerate deployment over time.

time period (e.g., via financing) with potential offsets from energy bill savings.

- **Lock in cost-effective performance gains** by supporting the development and implementation of building codes, building performance standards, and equipment efficiency standards that apply to both new and existing construction and raise the energy and emissions performance "floor" for market-available buildings technologies.

Strategic coordination of actions increases their potential to accelerate progress. For example, successful prototyping and pilot demonstrations of low-carbon buildings technology innovations establish focal points for deployment programs that seek to increase product availability and consumer awareness while reducing barriers to installation. In turn, these deployment efforts create space to propose more aggressive codes and standards by normalizing technically feasible and cost-effective compliance pathways.

Individual federal agencies have specific roles in the low-carbon buildings transition that are often overlapping. Careful coordination is needed to ensure the work of various agencies is complementary and collectively maximizes progress toward the strategic objectives. Agencies such as the U.S. Department of Energy (DOE), U.S. Department of Housing and Urban Development (HUD), and U.S. Environmental Protection Agency (EPA) have a broad reach across multiple areas of focus and through ongoing interagency coordination, including the memorandum of understanding between DOE and HUD to advance building decarbonization. These agencies are therefore well positioned to coordinate federal efforts on building decarbonization, including by leading the development, dissemination, and implementation of this strategic framework.

Tables 3 through 6 further detail the extensive range of agency-specific implementation tools that are available to drive progress in each of the federal action categories. The following are examples of opportunities to stack implementation tools across federal agencies and programs.

- **Maximize technology performance and affordability** (Table 3):
  - Emerging technology RD&D: Breakthrough innovations from DOE-supported technology RD&D drive down the installed cost of emerging low-carbon building technologies with high energy performance and establish solutions for hard-to-decarbonize segments, such as heating in large commercial buildings. Research funded by other agencies such as the National Science Foundation supports further analysis and optimization of emerging technologies.
  - Pilot demonstrations: Initial real-world evaluation of pre-commercial emerging technologies via programs such as the General Services Administration's (GSA's) Green Proving Ground (GPG), DOE's High Impact Technologies (HIT) Catalyst program, and the Department of Defense's (DOD) Environmental Security Technology Certification Program (ESTCP) accelerate their transition to commercialization.
- **Develop markets and enable deployment** (Table 4):
  - Enabling tools, partnerships, and market-facing resources: DOE-, EPA-, and HUD-supported modeling tools, data, and decision-making guidance are disseminated through federal partnerships with states and municipalities, utilities, and the private sector to promote greater awareness of available low-carbon technology options, as well as their potential impacts and deployment considerations. Such partnerships and stakeholder engagement can help agencies maintain awareness of changing on-the-ground circumstances that impact the success of the full spectrum of federal action. Common federal definitions to guide building decarbonization, such as the National Definition for a Zero Emissions Building[145], spur market alignment for the low-carbon building transition.
  - Contractor and consumer outreach: ENERGY STAR® certification, market support, and consumer education for building equipment and envelope components increase the attractiveness of the lowest-carbon products on the market. Marketing low-carbon technologies to households, businesses, and installers is made more effective by DOE- and NSF-funded social science research that increases knowledge of key decision-making drivers and barriers. Federally supported research and communication by DOE and EPA of the non-energy benefits from building decarbonization, such as from the avoided health and safety risks of on-site combustion, provide compelling noneconomic reasons for consumers to consider adopting low-carbon building measures.

- Workforce and economic development: DOE-, HUD-, Department of Labor, and Education Department-supported education, training, recruitment, and housing programs foster a robust and diverse network of professionals to design, manufacture, market, install, and operate low-carbon building technologies in rural and urban areas, while developing local economies and building wealth in underserved communities.
- Technical assistance and validation: GSA-, DOD-, and DOE-supported case studies on emerging and early commercial low-carbon technologies demonstrate their real-world benefits and reduce uncertainties about performance and installation burdens. DOE research and technical assistance for utilities inform electricity rate designs that improve the economics of electrification and demand flexibility deployment. The economic viability of such measures is further improved by new value streams enabled by the Federal Energy Regulatory Commission (FERC) for building assets at the grid edge that participate in demand-side management programs.

- **Provide direct funding and financing** (Table 5):
    - Financing: EPA administers the Greenhouse Gas Reduction Fund to mobilize financing and private capital for greenhouse gas- and air pollution-reducing projects in communities across the country. Low-interest DOE loans, including in partnership with State Energy Financing Institutions, bridge gaps in the funding needed to bring emerging low-carbon building technologies to scale and develop pathways to increase access to financing in disadvantaged communities.
    - Direct procurement: For more mature low-carbon technologies, federal purchases lead by example and establish initial markets where technology uptake is currently low.
    - Rebates and tax incentives: Financing and procurement impacts are bolstered by federal administration of technology rebates, grants, and financing for low-carbon building technologies, as well as information provided about available tax credits. Parallel energy bill assistance from HUD and the U.S. Department of Health and Human Services provides assurance that energy burdens decrease in low-income and disadvantaged communities as deployment of low-carbon building technologies becomes more widespread.
- **Lock in cost-effective performance gains** (Table 6):
    - Equipment standards: DOE energy conservation standards ensure that replacements of building equipment are progressively more efficient.
    - Building codes: Adoption and enforcement of zero-energy or equivalent model codes for new buildings and major renovations at the state and local levels is supported by DOE analysis and funding resources, and energy codes and standards for HUD- and Federal Housing Authority-assisted properties are aligned to ensure benefits to LMI communities.
    - Energy efficiency resource and clean heat standards: DOE and EPA analysis resources for states support the establishment or improvement of policies that set quantitative energy and emissions savings targets for utilities.
    - Building performance standards (BPS): Federal BPS from the White House and DOE set and enforce aggressive targets for energy and emissions reductions across the existing federal portfolio.

Interagency agreements such as the 2023 memorandum of understanding between DOE and HUD to work together on domestic building decarbonization[146] are critical for formalizing specific coordination opportunities in advancing national building decarbonization goals.

Table 3. Federal tools for maximizing technology performance and affordability.

Federal stakeholder	Implementation tools
Department of Energy	• Fund emerging technology RD&D (by national labs, academia, and industry, with funding from multiple programs such as the Building Technologies Office [BTO], Office of Electricity, Geothermal Technologies Office, and Solar Energy Technologies Office, among others) and pilot demonstration/validation (e.g., via programs such as High Impact Technology [HIT] Catalyst in BTO and the Office of Clean Energy Demonstrations); key topics include: » Reduce costs of efficient heat pumps and appliances—in particular cold climate air-source heat pumps (e.g., Residential Cold Climate Heat Pump Challenge), ground-source (geothermal) heat pumps, 120V appliances, integrated (HVAC/water heating) systems, and district- and community-scale geothermal heating and cooling systems. » Streamline efficient and low-carbon technology deployment and building construction to reduce soft costs, including "do-it-yourself" installation options and packaged envelope retrofits. » Develop software platforms for deploying flexible grid edge control schemes; system performance measurement and verification; and whole-building integration of building energy loads with other distributed energy resources such as behind-the-meter storage, EVs and charging infrastructure, and on-site generation. » Develop commercially viable solutions for high-temperature heating end uses. » Develop and demonstrate equipment refrigerants with ultra-low global warming potential. » Develop carbon-negative and novel building materials and manufacturing processes for building equipment that improve resilience and reduce embodied emissions. » Reduce the cost of residential and community rooftop solar—particularly via reductions in soft costs such as permitting (e.g., the SolarAPP+ platform for streamlining solar permitting). • Facilitate federal/state collaboration on emerging buildings technology RD&D. • Provide grants for small-business innovation and technology. • Develop contests and prizes to stimulate private sector RD&D. • Build equity and environmental justice topic areas and criteria into RD&D funding solicitations (e.g., accessibility to renters).
General Services Administration	• Leverage federal buildings to pilot pre-commercial building technologies that improve efficiency, reduce carbon intensity, and/or provide grid-interactive capabilities (e.g., Green Proving Ground).
Department of Defense	• Pilot pre-commercial technologies and solutions to improve component and system efficiency, energy management and demand flexibility, resilience, and planning of military facilities (e.g., Environmental Security Technology Certification Program).
National Science Foundation	• Fund early-stage buildings technology RD&D. • Fund supporting research on key emerging building topics (e.g., effects of climate change, resilience, urbanization).
White House	• Lead initiatives to set leading-edge innovation targets for buildings technology categories with emphasis on achieving net-zero emissions economy wide (e.g., Net-Zero Game Changers).

Table 4. Federal tools for enabling deployment and developing markets.

Federal stakeholder	Implementation tools
Department of Energy	• Provide tools (e.g., building energy modeling), data, methods and metrics, technical assistance (e.g., from national labs), and recognition (e.g., Better Buildings, SolSmart) to help key stakeholders (e.g., state/local policymakers, regulators, utilities, installers, and consumers) identify and implement measures to improve energy efficiency, increase demand flexibility, accelerate electrification, and/or deploy on-site generation and storage in buildings. • Use ENERGY STAR certification (with the Environmental Protection Agency) and the Zero Energy Ready Home Program to increase market attractiveness of energy efficient, low-carbon products and buildings. • Support decision science to explore key technology adoption channels and characterize key drivers and barriers to adoption by installers and consumers. • Provide utility policy and planning support to demonstrate the grid impacts of efficiency, flexibility, and electrification and develop electricity rate designs that encourage low-carbon technology adoption. • Develop programs, prizes, coalitions, product databases, and other resources that reduce barriers to deployment of building decarbonization measures. These strategies include private sector partnerships and other industry engagement (e.g., Buildings Upgrade Prize; Better Buildings Initiative, Better Climate Challenge, National Emerging Technologies Collaborative, Advanced Building Construction Initiative), workforce development, consumer education and community engagement (e.g., Solar Energy Innovation Network, National Community Solar Partnership, and Community Geothermal Heating & Cooling Initiative), and student competitions that foster a robust and diverse science, technology, engineering, and medicine workforce. • Develop contractor standards (e.g., Energy Skilled) that increase the likelihood of quality work performance and help customers find quality contractors. • Fund demonstrations of distributed clean power generation, building electrification projects, and grid edge control platforms (e.g., Connected Communities). Innovations include connected thermostats, water heating, lighting, smart panels, wireless sensing networks, and their integration with other distributed energy resources, as well as supporting communication standards (e.g., OpenADR, CTA-2045). • Fund demonstration grant programs for states, local governments, public utilities, and other public agencies to procure commercial and industrial products, including building construction materials, that support carbon conversion/utilization and demonstrate a significant net reduction in life cycle greenhouse gas emissions (e.g., Utilization Procurement Grants).

Federal Energy Regulatory Commission (FERC)	• Implement regulations that enable participation of energy efficiency and demand-response measures as demand-side resources in wholesale power markets (e.g., FERC Order 2222). • Use public data to report on the beneficial grid impacts of building flexibility and track deployment (e.g., annual demand response assessments).
Department of Labor	• Leverage established training programs for entrants (e.g., YouthBuild, Job Corps, Workforce Innovation and Opportunity Act-funded programs, and Registered Apprenticeship programs) to develop workforce skills in low-carbon building construction, maintenance, and operation.
Department of Education	• Support education programs/career pathways for high school and post-secondary students for STEM careers in advanced manufacturing, construction, architecture, and engineering (e.g., by leveraging the Carl D. Perkins Career and Technical Education Act). • Promote expanded access to high-quality career and technical education programs, starting in middle school through college, to help young people pursue jobs in the building decarbonization workforce. • Maximize partnerships between local education agencies, institutions of higher education, and employers that support earlier enrollment in post-secondary-level coursework, provide work-based learning opportunities during high school, and result in earning industry-sought credentials in the building decarbonization workforce. • Recognize school sustainability achievements (e.g., via U.S. Department of Education Green Ribbon Schools award.)

Table 5. Federal direct funding and financing tools.

Federal stakeholder	Implementation tools
Department of Energy	• Distribute funds and provide guidance for state and Tribal rebate and loan programs that encourage clean power production, building electrification, virtual power plants, and home energy upgrades (e.g., Bipartisan Infrastructure Law and Inflation Reduction Act programs; tax credits 25C, 45L, 179D). • Deploy community-focused development grants (e.g., Energy Efficiency and Conservation Block Grants managed by the Office of State and Community Energy Programs) to support deep energy retrofits of residential and commercial buildings—including expanded support for renewable energy and advanced efficiency measures—and empower local community representation within the energy workforce (e.g., Weatherization Assistance Program, Enhancement and Innovation and Sustainable Energy Resource for Consumers programs). • Provide access to flexible, large, low-interest loans to help scale emerging building technologies and business models (e.g., via the Loan Programs Office to support VPPs). • Provide support to federal agencies implementing energy and water efficiency projects (e.g., Assisting Federal Facilities with Energy Conservation Technologies [AFFECT] grant and performance contracting support managed by the Federal Energy Management Program [FEMP], FedGeo Partnerships collaboration between the Geothermal Technologies Office and FEMP).

Environmental Protection Agency	• Use ENERGY STAR certification (with DOE), market support, and consumer education to increase market attractiveness of energy efficient, low-carbon products and buildings. • Provide resources to help state and local governments benchmark building energy performance (e.g., ENERGY STAR Portfolio Manager) and enhance the effectiveness of consumer rebate programs, including the facilitation of data sharing to populate building benchmarking databases. • Develop/curate state and local resources for assessing environmental and economic impacts of building efficiency and electrification (e.g., ENERGY STAR Portfolio Manager, Portfolio Manager Data Explorer, Energy Savings and Impacts Scenario Tool). • Provide resources, technical assistance, and guidance to promote and account for equity and environmental justice outcomes in sustainable community planning and development (e.g., Smart Location Database). • Provide grants, technical assistance, and tools to help manufacturers and other industry stakeholders measure, report, and reduce the embodied emissions of building products (e.g., Pollution Prevention program).
Department of Housing and Urban Development (HUD)	• Provide resources and technical support to improve equity in green community planning (e.g., Sustainable Communities Initiative). • Provide tools and other resources that support improved efficiency and resilience in HUD-assisted housing (e.g., HUD Community Resilience Toolkit, IRA/BIL Funding Navigator).
White House	• Develop common definitions to spur market alignment toward building decarbonization (e.g., National Definition for a Zero Emissions Building). • Implement executive to increase supply of heat pumps and other low-carbon building technologies (e.g., Defense Production Act) and scale deployment of decarbonization solutions in federal buildings (e.g., Federal Sustainability Plan, Federal Buy Clean Task Force and Initiative). • Initiate public-private partnerships that accelerate knowledge sharing and investment in building efficiency, electrification, and flexibility outside the federal portfolio (e.g., Climate Smart Buildings Initiative). • Lead cross-agency coordination on equity (e.g., Justice40) and develop tools, policies, and advisory groups to promote environmental justice (e.g., Environmental Justice Advisory Council). • Showcase federal leadership on building sustainability that can catalyze markets for low-carbon building innovations by coordinating planning across agencies to decarbonize the federal portfolio.
General Services Administration	• Leverage federal buildings to provide technical support for deployment of proven building technologies that improve efficiency, reduce carbon intensity, and/or provide grid-interactive capabilities across portfolios (e.g., Pilot to Portfolio).
Department of Defense	• Demonstrate and validate commercially available technologies and solutions (e.g., Environmental Security Technology Certification Program).
National Science Foundation	• Fund social, behavioral, and economic sciences research to improve understanding of energy stakeholder decision making (e.g., via Social, Behavioral and Economic Sciences Directorate).

Environmental Protection Agency	• Provide grants to mobilize financing and leverage private capital for low-carbon building projects (e.g., Greenhouse Gas Reduction Fund), particularly in low-income and disadvantaged communities (e.g., Community Change Grants). • Provide information and standards on the environmental and social impacts of materials and products (e.g., Electronic Product Environmental Assessment Tool (EPEAT) criteria for solar panels and inverters).
Department of Housing and Urban Development	• Direct investments in healthy, low-carbon, and climate-resilient building infrastructure for low-income and disadvantaged communities (e.g., Green and Resilient Retrofit Program, PRO Housing). • Provide direct financial assistance and best practices for operations and maintenance to reduce energy cost burdens in low-income communities. • Offer financing benefits for housing providers that commit to green building standards and utility benchmarking (e.g., Green Mortgage Insurance Premiums).
White House	• Direct federal purchasing and installation of low-carbon building technologies (e.g., Federal Sustainability Plan, Federal Buy Clean Initiative).
Department of Agriculture	• Provide loans, loan guarantees, and grants to support building efficiency improvements for agricultural producers and rural small businesses (e.g., Rural Energy for America Program).
Department of Health and Human Services	• Direct financial assistance for households in need of assistance with home energy bills, energy crises, weatherization, and minor energy-related home repairs (e.g., Low Income Home Energy Assistance Program).
Federal Emergency Management Agency	• Fund community pre-disaster mitigation projects that reduce natural hazard risk and improve resilience of building infrastructure (e.g., Building Resilient Infrastructure and Communities). • Fund costs associated with low embodied carbon construction materials, even when the costs are higher than those for conventional materials, and provide incentives that encourage low-carbon and net-zero emissions energy projects. • Fund net-zero projects as part of support for disaster recovery and rebuilding, including solar, heat pumps, and efficient appliances (e.g., Public Assistance).

Table 6. Federal tools for locking in cost-effective performance gains.

Federal stakeholder	Implementation tools
Department of Energy (DOE)	• Update and publish progressively more efficient, cost-effective appliance and equipment efficiency standards. • Issue determinations on the latest model building energy codes (e.g., American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE] 90.1, International Energy Conservation Code) consistent with DOE's authority. • Provide cost-effectiveness analysis, technical assistance, and resources to states and municipalities for development, implementation, and compliance of building energy codes and performance standards. • Set and adhere to federal energy efficient product procurement requirements (supported, for example, by Federal Energy Management Program Energy-Efficient Product lists and trainings).
Environmental Protection Agency	• Provide tools to help building owners and jurisdictions benchmark, track, and improve efficiency and reduce carbon (e.g., ENERGY STAR Portfolio Manager, Portfolio Manager Data Explorer). • Provide resources to help state and local governments develop and implement building performance standards (e.g., Benchmarking and Building Performance Standards Policy Toolkit). • Require equipment used in buildings to meet refrigerant GWP standards under existing Technology Transition rules.
Department of Housing and Urban Development (HUD)	• Adopt the latest energy codes (e.g., ASHRAE 90.1) for HUD-assisted properties, including affordable and rental housing and multifamily buildings.
White House	• Publish performance standards for federal buildings that require efficient electrification, grid interactivity, and resilience and support state and local decision-makers in advancing performance standards (e.g., National Building Performance Standards Coalition, Federal Building Performance Standards).
Department of Agriculture	• Adopt the latest energy codes (e.g., ASHRAE 90.1) for department-assisted properties, including rural housing.
National Institute of Standards and Technology	• Develop technical findings to support enhanced building codes and standards. • Provide critical measurement solutions to enable buildings sector decarbonization.
Federal Emergency Management Agency	• Help state, local, Tribal, and territorial governments adopt and enforce the latest, or next most recent, building code or standard with hazard resistant provisions (e.g., National Initiative to Advance Building Codes, Building Resilient Infrastructure & Community [BRIC] grants).

THE INFLATION REDUCTION ACT AND BIPARTISAN INFRASTRUCTURE LAW

The Inflation Reduction Act of 2022 (IRA) and 2021's Bipartisan Infrastructure Law (BIL) are historic investments in the U.S. economy, opening doors for opportunities and engagement across the country to support equitable and just clean energy infrastructure projects.

IRA and BIL include many provisions that relate to buildings, including:

- HUD Green and Resilient Retrofit Program
- EPA Greenhouse Gas Reduction Fund
- DOE Home Efficiency Rebate and Home Electrification and Appliance Rebate Programs
- Revised and extended 25C Energy Efficient Home Improvement Tax Credit
- Revised and extended 25D Residential Clean Energy Tax Credit
- 48e Low-Income Communities Bonus Program (solar and wind)
- Revised and extended 45L energy efficient new home tax credit
- Revised 179D energy efficient commercial buildings tax deduction
- New and expanded loan authority for DOE's Loan Programs Office
- Support for model building energy codes and zero energy codes
- Funding to carry out the Defense Production Act to accelerate electric heat pump manufacturing

The Biden-Harris Administration developed IRA and BIL guidebooks that provide more details on these programs.[*,**]

Recent developments at DOE provide one example of the far-reaching impacts of BIL and IRA across federal agencies. Through the BIL and IRA, the DOE Office of State and Community Energy Programs (SCEP) is investing $16 billion and creating more than 25 programs to help build greater capacity for states, federally recognized Tribes, local governments, nonprofits, and community-serving entities to accelerate the deployment of clean energy technologies, catalyze local economic development, create jobs, reduce energy costs, and avoid pollution through place-based strategies.

The provisions in these two laws enable SCEP to provide federal funding, technical assistance, and other resources that drive clean energy innovation, revitalize communities, and improve lives. Programs such as the Energy Efficiency and Conservation Block Grant infuse more than $430 million in formula grant funding to more than 2,700 states, territories, local governments, and Tribes from every region of the

* The White House. 2022. Building a Better America: A Guidebook to the Bipartisan Infrastructure Law for State, Local, Tribal, and Territorial Governments, and Other Partners. https://www.whitehouse.gov/wp-content/uploads/2022/05/BUILDING-A-BETTER-AMERICA-V2.pdf.

** The White House. 2023. Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action. https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf.

country to increase energy efficiency and advance clean energy and infrastructure upgrades.

Furthering home retrofits and critical weatherization services for low-income families are prioritized through these provisions and allow for a greater expansion of services. Two new weatherization initiatives funded by the BIL—the Enhancement & Innovations (E&I) grant and the Sustainable Energy Resources for Consumers (SERC) grant—promote innovation in renewable energy and home electrification while empowering the local workforce.

Because of BIL and IRA, SCEP fosters programs that increase the efficiency and resiliency of buildings, increase state and local staffing capacity, develop and train the workforce, and support the adoption and implementation of the latest and zero building energy codes.

The laws created first-of-its-kind investments in local educational agencies and nonprofit organizations, enabling them to fund building and energy upgrades with $500 million for the Renew America's Schools program and $45 million for the Renew America's Nonprofits program. Moreover, $260 million was invested to train a qualified, diverse clean energy workforce to help implement these planned improvements. The State Energy Program equips states with $500 million to support planning activities and transformational programs that help reduce carbon emissions in all sectors of the economy in addition to another $250 million to support states, territories, and the District of Columbia with capitalizing revolving loan funds to retrofit buildings.

While driving the creation of good-paying jobs and local economic development, these historic investments will benefit communities and extend access to clean energy resources to disadvantaged, underserved, and energy-burdened communities, boosting the health of all communities and increasing efforts to achieve environmental justice.

With the inclusion of $8.8 billion in rebates for home energy efficiency and electrification projects, which are targeted at low- and moderate-income households, these IRA provisions enable Americans to upgrade their home appliances, water heating and HVAC systems, and more to clean energy equipment, resulting in saving money on energy bills, improving energy efficiency, and reducing indoor and outdoor air pollution.

While driving the creation of good-paying jobs and local economic development, these historic investments will benefit communities and extend access to clean energy resources to disadvantaged, underserved, and energy-burdened communities, boosting the health of all communities and increasing efforts to achieve environmental justice.

4.4 • Support for State, Local, and Tribal Action

While coordinated federal action is critical for decarbonizing the buildings sector, strong action by state, local, and Tribal governments will be equally critical for achieving each of the strategic objectives described above. As highlighted in Figure 14, federal agencies can support state, local, and Tribal action by providing technical assistance, data sharing and decision tools, capacity building resources, peer information, public outreach and education, and recognition programs. Complementary actions on building decarbonization from state, local, and Tribal governments will vary depending on the needs and priorities of each jurisdiction. High-priority state, local, and Tribal actions are further described below, along with key opportunities for federal agency support.

Fund Investments in Building Decarbonization

- Deploy BIL/IRA programs
  - States and Tribes are developing several building decarbonization programs funded through IRA and BIL, including the residential electrification and efficiency rebates which primarily benefit lower-income households.
  - Federal agencies can provide technical assistance, data, and tools in support of program design and implementation tailored to each jurisdiction.
- Enable and deploy financing
  - State, local, and Tribal green banks can play a key role in deploying financing for equitable building decarbonization. While state green banks have been capitalized by a variety of sources such as state, federal, and utility ratepayer funds, the federal Greenhouse Gas

Key state, local, and Tribal actions → Federal agency support

Key state, local, and Tribal actions	Federal agency support
Fund investments • Deploy BIL/IRA programs • Enable and deploy financing • Utility ratepayer-funded programs	• Provide guidelines and technical assistance for BIL/IRA programs • Create datasets and tools to facilitate decision making
Set codes and standards • Building codes • Building performance standards • State-level appliance standards • Procurement standards	• Technical assistance supporting definition, adoption and enforcement of standards and building codes • Technical assistance to support energy and utility policy analysis
Lead policy to enable greater investments • Utility rate reform • Utility infrastructure subsidy reform • Energy efficiency resource standards • Clean heat standards • Zoning reform	• Provide resources for under-staffed state regulators and state, local, and Tribal energy offices • Support NASEO/NARUC task forces and committees • Recognize leading communities through prizes and designation programs

Figure 14. Federal support for state and local actions on building decarbonization.

Reduction Fund created under the IRA may dramatically increase the amount of funding available for green bank and other nonprofit financial institution financing. It includes $20 billion to support financial and technical assistance, with $8 billion of that designated for low-income and disadvantaged communities. Similarly, DOE's LPO has partnerships with state green banks and other IRA-authorized State Energy Financing Institutions.

- State energy offices and utility regulators can also develop or approve financing mechanisms, such as tariffed on-bill financing, property-assessed clean energy, energy savings performance contracting (ESPC), and energy-as-a-service programs, for use alongside financing from green banks, community development financial institutions (CDFIs), or other nonprofit financial institutions.
- In addition to administering the Greenhouse Gas Reduction Fund, federal agencies can provide state-specific information on the costs and benefits of building decarbonization measures and can offer technical assistance on developing financing mechanisms at the regional and local levels.

- Utility ratepayer-funded programs
  - State utility regulators oversee investor-owned utility ratepayer-funded programs, which, together with municipally owned and cooperative utilities, spend over $8 billion annually to deploy energy efficiency, as well as demand response and, in some cases, electrification measures.[147] Regulators determine the scale of demand-side measure deployment by utilities or program operators, which measures are prioritized, and whether programs allow fuel switching. Greater integration of utility energy efficiency and demand response programs is needed to support a more robust building load management resource at the grid edge.
  - Federal agencies can develop technical guidance on best practices for utility program design and customer outreach. Agencies can also provide data and analysis of efficiency, demand response, and electrification measure energy and emissions impact potential in order to inform the focus of utility programs that incentivize these measures.

Set Codes, Standards, and Other Requirements for Building Decarbonization

- Building codes (electric-ready, zero-carbon life cycle, etc.)
  - States and local jurisdictions adopt and enforce building energy code requirements that apply to new construction and major renovations. Jurisdictions typically adopt a national model code with amendments. Several states and municipalities have enacted or are developing "stretch" codes, which are more aggressive than base code levels, or electric-ready codes that help advance national building decarbonization goals.
  - Federal agencies such as DOE, the Federal Emergency Management Agency (FEMA), and HUD can participate in the model code development process and provide cost-effectiveness analysis and technical assistance in support of adopting and enforcing the latest energy codes or stretch codes.
- Building performance standards
  - State and local decision-makers can enact building performance standards that require existing buildings to meet energy and/or GHG emissions-based performance targets.
  - The federal government can lead by example by developing and updating aggressive performance standards for federal buildings.
  - Federal agencies can also provide standardized metrics, tools, and technical

assistance in support of adoption and enforcement of building performance standards by jurisdictions.

- State-level or regional appliance standards
  - While the federal government sets energy standards for many appliances that generally preempt state-level standards, states can request waivers from DOE to set their own stricter standards. Additionally, 19 states have adopted appliance energy efficiency standards for products not currently covered by federal regulations.[148] In addition to appliance energy standards, starting in 1978, several states and air districts have enacted appliance emission standards that limit NO_x emissions from residential water heaters and furnaces.[149] Some states and air districts are now considering zero-emission appliance standards to reduce GHG or NO_x pollution.[150]
  - Federal agencies can provide standardized metrics, data, and tools related to appliance emissions and their health impacts.[151]
- Procurement standards
  - State, local, and Tribal governments can lead by example by setting requirements for the design of their new buildings, renovation of existing ones, and equipment replacement. Example requirements include building performance standards, all-electric equipment requirements, and low embodied carbon material (Buy Clean) requirements.
  - Federal agencies can lead by example through the development of procurement standards (e.g., EPEAT for Solar)[152] and can work to ensure that material life cycle assessments and environmental product declarations (EPDs) are as accurate as possible.

Lead Policy to Enable Greater Investments

- Utility planning reform
  - State utility commissions set resource planning requirements (e.g., Distribution System Planning, Integrated Resource Planning) that determine the future mix of supply- and demand-side resources for meeting customer electricity demand, along with the infrastructure needed to deliver this mix of resources. Such planning frameworks can be designed by regulators to boost the consideration of demand-side resources as non-wires alternatives (e.g., resources that defer or replace the need for transmission and/or distribution projects) as cost-effective alternatives to traditional investments in supply-side resources and expanded system infrastructure. Regulators of natural gas utilities could similarly require the consideration of efficiency, electrification, and gas demand response as "non-pipes" alternatives to expanded system infrastructure.
  - Federal agencies can support these actions by providing data and tools to facilitate accurate decision making, including data to characterize demand-side building measure operations and their hourly impacts on regional grids.
- Utility rate reform
  - State utility regulators determine the electricity and natural gas rate structures that, together with use patterns, determine how much customers of investor-owned utilities pay on their utility bills. Municipal and cooperative utilities similarly determine rate structures for their customers and members. These entities can develop new utility rate structures that protect low-income customers, promote electrification and demand flexibility, and/or compensate customers for participating in demand flexibility programs.
  - Federal agencies can facilitate accurate rate making by providing technical assistance that, for example, explores the implications of multiple future scenarios of building electricity demand and accounts for distributional impacts across different customer segments.

- Utility data access requirements
  - State regulators can require utility companies to provide customers with access to their meter data in a standardized format, which is critical for benchmarking and building performance disclosure requirements, especially for multifamily and multi-tenant commercial buildings. Local governments may also be able to make similar requirements as part of franchise agreements with investor-owned utilities. Municipal and electric co-op utility boards can adopt similar practices.
  - Federal agencies can offer support through technical assistance, best practice guides, and development of machine-readable data formats (e.g., Green Button).[153]
- Utility infrastructure subsidy reform
  - State regulators, municipal utilities, and cooperatives can change policies on which types of electricity and natural gas infrastructure can be paid for by ratepayers. This can reduce the burden of grid edge and behind-the-meter electrical upgrades on customers, especially low-income customers, so they are not left behind on technology adoption.
  - Federal agencies can provide technical assistance, data, and analysis to facilitate accurate decision making on these types of reforms, including offering robust estimates of the costs of behind-the-meter electrical upgrades in different regions and assessments of upgrade costs and benefits for different customer segments.
- Energy efficiency resource and clean heat standards for utilities
  - State legislators or regulators can adopt or expand energy efficiency resource standards (EERS) that establish long-term energy savings targets that utilities and program administrators will meet. EERS have been adopted by 27 states over the past 20 years.[154] Similar to EERS, clean heat standards are outcome-based standards that require providers of heat or heating fuels to gradually decrease their emissions through a variety of actions that could include weatherization, electrification, low-carbon district heating, low-carbon hydrogen blending, and addressing methane leaks. Clean heat standards are much newer; they have been adopted by Colorado and Vermont and are under consideration in several other states.
  - Federal agencies can provide data and analysis of the technical potential and cost-effectiveness of various EERS and clean heat standard compliance pathways.
- New utility business models
  - State regulators can allow gas and electric utilities to explore and develop new business models, such as becoming thermal utilities that operate underground thermal pipe networks (e.g., networked geothermal), and performance-based regulation approaches that incentivize achievement of clean energy goals while reducing costs and improving customer service.[155]
  - Federal agencies can provide technical assistance, data, and analysis to

facilitate accurate decision making on these types of new business models, including, for example, assessments of the climate and environmental costs of new gas infrastructure and resources for retraining the fossil fuel workforce to build and maintain clean energy infrastructure.

- Zoning reform
  - Several states and local governments have enacted zoning reforms with the potential to increase housing affordability and options for both housing and transportation, while providing the opportunity for people to choose to live in homes with lower energy and emissions intensity on a per-person basis. Reducing regulatory barriers to infill development will also lead to more dense development, resulting in a growing share of the U.S. housing stock that is newer and inherently more structurally efficient.
  - HUD has funded research and data collection related to the effects of restrictive land use policies on housing supply, location, and affordability.[156]

4.5 • Technology, Market, and Policy Milestones

In practice, a building decarbonization pathway that successfully implements the strategic framework presented above will involve significant on-the-ground transformation of buildings technology features, product markets, and policy approaches to increase penetration of efficient, flexible, and low-carbon solutions. To relate these changes to the Blueprint's strategic framework, Table 7 lists critical technology, market, and policy milestones that must be achieved in a manner that overcomes key challenges and meets the Blueprint's cross-cutting goals and strategic objectives. Together with the Blueprint's higher-level performance targets, these lower-level milestones will inform assessments of the successes and shortcomings of each Blueprint implementation stage.

Table 7. Technology, market, and policy milestones that support the Blueprint's three cross-cutting goals of equity, affordability, and resilience.

Goal 1: Equity – Deliver benefits to disadvantaged communities	
by 2035	**by 2050**
• Federal entities continue to engage with representatives from disadvantaged communities and Tribal governments when designing and evaluating programs and metrics; federal funding for state and local jurisdictions similarly requires engagement with communities on their interests. • Rates of deployment of efficiency measures, efficient electric appliances, distributed solar, EV chargers, and energy storage are higher in disadvantaged communities than for the general population. • At least 40% of BIL and IRA building program benefits have been delivered to disadvantaged communities. • All building decarbonization education and training programs follow equitable workforce development best practices* that seek to engage underrepresented populations in clean energy careers. • Zoning and urban planning policies prioritize equitable distribution of sustainable building infrastructure and green spaces in all neighborhoods.	• Targeted upgrades to aging building envelopes, ventilation improvements, and electrification in disadvantaged communities result in no significant differences in the indoor air quality of U.S. buildings across socioeconomic groups. • The demographic composition of the building decarbonization workforce—encompassing careers in manufacturing, construction, architecture, engineering, real estate, and professional service—is representative of the nation's diversity as a whole.
Goal 2: Affordability – Reduce energy-related costs	
by 2035	**by 2050**
• Technology cost reductions, bill savings, and widely available financing and incentives collectively enable ***most*** building owners—particularly households and businesses in disadvantaged communities—to decarbonize with positive cash flow. • On-bill financing or repayment of efficiency and electrification upgrades is offered by utilities in areas representing at least 25% of the U.S. population. • Reductions of >50% in the cost of low-carbon building upgrades are enabled via R&D innovations and reduced soft costs, relative to 2023. • Efficient envelopes and equipment enable a 20% reduction in building energy costs, relative to 2023. • In areas with sufficient solar resources, community or rooftop solar is accessible to low-income households and businesses to reduce energy costs. • Electricity rate designs encourage electrification in low-income communities while preserving the value of energy efficiency and time-of-use flexibility in reducing energy bills.	• Technology cost reductions, bill savings, and widely available financing and incentives collectively enable ***all*** building owners—including those with the hardest-to-decarbonize building types and in the most challenging climates—to decarbonize with positive cash flow. • On-bill financing or repayment of efficiency and electrification upgrades is offered by utilities in areas representing at least 50% of people in the United States. • Median energy burden for households with low-to-moderate incomes (<80% area median income) is reduced to below 6% of household income, vs. 2020 benchmark of >8%.[†] • At least 50% reduction in the share of households that experience severe energy burdens (>10% of household income), vs. 2017 benchmark of 13%.[††]

Goal 3: Resilience – Increase the resilience of communities	
by 2035	**by 2050**
• Universal access to safe and comfortable home and workplace temperatures to prevent serious injury from extreme heat and cold. • Model building codes, green building rating systems, and ratepayer-funded utility efficiency programs all credit the value of resilience in cost benefit analysis (e.g., passive survivability, ability to withstand power outages). • Whole building design and retrofit practices incorporate standard resilience metrics and valuation data. • Control platforms support islanded mode that maximizes use of on-site generation and storage with efficient load management during grid outages. • Model zoning and building codes integrate strategies to reduce urban heat island effects.	• Deaths due to environmental heat and cold exposure are reduced by 50% to less than 0.2 per 100,000 people. • Vehicle-to-everything, vehicle-to-building, stationary battery storage, or microgrid solutions are affordable and accessible methods to provide electrical resilience for all buildings. • Zoning and building codes that integrate strategies to reduce urban heat island effects are adopted in areas representing at least 25% of the U.S. population.

* For example, Northeast Energy Efficiency Partnership's Equitable Workforce Best Practice Guidance. 2021. https://neep.org/sites/default/files/media-files/equitable_workforce_best_practice_guidance.pdf.

† Drehobl, A., L. Ross, and R. Ayala. 2020. How High Are Household Energy Burdens? An Assessment of National and Metropolitan Energy Burden across the United States. https://www.aceee.org/sites/default/files/pdfs/u2006.pdf.

†† Drehobl, A., L. Ross, and R. Ayala. 2020. How High Are Household Energy Burdens? An Assessment of National and Metropolitan Energy Burden across the United States. https://www.energy.gov/sites/default/files/2022-10/16.%20How%20high%20are%20household%20energy%20burdens_ds_0.pdf.

Table 8. Technology, market, and policy milestones that support the Blueprint's four strategic objectives of improving efficiency, reducing on-site emissions, transforming the grid edge, and reducing embodied life cycle emissions.

Objective 1: Increase building energy efficiency	
by 2035	**by 2050**
• >75% of building contractor education and training programs include energy efficiency skills as a graduation requirement. • Building energy disclosure requirements are adopted in states and jurisdictions representing >50% of people in the United States and include point-of-sale/rental disclosure requirements for homes.* • Zero-energy or equivalent codes and BPS are each adopted in states and jurisdictions representing >25% of people in the United States. • 3% annual efficient envelope retrofit rate for existing residential and 2% for existing commercial are achieved and maintained or exceeded thereafter. • At least 75% of new buildings are constructed at or above the latest model energy code performance levels. • More than 50% of all homes and businesses have automated control platforms that reduce energy waste and enable flexibility.	• Building energy disclosure requirements adopted in states and jurisdictions representing >75% of people in the United States and include point-of-sale/rental disclosure requirements for homes. • Zero-energy or equivalent codes and BPS are adopted in states and jurisdictions representing >50% of people in the United States. • All federal buildings meet stringent energy use intensity (EUI) targets.** • All primary electric resistance space and water heating is replaced by heat pumps. • More than 75% of all homes and businesses have automated control platforms that reduce energy waste and enable flexibility.
Objective 2: Accelerate on-site emissions reductions	
by 2035	**by 2050**
• Model building codes for electric-ready, electric vehicle-ready, and all-electric construction are widely available for jurisdictions choosing to adopt them, with technical support available for code adoption and compliance. • >90% of air conditioners sold can provide heating (e.g., heat pumps). • Heat pumps for residential and small-to-medium commercial applications reach 75% of space heating sales and 25% of water heating sales, with accelerated growth in ground-source (geothermal) heat pumps. • 120-volt appliances are widely available and increase the ease of deploying electric equipment. • Building heating, cooling, water heating, and refrigeration equipment with 100-year GWP<10 refrigerants is widely available. • 85% reduction in the use of hydrofluorocarbons (HFCs) is achieved relative to 2011–2013.†	• Heat pumps for residential and small-to-medium commercial applications constitute >90% of space heating and water heating equipment sales. • Heat pumps or zero-carbon heat alternatives for large commercial applications constitute >75% of annual space heating and water heating equipment installations in these contexts. • No new fossil-based district steam heating systems are constructed; all existing district steam systems have been converted to ambient loop networks or renewable steam sources. • 75% of installed building equipment uses refrigerants that have a 100-year global warming potential (GWP)<150. • All federal buildings have zero on-site fossil fuel emissions.†† • Low-GWP blowing agents are available and widely used for foam insulation and air-sealing products.

Objective 3: Transform the grid edge	
by 2035	**by 2050**
• Commercially available low-power appliances and smart controls enable full electrification without upgrades to behind-the-meter electrical infrastructure. • Widespread availability of appliances with integrated battery storage adds flexibility and resilience without utility interconnection and permitting requirements. • Standardized communications and cybersecurity protocols increase customer confidence in device security. • 50% of commercial and 25% of residential electricity customers are offered incentives for flexible use of their HVAC and/or water heating equipment; incentives reflect new revenue streams such as virtual power plants and distribution grid value. • Utilities in areas representing at least 25% of people in the United States conduct integrated resource, transmission, and distribution planning that accounts for building efficiency and demand response and regularly apply these resources as non-wires alternatives.	• More than 75% of installed HVAC and lighting equipment in homes and businesses is network connected and supports flexible control. • More than 90% of residential and commercial customers are offered incentives for flexible use of their HVAC and/or water heating equipment. • Utilities in areas representing at least 50% of people in the United States conduct integrated resource, transmission, and distribution planning that accounts for building efficiency and demand response and regularly apply these resources as non-wires alternatives.
Objective 4: Minimize embodied life cycle emissions	
by 2035	**by 2050**
• A data-driven 2050 target for reduction in U.S. buildings sector embodied carbon emissions has been established, along with an extensive stock-scale inventory of material life cycle emissions from annual U.S. building construction and renovation. • Whole-building modeling and design tools include standardized embodied carbon calculations for building material components. • Model building codes and green building rating systems limit embodied carbon emissions for larger building types and encourage focus on circular economy practices for building construction and/or renovation.	• Model building codes and green building rating systems limit embodied carbon emissions for all building types. • All new building envelope designs extend the service lifetimes of envelope components by enabling disassembly, reuse, and recycling. • All new building and retrofit designs use lower embodied carbon alternatives to concrete and steel, including mass timber construction. • Bio-based insulation and other carbon-negative building materials are widely used in building construction and renovation.§ • U.S. cement manufacturing greenhouse gas (GHG) emissions decrease to near zero, while cement production increases by 46%.§§ • U.S. steel industry GHG emissions decrease to near zero, while steel production increases by 12%.‡

* See also examples of current residential energy disclosure policies tracked by the National Association of State Energy Officials (NASEO). https://www.naseo.org/Data/Sites/1/documents/jx-documents/home-energy-labeling-map_v2.pdf.

** The White House Council on Environmental Quality. 2022. Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability. https://www.sustainability.gov/pdfs/EO_14057_Implementing_Instructions.pdf.

† U.S. Department of State. 2022. U.S. Ratification of the Kigali Amendment. https://www.state.gov/u-s-ratification-of-the-kigali-amendment/.

†† The White House Council on Environmental Quality. 2022. Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability. https://www.sustainability.gov/pdfs/EO_14057_Implementing_Instructions.pdf.

§ See the Advanced Research Projects Agency – Energy, Harnessing Emissions into Structures Taking Inputs from the Atmosphere (HESTIA) program, which seeks to expand feedstocks of building materials that can durably sequester carbon dioxide: https://arpa-e.energy.gov/technologies/programs/hestia.

§§ U.S. Department of Energy. 2022. Industrial Decarbonization Roadmap. https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf.

‡ U.S. Department of Energy. 2022. Industrial Decarbonization Roadmap. https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf.

DIFFERENT SOLUTIONS AND TOOLS FOR DIFFERENT CONTEXTS

From retrofitting a 200-year-old, single-family home to designing a new refrigerated warehouse, there is a wide diversity of applications that must be considered to fully decarbonize the buildings sector. As such, the various technical solutions and federal, state, local, and Tribal implementation tools presented may vary in how relevant or challenging they are in different contexts.

For example, technical solutions for new construction can look very different from those for existing buildings. Low embodied carbon materials are more impactful for new construction than for existing building retrofits, as they make up a larger share of the building's total life cycle emissions. Upgrades to building insulation levels and electrical systems are more costly when performed as retrofits compared to changing insulation levels or electrical capacity during new building design. The same is true for solutions like whole-building controls systems, which require installation and configuration of supporting sensing and actuation hardware as well as software platforms that support sophisticated operational schemes.

Similarly, building energy codes are relevant implementation tools for new construction and major renovations but are not a driver of existing building envelope retrofits or equipment replacements. In this case, building performance standards are a complementary policy that can accelerate deployment of decarbonization solutions in existing buildings.

The size of buildings and how they are used can also determine the relevance of different technical solutions and implementation tools. For example, many commercial buildings use packaged rooftop HVAC units that are distinct from residential-style HVAC equipment. Heating and cooling outdoor ventilation air uses significant energy in most commercial building types, whereas whole-building ventilation is rarely provided in existing low-rise residential buildings.

Regarding implementation tools, building performance standards are an example of a tool that mainly applies to larger buildings, so other types of tools such as labeling programs and incentives will be needed in parallel to accelerate retrofits in smaller existing buildings. Whether a building is owned or leased can also determine the difficulty of pursuing building decarbonization measures, and targeted tools such as green lease programs may be needed to accelerate certain types of low-carbon buildings technology adoption in such cases.

5 CALL TO ACTION

5.1 • Implementation Stages and Activities

The federal actions and areas of support for state, local, and Tribal actions outlined in the previous section enable a three-stage transition toward a net-zero emissions buildings sector, which is outlined in Figure 15:

- **Near-term (now through 2030)**: activities catalyze the transition to a deeply decarbonized buildings sector and lay the initial groundwork for future gains,
- **Mid-term (2030–2040)**: activities increase progress and further scale deployment by learning from near-term challenges and successes, and
- **Long-term (2040–2050)**: activities address remaining building emissions sources and complete the transition.

To achieve the 2050 vision, federal actions in each implementation stage must span all four of the categories introduced in Figure 13.

5.2 • Before 2030: Catalyze the Transition

Federal stakeholders must take urgent action now to lay the groundwork for a rapid transition toward widespread deployment of low-carbon building technologies and operational approaches by 2050. Equity, affordability, and resilience must be embedded within this initial groundwork and carried forward as key values of all future phases. It is critical to direct federal support toward nascent, high-impact technology and program model solutions today so they can be de-risked and scaled up in time to deliver broad emissions reduction benefits in later stages of the transition. Key innovation opportunities can be highlighted by data from BIL, IRA, and other deployment programs. Failure to catalyze a broad transformation of building design and retrofit approaches and product markets toward low-carbon solutions before 2030 will significantly increase the challenge of meeting the 2050 vision. Future decision-makers and consumers would be burdened with the complexity and cost of replacing high-emissions building components and equipment before the end of their useful lifetimes to maintain a course for net-zero building emissions by 2050. Federal incentives for low-carbon technology deployment in the BIL and IRA legislation offer an unprecedented opportunity to break from business-as-usual trends in building energy and emissions within this decade. However, the full leverage of these laws will not be realized without establishing supporting conditions through additional federal action within the next few years.

For example, even after considering incentives from the IRA, the first cost of switching fossil-based equipment to the highest-performance electric alternatives is likely to remain high for many consumers, especially those in low-income communities. Federally supported technology innovations, such as the development of low-power electric appliances with load management capabilities, can avoid large portions of electrification costs to achieve greater cost parity with fossil-based alternatives after factoring in available incentives and supportive electricity rate designs. Furthermore, near-term efforts to build a decarbonization workforce will develop robust networks of contractors and installers with the skills needed to deploy the low-carbon technologies incentivized by recent legislation.

Locking in cost-effective performance gains using the existing regulatory authority of federal, state, and local agencies will be critical for catalyzing the transition to a low-carbon buildings sector. Federal support for zero-carbon, electric-ready, and electric vehicle-ready code adoption for new buildings ensures that continued growth in the building stock does not add to sector emissions, while increasing the adoption of performance standards for existing buildings within the next few years pushes technology retrofit decisions away from high-emissions technologies that would otherwise be operating for decades to come. DOE

Before 2030: Catalyze the transition	2030–2040: Adapt and scale	2040–2050 Complete the transition
• Improve heat pump affordability for low-to-middle income customers. • Develop 120V appliances. • Improve load management at grid edge, including for electric vehicles and distributed energy resources.	• Market scalable solutions for hard-to-decarbonize segments and sustainable building materials. • Achieve cost reductions for more mature solutions across broader applications.	• Reassess and develop solutions for remaining emissions from fossil-based operations, material life cycle, and refrigerant leakage.
• Begin growing the building decarbonization workforce. • Improve awareness of low-carbon solutions and their benefits. • Support novel rate designs and on-site photovoltaic panels and storage to reduce bills.	• Ensure that marketing and training resources address emerging solutions and deployment challenges.	• Focus on marketing and enabling low-carbon retrofit deployment in segments with low adoption.
• Accelerate federal low-carbon procurement. • Maximize BIL and IRA.	• Extend and adapt consumer funding support and incentives to address lagging consumer segments.	• Weight funding and financial support to encourage low-carbon retrofits in segments with low adoption.
• Lead by example with federal facility decarbonization. • Support zero-carbon/ electric-ready/EV ready code adoption. • Update appliance standards. • Provide state and local resources for regulation development and outreach.	• Expand federal facility decarbonization. • Learn from early building performance standards and stretch codes to enable wider adoption. • Continue increasing appliance standards and supporting state and local regulations.	• Support compliance and continued adoption of zero-carbon codes, building performance standards, and clean heat and emissions standards in most states.

Figure 15. Near-, mid-, and long-term implementation activities across the four categories of federal stakeholder action to accelerate building decarbonization.

appliance energy conservation standards similarly ensure that replacements of building equipment are progressively more efficient and cut harmful carbon pollution that would accumulate for many years. Such federal standards are complemented by state and local appliance emissions standards, which can directly align regulatory mechanisms with emissions reduction objectives. These near-term shifts in codes and standards serve as important bellwethers of the building industry's low-carbon transition, which can motivate further private investment and development of low-carbon product offerings.

5.3 • 2030–2040: Adapt and Scale

The mid-stage of the transition will see implementation shift toward assessing gaps and challenges with initial low-carbon technology deployment efforts while leveraging the full range of available federal actions to address critical gaps. Progress on equity, affordability, and resilience goals should continue to be evaluated to determine if the approach for promoting these values requires adjustment. For building segments where early efforts to catalyze low-carbon technology deployment were successful, mid-stage implementation approaches will seek to scale deployment to a broader array of applications that are likely to be more challenging from both the technical performance and consumer value proposition perspectives.

For example, mid-stage RD&D innovations can focus on commercializing solutions for hard-to-decarbonize segments of operational emissions such as large commercial buildings, for which currently available low-carbon technology options may have service limitations and/or be prohibitively expensive. The scope of these solutions will likely extend beyond individual buildings to clusters and districts, given the potential for more favorable economics and financing options for the cities, and other large organizations such as utilities, that are able to deploy low-carbon technologies at larger scales. Mid-stage RD&D can also expand market-viable solutions to reduce building material life cycle emissions and emissions from equipment refrigerant leaks. Such innovations will be contingent on earlier improvements in the data and accounting methods that are available to characterize these other building emissions sources.

For technology applications that will be more mature by 2030, such as residential cold climate air-source heat pumps, the RD&D innovation priority is to achieve further reductions in installed costs to enable favorable consumer economics in contexts that were cost prohibitive during the earlier stage of the transition, potentially without the support of large tax credits or rebates.

In parallel, mid-stage market transformation efforts will continue to scale the decarbonization workforce to match the growing demand for low-carbon technology deployments across a greater number of buildings. During this period, existing direct federal funding for low-carbon building technologies could continue to catalyze additional deployment. The impacts of extended federal funding and incentives can be amplified by wider enactment of codes and standards that continue to accelerate energy and emissions reductions and increase consumer cost savings. Here, increased adoption of BPS and stretch codes at the state and local levels can be encouraged by federal assistance that incorporates lessons from early adopters of these regulatory tools and directs resources toward areas where adoption remains limited at the mid-stage of the transition.

5.4 • 2040–2050: Complete the Transition

The final stage of implementation will focus on identifying and addressing remaining sources of building emissions with an eye toward reducing total sectoral emissions to as close to zero as possible and ensuring no segments of the building stock are left behind, consistent with the vision of achieving a net-zero emissions buildings sector by 2050. These remaining emissions are likely to come from the hard-to-decarbonize segments of operation—heating in large commercial buildings and miscellaneous fossil-fired loads such as generators and manufacturing in commercial spaces, for example—as well as from emissions embodied in building material manufacturing, transportation, and construction and from leakage of older equipment refrigerants. Because turnover of existing building components, such as windows, and equipment can be slow, the final stage of implementation can prioritize solutions that encourage early retrofitting to zero-carbon building components and equipment. These solutions could include integrated envelope retrofits, new methods for low-GWP refrigerant replacements, and other approaches that have not yet been envisioned. Parallel federal funding support for deployment could similarly focus on strongly incentivizing early retrofitting decisions for key remaining emissions segments. BPS emissions standards for existing buildings can further drive retrofits, and additional state-level standards for clean heat and appliance emissions would also help.

5.5 • Tracking Progress

This Blueprint's effectiveness will be judged by benchmarking key buildings sector indicators at each stage of implementation against the cross-cutting goals and strategic performance targets introduced in the *Strategic Framework* section and against the lower-level milestones introduced in the *Technology, Market, and Policy Milestones* sections. Table 9 summarizes a range of currently available data sources for tracking the cross-cutting goals and performance targets. Many of these data sources are national in scope and were used in the process of setting quantitative targets (where applicable) to provide historical context and determine target feasibility (see *Appendix, Development of Performance Targets*, for examples of how these sources can be leveraged to provide tracking benchmarks). Sources range from well-established EIA survey and modeling datasets (e.g., *Monthly Energy Review*, *Annual Energy Outlook*, and technology cost data) to data that are more commonly cited outside the buildings sector (FERC reports and EIA-861 data) and emerging datasets that are being developed at the sub-national level (e.g., TECH Clean California project cost data). Most of these datasets are publicly available and regularly updated, facilitating point-in-time assessments and exploration of rates of change against the accelerated levels of progress that are needed to realize a net-zero emissions buildings sector by 2050.

Each of the data sources shown in Table 9 has tracking limitations and will benefit from future supplementation with new data sources and collection methods that allow for a more comprehensive view of building decarbonization progress. Key limitations in currently available data include the following:

- **Equity**: While federal agencies develop annual progress reports for the Justice40 Initiative implementation, reporting approaches may differ across agencies, creating challenges to isolating the benefits of buildings-specific investments in disadvantaged communities. Integration of reporting data is also needed to facilitate cross-agency coordination on J40 strategy and impact assessments.
- **Energy-related costs**: Technology cost data collection approaches and definitions vary greatly across the listed sources, making it difficult to develop a common baseline for assessing cost reductions.
- **Resilience**: FEMA data present a picture of the structural resilience of the buildings stock and community building infrastructure to natural hazards, but do not address operational resilience to disruptions in energy services, a key aspect of this strategy's resilience priority.
- **Efficiency and on-site emissions**: Definitional issues with these data will grow in the coming years as, for example, gray areas emerge around how to classify new behind-the-meter loads like EV charging, which belongs to both the building and transportation sectors. EIA on-site emissions reporting also reflects

substantial emissions from "non-building" end uses, such as unknown/miscellaneous end uses and manufacturing in commercial spaces, that will comprise an increasing share of totals as building end uses are decarbonized. Data will increasingly need to look more holistically at the impact of land use, transportation, and proximity between households, employment, and other activities on GHG emissions reporting.

- **Grid edge**: FERC and EIA data report peak reduction potential from demand response programs, which is an imperfect indicator for the development of a broader grid edge resource in buildings. Moreover, currently available estimates of peak reduction potential in wholesale power markets are not disaggregated by customer class, which precludes specific attribution of changes in the wholesale demand flexibility resource to the buildings sector. There may also be a need for more nuanced planning metrics for representing grid decarbonization challenges, such as peak *net* load (after subtracting variable renewable electricity), multiday periods with low solar/wind resource, and multiyear variability in winter peak demand. Trends in grid infrastructure costs are another possible indicator of grid edge benefits but are influenced by a wide range of factors that extend beyond the scope of this buildings-focused strategy.
- **Life cycle emissions**: Regularly updated estimates of the embodied emissions associated with building materials and construction do not currently exist and would need to be established to track decarbonization progress in this strategic area.

Given these limitations, it will be important to periodically revisit the data available for tracking the goals and strategic targets and to fold in emerging data sources, including those being developed at the state and local levels.

Tracking progress on lower-level technology, market, and policy milestones is more challenging due to greater data collection complexity at this level. However, regularly reported datasets do exist for tracking many of these lower-level conditions, for example, heat pump sales,[157] envelope renovations,[158] and building code adoption,[159] among others.

Table 9. Regularly updated data sources for tracking progress on strategic framework implementation.

Strategic framework category	Currently available tracking data sources
Prioritize equity, affordability, and resilience	Equity: Department of Energy building-related program benefit reports submitted via Justice40 Implementation Guidance,[*] Energy Information Administration (EIA) Residential Energy Consumption Survey and Commercial Buildings Energy Consumption Survey (CBECS)[**, ***] Affordability: EIA Updated Buildings Sector Appliance and Equipment Costs and Efficiencies,[****] National Residential Efficiency Measures Database,[†] State-level project cost databases (e.g., TECH Clean California,[††] New York State Energy Research and Development Authority)[†††] Resilience: Federal Emergency Management Agency (FEMA) National Building Code Adoption Tracking,[††††] FEMA Community Resilience Index,[§] Building Resilient Infrastructure and Communities Index (Infrastructure/Built Environment/Housing)[§§]
Increase building energy efficiency	Residential floor area: Moura et al (1980–2005),[§§§] EIA Annual Energy Outlook (AEO) Table 4 (2005–present and projections)[§§§§] Commercial floor area: EIA CBECS (1980–2003),[‡] EIA AEO Table 5 (2005–present and projections)[‡‡] Site total energy use: EIA Monthly Energy Review, Tables 2.2–2.3 (1980–present),[‡‡‡], [‡‡‡‡] AEO Tables 4 and 5 (projections)[‖, ‖‖]
Accelerate on-site emissions reductions	Emissions from fossil-based combustion energy use: EIA Monthly Energy Review, Tables 11.2–11.3 (projections);[‖‖‖, #] AEO Table 18 (projections)[##] Emissions from equipment refrigerant HFCs: Environmental Protection Agency Greenhouse Gas Inventory, Table 4–115 (1990–present)[###]
Transform the grid edge	Retail building demand response (DR) potential: EIA-861 Demand-Side Management/Demand Response (2001–present)[####] Wholesale DR potential: Federal Energy Regulatory Commission (FERC) Reports on Demand Response and Advanced Metering (2006–present)[a] Grid infrastructure costs: FERC Form 1 – Electric Utility Annual Reportaa and EIA summaries of these data (e.g., Table 8.3 of Electric Power Annual report)[aaa]
Minimize embodied life cycle emissions	Current estimates are based on irregularly published literature and require additional assumptions;[aaaa, b, bb] Carbon Leadership Forum Whole-Building Life Cycle Assessment (WBLCA) Benchmark Studies (v1: 2017, v2: forthcoming in 2024)[bbb, bbbb]

* Office of Management and Budget. 2021. M-21-28: Interim Implementation Guidance for the Justice40 Initiative. https://www.whitehouse.gov/wp-content/uploads/2021/07/M-21-28.pdf.

** U.S. Energy Information Administration. 2023. 2020 Residential Energy Consumption Survey (RECS) Microdata. https://www.eia.gov/consumption/residential/data/2020/.

*** U.S. Energy Information Administration. 2024. Commercial Buildings Energy Consumption Survey (CBECS). https://www.eia.gov/consumption/commercial.

**** U.S. Energy Information Administration. 2023. Updated Buildings Sector Appliance and Equipment Costs and Efficiencies. https://www.eia.gov/analysis/studies/buildings/equipcosts/.

† National Residential Efficiency Measures Database. https://remdb.nrel.gov/.

†† TECH Clean California. https://techcleanca.com/.

††† New York State Energy Research and Development Authority. Resources: Important Resources and Project Information. https://www.nyserda.ny.gov/All-Programs/Multifamily-Buildings-of-Excellence/Winners/Resources.

†††† FEMA. 2023. Building Code Adoption Tracking. https://www.fema.gov/emergency-managers/risk-management/building-science/bcat.

§ FEMA. Community Resilience. https://hazards.fema.gov/nri/community-resilience.

University of South Carolina. Baseline Resilience Indicators for Communities.

§§ https://www.sc.edu/study/colleges_schools/artsandsciences/centers_and_institutes/hvri/data_and_resources/bric/index.php.

§§§ Moura, M.C.P., S.J. Smith, and D.B. Belzer. 2015. 120 Years of U.S. Residential Housing Stock and Floor Space. PLoS ONE 10(8): e0134135. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0134135.

§§§§ U.S. Energy Information Administration. 2023. Annual Energy Outlook. Table 4. Residential Sector Key Indicators and Consumption. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=4-AEO2023&cases=ref2023&sourcekey=0.

‡ U.S. Energy Information Administration. 2018. Commercial Buildings Energy Consumption Survey. https://www.eia.gov/consumption/commercial/data/2018/.

‡‡ U.S. Energy Information Administration. 2023. Annual Energy Outlook. Table 5. Commercial Sector Key Indicators and Consumption. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=5-AEO2023&cases=ref2023&sourcekey=0.

‡‡‡ U.S. Energy Information Administration. 2023. Total Energy. Table 2.2. Residential Sector Energy Consumption. https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T02.02#/?f=M&start=200001.

‡‡‡‡ U.S. Energy Information Administration. 2023. Total Energy. Table 2.3. Commercial Sector Energy Consumption. https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T02.03#/?f=M&start=200001.

ll U.S. Energy Information Administration. 2023. Annual Energy Outlook. Table 4. Residential Sector Key Indicators and Consumption. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=4-AEO2023&cases=ref2023&sourcekey=0.

llll U.S. Energy Information Administration. 2023. Annual Energy Outlook. Table 5. Commercial Sector Key Indicators and Consumption. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=5-AEO2023&cases=ref2023&sourcekey=0.

llllll U.S. Energy Information Administration. 2023. Monthly Energy Review. Table 11.2. Carbon Dioxide Emissions from Energy Consumption: Residential Sector. https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T11.02#/?f=M&start=200001.

U.S. Energy Information Administration. 2023. Monthly Energy Review. Table 11.3. Carbon Dioxide Emissions from Energy Consumption: Commercial Sector. https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T11.03#/?f=M&start=200001.

U.S. Energy Information Administration. 2023. Annual Energy Outlook 2023. Table 18. Energy-Related Carbon Dioxide Emissions by Sector and Source. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=17-AEO2023&cases=ref2023&sourcekey=0.

EPA. 2023. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021.

U.S. Energy Information Administration. 2023. Annual Electric Power Industry Report. https://www.eia.gov/electricity/data/eia861/.

a Federal Energy Regulatory Commission. 2023. Assessment of Demand Response and Advanced Metering. https://www.ferc.gov/power-sales-and-markets/demand-response/reports-demand-response-and-advanced-metering.

aa Federal Energy Regulatory Commission. Electric Utility Annual Report. https://www.ferc.gov/general-information-0/electric-industry-forms/form-1-electric-utility-annual-report.

aaa U.S. Energy Information Administration. 2023. Electric Power Annual. https://www.eia.gov/electricity/annual/.

aaaa Cabeza, L. F., Q. Bai, P. Bertoldi, J.M. Kihila, A.F.P. Lucena, É. Mata, S. Mirasgedis, A. Novikova, and Y. Saheb. 2022. "Buildings." In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press. doi: 10.1017/9781009157926.011. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter09.pdf.

b Pauliuk, S., N. Heeren, P. Berrill, T. Fishman, A. Nistad, Q. Tu, P. Wolfram, and E.G. Hertwich. 2021. "Global Scenarios of Resource and Emission Savings from Material Efficiency in Residential Buildings and Cars." Nature Communications, 12, Article 5097. https://doi.org/10.1038/s41467-021-25300-4.

bb Berrill, P., E.J.H. Wilson, J.L. Reyna, A.D. Fontanini, and E.G. Hertwich. 2022. "Decarbonization Pathways for the Residential Sector in the United States." Nature Climate Change, 12, 712–718. https://doi.org/10.1038/s41558-022-01429-y.

bbb Carbon Leadership Forum. 2017. 2017 Embodied Carbon Benchmark Study v1. https://carbonleadershipforum.org/lca-benchmark-database/.

bbbb Carbon Leadership Forum (CLF). 2023. CLF Whole-Building Life Cycle Assessment (WBLCA) Benchmark Study v2. https://carbonleadershipforum.org/clf-wblca-v2/

6 CONCLUSION

Achieving a net-zero emissions economy in the United States by 2050 requires near-complete decarbonization of U.S. buildings in the span of just a few decades, while widely distributing the resulting benefits for people and communities. Historical perspective shows that such a transformation will not occur without bold and coordinated action across all parties that influence how our buildings are sited, designed, operated, and retrofitted. The federal government is well positioned to lead this effort by virtue of its wide-ranging perspective and array of tools for accelerating building decarbonization while promoting equity, affordability, and resilience. These tools include innovative research and development programs, market transformation, deployment activities, direct funding support, and regulatory mechanisms. Those and other federal resources can be strategically marshalled toward realizing a 2050 built environment that is deeply decarbonized, energy efficient, flexible, and resilient, as well as broadly beneficial to the diverse individuals and communities that it supports.

The vision and approach presented here are reflective of where thinking and efforts on building decarbonization are today. DOE intends to continue to vet these recommendations with a wide range of stakeholders, track progress on their implementation, and amend this document in the future as needed. A regular strategy review and revision process will focus on:

- Updating key statistics demonstrating the buildings sector's relevance to economy-wide emissions;
- Updating the cross-cutting goals and strategic objectives to ensure they remain relevant as financial, social, and climate circumstances evolve over time;
- Incorporating additional evidence from analysis concerning the strategic areas; and
- Reporting results from goal tracking, key implementation issues, and lessons learned since the strategy's inception.

Such a review process will ensure federal support for building decarbonization remains relevant and useful to key decision makers, even as the buildings landscape evolves. For example, quantitative targets for embodied material emissions and emissions from methane leakage are currently highly uncertain, yet these sources of building emissions will grow in relative importance as operational emissions from buildings decrease and clean electricity deployment increases. At the same time, data and tools to account for and quantify such emissions sources are under active development and are likely to improve in the next few years. Such developments will likely warrant the refinement of the currently proposed targets for these areas, including through the addition of near-term reduction targets, which will help to track progress and the potential impacts of solutions in these emerging areas of interest with greater confidence.

Finally, the broad scope and range of actors addressed by this strategy mean that its guidance is inherently high-level, and follow-on planning work will be needed to operationalize key recommendations in the day-to-day activities of federal agencies and programs. DOE sees this Blueprint as a vehicle for maintaining momentum on the critical task of decarbonizing U.S. buildings. Future activities may include creating or joining forces with existing building decarbonization working groups in which interested federal and non-federal stakeholders can benefit from the sharing of technology RD&D breakthroughs; the results of pilot studies; best practices, tools, and data; and updates to building codes and product standards, all of which support the implementation of this Blueprint. DOE plans to post annual updates to the Blueprint's recommendations and associated data, as well as information about these working groups. DOE will also develop more detailed technology roadmaps and multiyear program plans in alignment with this Blueprint that provide greater depth about technology-specific challenges and deployment opportunities, while tying these specifics back to the higher-level vision and milestones established in this Blueprint.

APPENDIX

ADDITIONAL SEGMENTATION OF BUILDING EMISSIONS

Figure 16 shows a segmentation of operational energy-related building CO_2 emissions by building type, fuel type, and end use. It provides a more detailed version of the information shown in Figure 4. Fossil-based heating and water heating in single-family detached houses are the most impactful segments for operational building CO_2 emissions; commercial buildings sector impacts are distributed across a large set of heterogeneous building types.

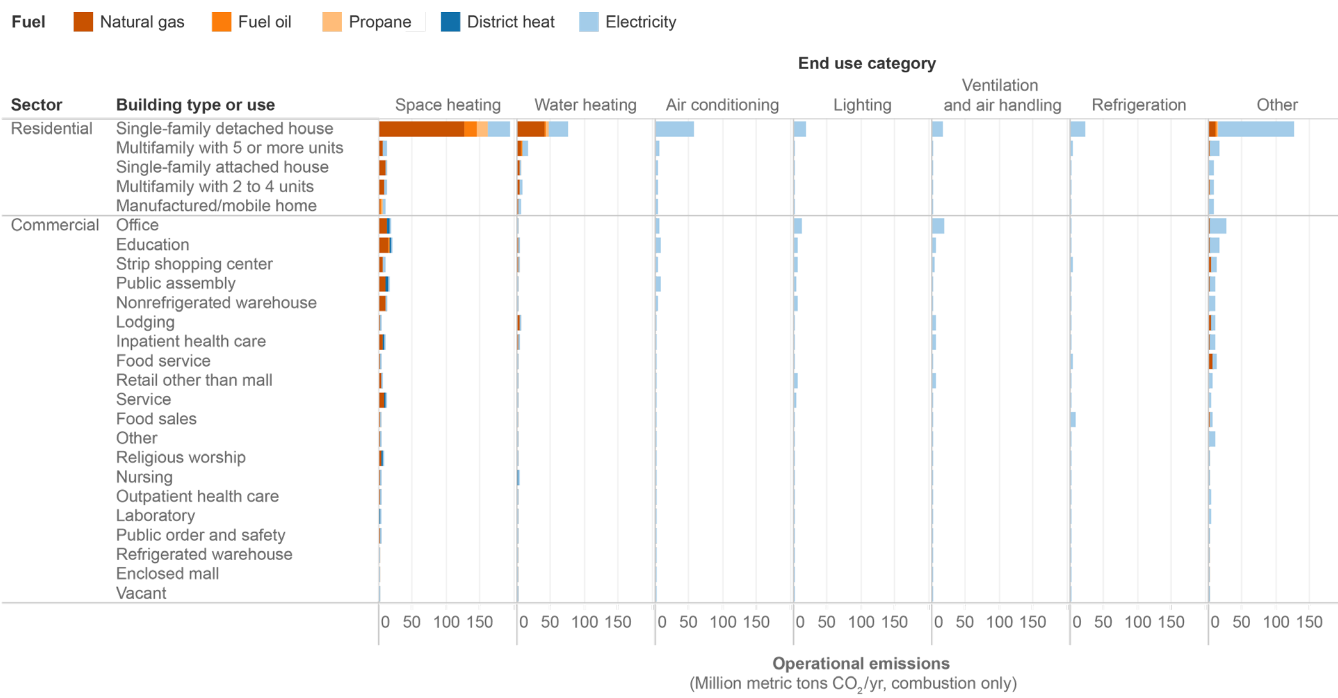


*Figure 16. Residential and commercial end-use contributions to operational energy-related emissions, by building type or primary activity. Annual operational energy-related emissions include upstream and non-CO_2 emissions (million metric tons CO_2e/yr).**

* Site energy by end use: U.S. Energy Information Administration. 2023. "2020 Residential Energy Consumption Survey (RECS) Microdata." https://www.eia.gov/consumption/residential/data/2020/; U.S. Energy Information Administration. 2022. 2018 Commercial Buildings Energy Consumption Survey (CBECS) Microdata. https://www.eia.gov/consumption/commercial/data/2018/, with DOE analysis of emissions. 2018 CBECS does not directly estimate site energy use for propane, so propane usage was estimated based on the ranges of propane use reported by survey respondents in field PRAMTC (100 was used for the "Less than 100" response, 5000 used for the "1,000 or more" response and the range midpoint used for other responses); Emissions factors for natural gas (0.053 Mt/TBtu), propane (0.063 Mt/TBtu), and fuel oil (0.073 Mt/TBtu): EIA. "Carbon Dioxide Emissions Coefficients." https://www.eia.gov/environment/emissions/co2_vol_mass.php; Emission factor for electricity (0.088 Mt/TBtu): National Renewable Energy Laboratory. 2022. Cambium full data sets. https://www.nrel.gov/analysis/cambium.html; Average emissions rate from the midcase scenario for the year 2024 and carbon dioxide are from combustion only.

DEVELOPMENT OF PERFORMANCE TARGETS

Overall Building Greenhouse Gas Emissions Reductions

Table 10 provides a breakdown of 2005 building GHG emissions sources and shows how targeted reductions for each of these sources roll up into the Blueprint's overall vision of a 65% and 90% reduction in building GHG emissions by 2035 and 2050, respectively (vs. 2005 levels). Reduction targets map to the Blueprint's strategic objectives with the exception of targeted reductions in the emissions from refrigerant leaks and other HFCs, which are drawn from the Kigali Amendment to the Montreal Protocol and AIM Act, and the targeted reduction in power generation emissions, which is drawn from the Biden-Harris Administration's climate goals.

Table 10. Overall buildings sector GHG emissions targets

Building GHG emissions source	2005 Mt/yr CO_2e*	2035 reduction target	2035 Mt/yr CO_2e (targeted)	2050 reduction target	2050 Mt/yr CO_2e (targeted)	Basis for reduction targets
Methane leaks	124	0%	124	75%	31	Strategic Objective 2: Accelerate on-site emissions reductions Strategic Objective 4: Minimize building life cycle emissions
On-site fossil combustion CO_2	592	25%	465	75%	208	
On-site fossil combustion other GHG	7	25%	5	75%	2	
Embodied life cycle	300	0%	300	90%	30	
Refrigerant leaks and other HFCs	28	0%	77	85%	12	Kigali Amendment to the Montreal Protocol/ AIM Act
Indirect power generation CO_2	1735	100%	0	100%	0	Biden-Harris Administration Goal
Indirect power other GHG	20	100%	0	100%	0	
Total building GHG emissions	2806		971		282	
% reduction from 2005	--		65%		90%	

*Data are generally drawn from EPA Greenhouse Gas Inventory with the exception of material life cycle emissions, which are estimated from multiple previous studies (see *Strategic Objective 4: Minimize Embodied Life Cycle Emissions*).

Increase Building Energy Efficiency

Estimates of potential reductions in building site energy use intensity (EUI)[160] vs. 2005 from previous decarbonization studies are summarized in Table 11. As mentioned, goal levels are generally consistent with scenarios that assume high but not universal electrification to efficient heat pumps by 2050 with aggressive efficiency deployment and regular rates of building and technology stock turnover. For example, the 2050 goal of a 50% EUI reduction vs. 2005 is roughly consistent with that of the "aggressive" scenario benchmark in the LBNL and Brattle study, which represents widespread efficiency gains without assuming that building retrofits occur before the end of existing technology or component lifetimes. Other studies, such as the "Halfway There" study by ACEEE, show deeper levels of potential reductions but represent efficiency improvements more coarsely with overall annual rates of improvement.

Table 11. Reductions in building site EUI from 2005 levels* across studies vs. Blueprint goal.

Source	Site EUI reduction	
	By 2035	By 2050
AEO 2023 forecast	27%	33%
AEO 2023 forecast w/ Objective 2 on-site emissions	29%	42%
Blueprint goal	35%	50%
LBNL/Brattle U.S. Building Sector Decarbonization Scenarios to 2050	31–45%	40–54%
Princeton Net Zero America scenarios (E– to E+)**	36–42%	53–59%
Evolved Energy 350 PPM Pathways	47%†	60%
Energy Innovation (EI) 1.5 Celsius Pathway	46%	58%
ACEEE Halfway There	-	76%
U.S. Long-Term Strategy††	-	51%

* Total building energy demand in the reference is after subtracting on-site renewable electricity generation (~0.6 quads in 2005).

** Buildings sector definition may not include certain miscellaneous loads that are included in the 2005 CBECS/RECS-based EUI benchmark, which would overstate relative reductions.

† Interpolated between 2030 and 2040.

†† Estimated based on reported 30% reduction in building demand by 2050, assessed relative to AEO 2021 Ref. Case and square footage projections.

Figure 17 shows how targeted decreases in building site EUI compare with projections from existing decarbonization studies, the historical trend for building EUI, and the reference case projections of building EUI in the 2023 EIA AEO. Targeted EUI reductions between 2023 and 2050 are double that projected in the EIA reference case and are greater than historical rates of EUI reduction in the period from 1980 to 2022, during which the first building codes and equipment standards were introduced. The targeted reductions are within the plausible range suggested by previous decarbonization studies.

Accelerate On-site Emissions Reductions

Estimates of potential reductions in on-site fossil combustion from previous decarbonization studies are summarized in Table 12. Based on these studies, elimination of on-site combustion emissions in buildings by 2050 through universal conversion of fossil-fired equipment to clean electric alternatives is not a realistic expectation, given the current market and policy landscape and the relatively long lifetime for heating equipment (20 years or longer), which would require 100% of heating equipment sales to be electric by 2030 or sooner. The selected targets therefore reflect an ambitious yet achievable objective—one recognizing that further progress on electrification may be achieved beyond 2050, which could help facilitate net-negative economy-wide emissions. Moreover, while equipment electrification is expected to be the primary pathway for reducing building emissions from on-site fossil fuel combustion, the broad framing of this objective in terms of on-site emissions reductions encompasses solutions other than full electrification—for example, deep envelope and controls efficiency in buildings with remaining fossil-fired heating, partial electrification with limited fossil-fuel backup, and/or limited use of low-carbon heating fuels for hard-to-decarbonize segments of the building stock.

Figure 18 shows how targeted decreases in building on-site fossil combustion emissions compare with projections from existing studies, the historical trend in these emissions, and reference case projections of these emissions in the 2023 EIA AEO. Targeted reductions in on-site fossil combustion emissions from

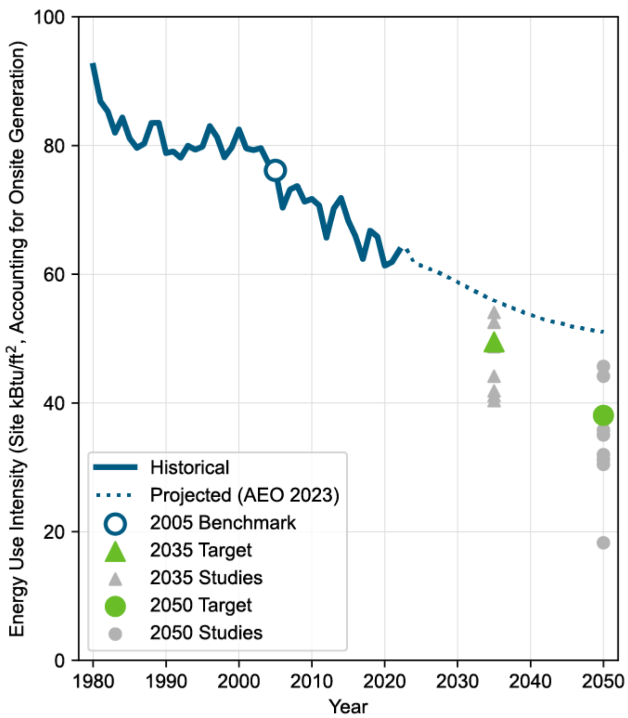


Figure 17. Historical and targeted buildings sector energy use intensity (EUI). Data sources: EIA Monthly Energy Review and square footage projections from Moura et al. (historical);, ** 2023 EIA AEO (projected).†*

* U.S. Energy Information Administration. 2023. Monthly Energy Review. https://www.eia.gov/totalenergy/data/monthly/.

** Moura, M.C.P., S.J. Smith, and D.B. Belzer. 2015. "120 Years of U.S. Residential Housing Stock and Floor Space." PLoS ONE 10(8): e0134135. https://doi.org/10.1371/journal.pone.0134135.

† U.S. Energy Information Administration. 2023. Annual Energy Outlook 2023. https://www.eia.gov/outlooks/aeo/tables_ref.php.

buildings break markedly with historical trends in these emissions, which decreased just 6% from 1980 to 2022. The targeted reductions are also about eight times larger than those projected in the AEO reference case between 2023 and 2050; the AEO projects just a 9% decrease in fossil combustion emissions from buildings during this period, compared with 2005 levels. The targeted reductions are within the plausible range suggested by previous decarbonization studies.

Transform the Grid Edge

Existing studies concerning demand-side management potential from buildings use varying metrics and baselines, generally do not address distribution system benefits, and vary in their inclusion of energy efficiency. However, multiple studies report potential decreases in peak demand from building demand response (DR) across a distinct time period, and the comparison of these estimates informs the goal of increasing buildings' flexible potential by 3X vs. 2020 under deep decarbonization (Table 13); the comparison of these estimates informs the goal of increasing buildings' flexible potential by 3X vs. 2020 under deep decarbonization. This goal is on the conservative end of the range of estimates once the time period is taken into account. However, high-end estimates in previous studies tend to reflect very aggressive technology adoption and turnover assumptions, and the 3X level should be interpreted as the minimum level of increase needed to keep pace with expected increases in power grid capacity under high electrification scenarios.[161]

Figure 19 shows how the targeted 3X increase in DR peak reduction potential by 2050 compares with projections from existing DR potential studies, the historical trend for building retail and wholesale DR, and a projection forward of the historical trend based on the last 10 years of data. DR potential grew significantly beginning in the early 2000s, driven largely by the development of wholesale markets. Though DR potential as of 2021 was 21% greater than in 2010, growth has slowed significantly since 2012; DR potential has increased by only 9% since that point. The 2021 DR potential estimate is also virtually unchanged from that of the 2020 benchmark year for the Blueprint target (~45 GW), as a 6% increase in wholesale DR potential was offset by a 10% decrease in retail DR potential. This stagnation reflects the maturation of conventional DR markets, where participation rules have become increasingly stringent and peak capacity needs have stalled.[162]

Table 12. Reductions in building on-site fossil CO_2 from 2005 levels* across studies vs. Blueprint goal.

Source	On-site fossil CO_2 reduction		
	by 2030	by 2035	by 2050
AEO 2023 forecast	4%	5%	8%
Blueprint goal*	–	25%	75%
LBNL/Brattle Building Decarbonization Scenarios to 2050	12–26%	18–42%	41–73%
Princeton Net Zero America scenarios (E- to E+)**	10–11%	17–38%	56–88%
Evolved Energy 350 PPM Pathways	44%	–	91%
Energy Innovation (EI) 1.5 Celsius Pathway	32%	–	99%
ACEEE Halfway There	–	–	63%
Bistline et al. (meta-analysis of six 2030 studies†)	16–31%	–	–
U.S. Long Term Strategy††	–	–	57–95%

* Initial 2005 benchmark of 592 Mt CO_2 from EIA 2023 Monthly Energy Review. Final benchmark excludes ~74 Mt CO_2 assigned to non-building loads in the year 2015 of the AEO 2023 commercial microtables (2005 benchmark = 592 – 74 = 518 Mt CO_2); non-building loads in 2030, 2035 and 2050 (~76 Mt CO_2 for 2030 and 2035 and 78 Mt CO_2 for 2050, respectively) are also removed in estimating reductions.

** Assumes that reference case projections for this study already exclude the "non-building" portion—therefore, takes projections of remaining on-site fossil fuel emissions as-is and compares to the 2005 reference point with "non-building" removed (518 Mt CO_2).

† Excludes N. Abhyankar et al., "*Illustrative Strategies for the United States to Achieve 50% Emissions Reduction by 2030*" (Lawrence Berkeley National Laboratory, 2021), which showed a 4% increase.

†† Estimated based on inspection of Figure 4, which shows ~100-300 Mt CO_2 remaining for buildings in 2050 under electricity that is effectively fully decarbonized.

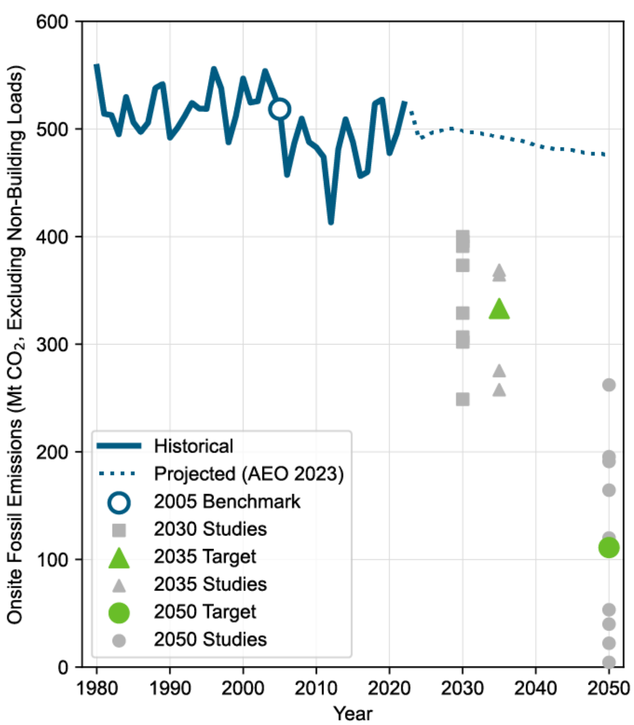


Figure 18. Historical and targeted buildings sector on-site combustion emissions. Data sources: EIA Monthly Energy Review (historical); 2023 EIA AEO (projected).***

* U.S. Energy Information Administration. 2023. Monthly Energy Review. https://www.eia.gov/totalenergy/data/monthly/.

** U.S. Energy Information Administration. 2023. Reference Case Projection Tables. In Annual Energy Outlook 2023. https://www.eia.gov/outlooks/aeo/tables_ref.php.

Table 13. Increase in buildings' demand response (DR) potential relative to base year across studies vs. Blueprint goal.

Source	Increase in DR potential (year range)
Blueprint goal*	3X (2022–2050)
DOE GEB Roadmap**	2.5–4X (2020–2030)
Brattle National Potential for Load Flexibility†	2–3X (2020–2030)
Virtual Power Plants (VPP) Liftoff Report††	1.5-3X (2023–2030)
FERC 2009 National Assessment of DR Potential§	2–5X (2008–2019)
EPRI Assessment of Achievable Potential from EE/DR§§	2–2.5X (2008–2030)

* Benchmark of ~45 GW flexibility potential in 2020 includes retail building DR and wholesale DR from FERC reports that also include industrial.

** Relative estimate is based on Figure 4, which shows a ~2.5-4X increase in dispatchable peak demand reduction capability vs. an estimated baseline of 10.2 GW in potential added from 2010-2019 that excludes wholesale markets. Assumes low-high adoption of grid-interactive technologies that begins in 2020. Does not consider a high building electrification case.

† Relative estimate is based on slide 18, which finds that under market conditions as of 2019, existing DR capability could roughly double to 115GW (from 59 GW, which includes industrial) and a further increase 198 GW is possible with additional market transformation through 2030. Does not consider a high electrification case.

†† Updates Brattle National Potential for Load Flexibility study; finds potential to add 80-160 GW of VPPs, where the latter triples the current estimated scale. Upper end of range requires aggressive deployment of VPPs from 2023.

§ Relative estimate is based on comparing "Expanded BAU" and "Full Participation" estimates of reduction potential (82 GW and 188 GW, respectively) to "BAU" reduction potential (38 GW) in Figure 9. Data include industrial and do not assume high electrification.

§§ Relative estimate based on Table ES-3, which shows ~78-101 GW additional DR potential over 2008 by 2030 in the realistic to maximum achievable potential cases. These are benchmarked on an estimated 39 GW of total retail and wholesale DR potential from EIA-861 and FERC data for 2008. Data include industrial and do not assume high electrification.

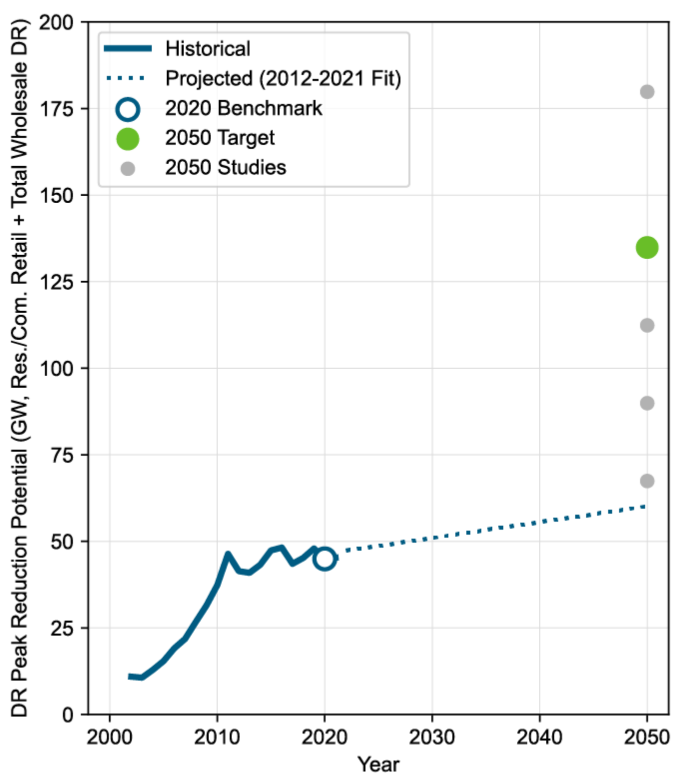


Figure 19. Historical and targeted building flexibility potential, as measured by the total peak reduction potential of retail and wholesale demand response (DR) programs. Note that historical wholesale DR data include industrial loads.[*, **]

* U.S. Energy Information Administration. 2023. Annual Electric Power Industry Report, Form EIA-861, Detailed Data Files. https://www.eia.gov/electricity/data/eia861/.

** Federal Energy Regulatory Commission. 2023. Reports on Demand Response and Advanced Meeting. https://www.ferc.gov/power-sales-and-markets/demand-response/reports-demand-response-and-advanced-metering.

REFERENCES AND ENDNOTES

1 National Climate Task Force. 2021. https://www.whitehouse.gov/climate/.

2 Meaning that remaining GHG emissions sources are offset by available carbon removals.

3 This Blueprint uses a definition of disadvantaged communities that is based on "Addendum to the Interim Implementation Guidance for the Justice40 Initiative, M-21-28, on using the Climate and Economic Justice Screening Tool (CEJST)." https://www.whitehouse.gov/wp-content/uploads/2023/01/M-23-09_Signed_CEQ_CPO.pdf.

4 U.S. Department of State and the United States Executive Office of the President. 2021. *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*. https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

5 The Breakthrough Agenda. https://breakthroughagenda.org/.

6 United Nations Environment Programme. 2023. *Global Cooling Pledge*. https://www.unep.org/resources/report/global-cooling-pledge.

7 Office of the Federal Chief Sustainability Officer, Council of Environmental Quality. "Net-Zero Emissions Buildings by 2045, including a 50% reduction by 2032." https://www.sustainability.gov/federalsustainabilityplan/buildings.html.

8 U.S. Environmental Protection Agency. 1989. *Report to Congress on Indoor Air Quality: Volume 2*. EPA/400/1-89/001C. https://www.epa.gov/report-environment/indoor-air-quality.

9 U.S. Department of Energy. 2023. *United States Energy & Employment Report 2023*. https://www.energy.gov/sites/default/files/2023-06/2023%20USEER%20REPORT-v2.pdf.

10 Energy expenditures calculated by summing energy expenditures in the U.S. Energy Information Administration residential and commercial buildings energy consumption surveys.

11 U.S. Energy Information Administration. 2023. "2020 RECS Survey Data." Residential Energy Consumption Survey. https://www.eia.gov/consumption/residential/data/2020/.

12 U.S. Energy Information Administration. 2022. "2018 CBECS Survey Data." Commercial Buildings Energy Consumption Survey. https://www.eia.gov/consumption/commercial/data/2018/.

13 U.S. Department of Energy, Office of State and Community Energy Programs. "Low-Income Community Energy Solutions." https://www.energy.gov/scep/slsc/low-income-community-energy-solutions.

14 U.S. Energy Information Administration. 2023. "2020 RECS Survey Data." Residential Energy Consumption Survey. https://www.eia.gov/consumption/residential/data/2020/.

15 U.S. Energy Information Administration. 2022. "2018 CBECS Survey Data." Commercial Buildings Energy Consumption Survey. https://www.eia.gov/consumption/commercial/data/2018/.

16 Based on reference case projections of new home construction and new commercial floor space additions between 2024 and 2050. U.S. Energy Information Administration. 2023. "Reference Case Projections Tables." Annual Energy Outlook 2023. https://www.eia.gov/outlooks/aeo/tables_ref.php.

17 Based on residential building and commercial square footage projections in the AEO 2023 microtables. https://www.eia.gov/outlooks/aeo/tables_ref.php.

18 U.S. Department of Health and Human Services. Healthy People 2030 – Quality of Housing. https://health.gov/healthypeople/priority-areas/social-determinants-health/literature-summaries/quality-housing.

19 Langevin, J., A. Satre-Meloy, A. Satchwell, R. Hledik, J. Olszewski, K. Peters, and H. Chandra-Putra. 2023. "Demand-Side Solutions in the US Buildings sector Could Achieve Deep Emissions Reductions and Avoid Over $100 Billion in Power Sector Costs." One Earth. https://doi.org/10.1016/j.oneear.2023.07.008.

20 State-level roadmaps that were available at the time of writing: California Air Resources Board. 2022. 2022 Scoping Plan. https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp-appendix-f-building-decarbonization.pdf; Colorado Energy Office. GHG Pollution Reduction Roadmap 2.0. 2021. https://energyoffice.colorado.gov/climate-energy/ghg-pollution-reduction-roadmap-20; Maine Climate Council. 2020. Maine Won't Wait: A Four-Year Plan for Climate Action. http://www.maine.gov/climateplan/sites/maine.gov.climateplan/files/inline-files/MaineWontWait_December2020_printable_12.1.20.pdf; Massachusetts Executive Office of Energy and Environmental Affairs. 2020. Massachusetts 2050 Decarbonization Roadmap. https://www.mass.gov/doc/ma-2050-decarbonization-roadmap/download; Michigan Department of Environment, Great Lakes, and Energy. 2022. MI Healthy Climate Plan. https://www.michigan.gov/egle/-/media/Project/Websites/egle/Documents/Offices/OCE/MI-Healthy-Climate-Plan.pdf; Minnesota Climate Change Subcabinet. 2022. Minnesota's Climate Action Framework. https://climate.state.mn.us/sites/climate-action/files/Climate%20Action%20Framework.pdf; New York State Climate Action Council. 2022. "Chapter 12: Buildings." Scoping Plan. https://climate.ny.gov/resources/scoping-plan/-/media/project/climate/files/Chapter12Buildings.pdf; Rhode Island Executive Climate Change Coordinating Council. 2022. "2025 Climate Action Strategy." https://climatechange.ri.gov/act-climate/2025-climate-update; Rhode Island Division of Public Utilities and Carriers, Rhode Island Office of Energy Resources. 2020.

Heating Sector Transformation in Rhode Island: Pathways to Decarbonization by 2050. https://energy.ri.gov/documents/HST/RI%20HST%20Final%20Pathways%20Report%205-27-20.pdf; Vermont Climate Council. 2021. Initial Vermont Climate Action Plan. https://climatechange.vermont.gov/sites/climatecouncilsandbox/files/2021-12/Initial%20Climate%20Action%20Plan%20-%20Final%20-%2012-1-21.pdf.

21 World Business Council for Sustainable Development and World Resources Institute. The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard, Revised Edition. https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf.

22 For example, analysis by RMI suggests that a high leakage scenario could contribute up to 465 Mt CO_2e, nearly as much as the direct CO_2 emissions impacts of building fossil fuel combustion. RMI. 2019. "The Impact of Fossil Fuels in Buildings: A Fact Base." https://rmi.org/insight/the-impact-of-fossil-fuels-in-buildings/.

23 Percentages based on Figure 4.

24 2018 CBECS estimates 1.5% of energy consumption for cooling uses natural gas, fuel oil, or district heat. CBECS does not estimate energy consumption by district cooling, but finds 55,000 buildings (1% of total) with 4,288 million square feet (4% of total) use district chilled water as a cooling energy source.

25 U.S. Energy Information Administration (EIA). 2022. "2018 CBECS Survey Data." Commercial Buildings Energy Consumption Survey. https://www.eia.gov/consumption/commercial/data/2018/. 2018 CBECS finds 304 TBtu of energy; assuming the same emissions factor as natural gas (0.053 Mt/TBtu) yields an estimate of 16.1 Mt CO_2 (combustion only), or about 1% of total operational end-use emissions.

26 U.S. Energy Information Administration. 2023. "U.S. Energy Flow, 2022." https://www.eia.gov/totalenergy/data/flow-graphs/total-energy.php. (19.68+16.42)/94.79 = 38%.

27 Waite, M., and V. Modi. 2020. "Electricity Load Implications of Space Heating Decarbonization Pathways." Joule. https://doi.org/10.1016/j.joule.2019.11.011.

28 One recent study estimates that aggressive deployment of building efficiency and flexibility would avoid up to a third of the incremental cost of power sector decarbonization, or $100B annually, by 2050. Langevin, J., A. Satre-Meloy, A. Satchwell, R. Hledik, J. Olszewski, K. Peters, and H. Chandra-Putra. 2023. "Demand-Side Solutions in the US Buildings Sector Could Achieve Deep Emissions Reductions and Avoid Over $100 Billion in Power Sector Costs." One Earth. https://doi.org/10.1016/j.oneear.2023.07.008.

29 U.S. Energy Information Administration. 2023. "Natural Gas Consumption by End Use." https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_m.htm. Percentages based on annual values for 2022.

30 U.S. Energy Information Administration. 2023. "Natural gas explained: Natural gas pipelines." https://www.eia.gov/energyexplained/natural-gas/natural-gas-pipelines.php.

31 U.S. Energy Information Administration. 2023. "Table 2. Energy Consumption by Sector and Source." Annual Energy Outlook 2023. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2023&cases=ref2023&sourcekey=0.

32 Climate & Clean Air Coalition. Global Methane Pledge. https://www.globalmethanepledge.org/.

33 The White House. 2023. Accelerating Progress: Delivering on the U.S. Methane Emissions Reduction Action Plan. https://www.whitehouse.gov/wp-content/uploads/2023/12/Methane-Action-Plan-2023-Topper.pdf.

34 Langevin, J., A. Satre-Meloy, A. Satchwell, R. Hledik, J. Olszewski, K. Peters, and H. Chandra-Putra. 2023. "Demand-Side Solutions in the US Buildings sector Could Achieve Deep Emissions Reductions and Avoid Over $100 Billion in Power Sector Costs." One Earth. https://doi.org/10.1016/j.oneear.2023.07.008.

35 U.S. Department of Energy. 2023. "DOE Releases New Report on Pathways to Commercial Liftoff for Virtual Power Plants." https://www.energy.gov/lpo/articles/doe-releases-new-report-pathways-commercial-liftoff-virtual-power-plants.

36 U.S. Department of Energy, U.S. Department of Transportation, U.S. Environmental Protection Agency, and U.S. Department of Housing and Urban Development. 2023. The U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation. https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf.

37 The 116,980 building facilities manager jobs in 2022 do not appear to be included in this figure but are nonetheless critical to implementation of building decarbonization solutions. U.S. Bureau of Labor Statistics. 2022. Occupational Employment and Wages, May 2022. https://www.bls.gov/oes/current/oes113013.htm#nat.

38 U.S. Department of Energy. 2023. United States Energy & Employment Report 2022. https://www.energy.gov/sites/default/files/2023-06/2023%20USEER%20REPORT-v2.pdf.

39 Alliance to Save Energy. "Jobs & Workforce Development." https://www.ase.org/categories/jobs-workforce-development.

40 U.S. Department of Energy. 2023. United States Energy & Employment Report 2023. https://www.energy.gov/sites/default/files/2023-06/2023%20USEER%20REPORT-v2.pdf.

41 Interstate Renewable Energy Council. "Green Buildings Career Map." https://greenbuildingscareermap.org/.

42 U.S. Department of Commerce and U.S. Department of Labor. "Good Jobs Principles." https://www.dol.gov/sites/dolgov/files/goodjobs/Good-Jobs-Summit-Principles-Factsheet.pdf.

43 U.S. Energy Information Administration. 2022. Today in Energy. “In 2020, 27% of U.S. Households Had Difficulty Meeting Their Energy Needs.” Today in Energy. https://www.eia.gov/todayinenergy/detail.php?id=51979.

44 Mann, R., and J. Schuetz. 2022. “As Extreme Heat Grips the Globe, Access to Air Conditioning Is an Urgent Public Health Issue.” Brookings. https://www.brookings.edu/articles/as-extreme-heat-grips-the-globe-access-to-air-conditioning-is-an-urgent-public-health-issue/.

45 Federal Emergency Management Agency. “Community Resilience.” https://hazards.fema.gov/nri/community-resilience.

46 Institute for Health Metrics and Evaluation. 2019. “2019 Global Burden of Disease (GBD) Study: Results.” https://vizhub.healthdata.org/gbd-results/.

47 U.S. Environmental Protection Agency. 2023. “2017 National Emissions Inventory (NEI) Data.” https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

48 Gilmore, E. A., J. Heo, N. Z. Muller, C. W. Tessum, J. D. Hill, J. D. Marshall, and P. J. Adams. 2019. “An Inter-comparison of the Social Costs of Air Quality from Reduced-Complexity Models.” Environmental Research Letters. https://iopscience.iop.org/article/10.1088/1748-9326/ab1ab5.

49 Tessum, C. W., D. A. Paolella, S. E. Chambliss, J. S. Apte, J. D. Hill, and J. D. Marshall. 2021. “$PM_{2.5}$ Polluters Disproportionately and Systemically Affect People of Color in the United States.” Science Advances. https://www.science.org/doi/10.1126/sciadv.abf4491.

50 The White House. Climate and Economic Justice Screening Tool (CESJT). Version 1.0. https://screeningtool.geoplatform.gov.

51 Romero-Lankao, P., and E. Nobler. 2021. Energy Justice: Key Concepts and Metrics Relevant to EERE Transportation Projects. https://afdc.energy.gov/files/pdfs/energy-justice-key-concepts.pdf.

52 In the LTS, for example, roughly 100–300 Mt CO_2 from buildings remains in 2050 and is offset via two sources of carbon removal: maintaining and enhancing carbon removal through the U.S. land sink, and carbon removal through engineered approaches. The LTS estimates that there could be more than 1 Gt of CO_2 removal potential from these two sources by 2050. While this estimate carries substantial uncertainty and much of the carbon removal will be needed to offset non-CO_2 greenhouse gases and address hard-to-decarbonize segments of industry and transportation, the magnitude of potential removals would be sufficient to offset the targeted level of remaining building emissions if allocated in proportion with end-use sector GHG contributions. Note that targeted levels of remaining emissions do not assume the use of low-carbon fuels such as green hydrogen or renewable natural gas to abate on-site fossil fuel combustion in buildings.

53 Historical emissions values: U.S. Environmental Protection Agency. 2023. “Inventory of U.S. GHG Emissions and Sinks: 1990-2021.” EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021. Values for 2035 and 2050 are based on the strategic objective performance targets set in this Blueprint.

54 Based on modeling in “Demand-Side Solutions in the US Building Sector Could Achieve Deep Emissions Reductions and Avoid Over $100 billion in Power Sector Costs,” https://doi.org/10.1016/j.oneear.2023.07.008. The performance targets are broadly consistent with the “aggressive” benchmark, which avoids $107 billion in power system decarbonization investments annually by 2050.

55 Denholm, P., P. Brown, W. Cole, T. Mai, B. Sergi, M. Brown, P. Jadun, J. Ho, J. Mayernik, C. McMillan, R. Sreenath. 2022. Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035. https://www.nrel.gov/docs/fy22osti/81644.pdf.

56 The U.S. National Blueprint for Transportation Decarbonization, https://www.energy.gov/eere/us-national-blueprint-transportation-decarbonization-joint-strategy-transform-transportation.

57 Infrastructure Investment and Jobs Act, Pub. L. 117-58, (November 15, 2021), PUBLhttps://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf058.PS (congress.gov).

58 Inflation Reduction Act, Pub. L. 117-169, (August 16, 2022), untitled (govinfo.gohttps://www.govinfo.gov/content/pkg/PLAW-117publ169/pdf/PLAW-117publ169.pdfv).

59 For example, the aggressive benchmark scenario in Langevin et al. requires deployment rates of envelope retrofits, heat pumps, and controls that represent multiple-fold increases over historical trends; the authors suggest these levels of deployment will likely exceed that spurred by the IRA/BIL legislation. See Langevin, J., A. Satre-Meloy, A. Satchwell, R. Hledik, J. Olszewski, K. Peters, and H. Chandra-Putra. 2023. “Demand-Side Solutions in the US Building Sector Could Achieve Deep Emissions Reductions and Avoid Over $100 Billion in Power Sector Costs.” One Earth. https://doi.org/10.1016/j.oneear.2023.07.008.

60 The American Housing Survey and Commercial Buildings Energy Consumption Survey suggest annual residential and commercial replacement rates of 3.2% and 0.6% for windows; 3% and 1.2% for roofs; and 1.1% and 0.4% for insulation, respectively. U.S. Census Bureau. “2021 National — Home Improvement Costs — Owner-occupied Units.” American Housing Survey. https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html?s_areas=00000&s_year=2021&s_tablename=TABLE10&s_bygroup1=1&s_bygroup2=1&s_filtergroup1=1&s_filtergroup2=1; U.S. Census Bureau. “2021 General Housing Data — All Occupied Units.” American Housing Survey. https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html?s_areas=00000&s_year=2021&s_tablename=TABLE1&s_bygroup1=1&s_bygroup2=1&s_filtergroup1=1&s_filtergroup2=1; U.S. Energy Information Administration. 2022. “Table B12. Selected Principal Building Activity: Part 1, Floorspace, 2018.” Commercial Buildings Energy Consumption Survey. https://www.eia.gov/consumption/commercial/data/2018/bc/html/b12.php. To derive the residential rates, total housing units reporting that component was renovated in the past two years in the “Exterior Additions and Replacements” section of “Home Improvement Costs” table was divided by 2 to annualize; this number was in turn divided by the total number of housing units in millions, excluding the most recent vintage bin (2020 to 2021 in “Year Structure Built” section of “Gen-

eral Housing Data"). To derive the commercial rates, square footage values for each envelope component in the CBECS Table B12 section "Renovations since 2000" and "All buildings" column were divided by 20 years to annualize (2000 through 2019, the survey year); this number was in turn divided by the total square footage for all commercial buildings excluding the most recent vintage bin (constructed in 2013 or later).

61 Nadel, S., and A. Hinge. 2020. Mandatory Building Performance Standards: A Key Policy for Achieving Climate Goals. American Council for an Energy-Efficient Economy. https://www.aceee.org/sites/default/files/pdfs/buildings_standards_6.22.2020_0.pdf.

62 Conversion rate of 0.5% estimated based on data from U.S. Energy Information Administration. 2023. "2020 Residential Energy Consumption Survey (RECS) Microdata." https://www.eia.gov/consumption/residential/data/2020/; and U.S. Energy Information Administration. 2018. "2015 Residential Energy Consumption Survey (RECS) Microdata." https://www.eia.gov/consumption/residential/data/2015/.

63 The Air-Conditioning, Heating, and Refrigeration Institute. 2023. "Central Air Conditioners and Air-Source Heat Pumps." https://www.ahrinet.org/analytics/statistics/historical-data/central-air-conditioners-and-air-source-heat-pumps.

64 The White House. Inflation Reduction Act Guidebook. https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/.

65 U.S. Energy Information Administration. 2023. Updated Buildings Sector Appliance and Equipment Costs and Efficiencies. https://www.eia.gov/analysis/studies/buildings/equipcosts/. Typical lifetime for fuel-fired residential and commercial space heating equipment is 21 years, and typical lifetime for fuel-fired residential and commercial water heating equipment is 13 years.

66 Institute for Health Metrics and Evaluation. 2019. "2019 Global Burden of Disease (GBD) Study: Results." https://vizhub.healthdata.org/gbd-results/. 26,000 to 72,000 deaths values based on a query of the GBD tool for location = "United States of America," sex = "Both," age = "All ages," cause = "All causes," risk = "Ambient particulate matter pollution," metric = "Number," year = "2019."

67 Tessum, C. W., D. A. Paolella, S. E. Chambliss, J. S. Apte, J. D. Hill, and J. D. Marshall. "$PM_{2.5}$ Polluters Disproportionately and Systemically Affect People of Color in the United States." Science Advances. https://www.science.org/doi/10.1126/sciadv.abf4491.

68 Dennison, J., L. Louis-Prescott, T. Gruenwald. 2021. How Air Agencies Can Help End Fossil Fuel Pollution from Buildings. RMI. https://rmi.org/insight/outdoor-air-quality-brief.

69 This Blueprint uses a definition of "disadvantaged communities" that is based on "Addendum to the Interim Implementation Guidance for the Justice40 Initiative, M-21-28, on using the Climate and Economic Justice Screening Tool (CEJST)." https://www.whitehouse.gov/wp-content/uploads/2023/01/M-23-09_Signed_CEQ_CPO.pdf.

70 U.S. Department of Energy. "Justice40 Initiative." https://www.energy.gov/diversity/justice40-initiative.

71 U.S. Department of the Interior, Indian Affairs. "Tribal Leaders Directory." https://www.bia.gov/bia/ois/tribal-leaders-directory/.

72 The Justice40 commitment is in line with Section 223 of Executive Order 14008, Tackling the Climate Crisis at Home and Abroad.

73 U.S. Executive Office of the President, Office of Management and Budget. 2021. Memorandum for the Heads of Departments and Agencies. https://www.whitehouse.gov/wp-content/uploads/2021/07/M-21-28.pdf.

74 U.S. Executive Office of the President. 2023. Memorandum for the Heads of Departments and Agencies. https://www.whitehouse.gov/wp-content/uploads/2023/01/M-23-09_Signed_CEQ_CPO.pdf.

75 Barbose, G. L., N. R. Darghouth, B. Hoen, and R. H. Wiser. 2018. Income Trends of Residential PV Adopters: An Analysis of Household-Level Income Estimates. Lawrence Berkeley National Laboratory. Slide 1 (lbl.gov).

76 Ma, O., K. Laymon, M. H. Day, R. Bracho, J. D. Weers, and A. J. Vimont. 2019. Low-Income Energy Affordability Data (LEAD) Tool Methodology (No. NREL/TP-6A20-74249). U.S. Department of Energy and National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy19osti/74249.pdf.

77 U.S. Census Bureau. "American Housing Survey Table Creator, Housing Quality, 2021." https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html?s_areas=00000&s_year=2021&s_tablename=TABLE1&s_bygroup1=1&s_bygroup2=1&s_filtergroup1=1&s_filtergroup2=1.

78 Cong, S., D. Nock, Y. L. Qiu, and B. Xing. 2022. "Unveiling Hidden Energy Poverty Using the Energy Equity Gap." Nature Communications. https://doi.org/10.1038/s41467-022-30146-5.

79 U.S. Energy Information Administration. 2023. "2020 Residential Energy Consumption Survey (RECS) Microdata." https://www.eia.gov/consumption/residential/data/2020/.

80 Gagiuc, A. 2023. "Building the Case for Passive House Standards." Multi-Housing News. https://www.multihousingnews.com/making-the-case-for-passive-house-standards/.

81 Federal Reserve Bank of St. Louis. 2023. "Producer Price Index by Industry: HVAC and Commercial Refrigeration Equipment, 2003-12-01 to 2023-05-01." https://fred.stlouisfed.org/series/PCU3334133341#0.

82 Walker, I. S., N. Casquero-Modrego, and B. D. Less. 2023. "Challenges and Opportunities for Home Decarbonization." Lawrence Berkeley National Laboratory. U.S. Department of Energy, Building Technology Office. https://escholarship.org/uc/item/60x7310p.

83 The White House. 2023. "Fact Sheet: One Year in, President Biden's Inflation Reduction Act Is Driving Historic Climate Action and

Investing in America to Create Good Paying Jobs and Reduce Costs." https://www.whitehouse.gov/briefing-room/statements-releases/2023/08/16/fact-sheet-one-year-in-president-bidens-inflation-reduction-act-is-driving-historic-climate-action-and-investing-in-america-to-create-good-paying-jobs-and-reduce-costs/.

84 O'Brien, C. 2022. "Despite Booming Labor Market, Incomes Are Not Keeping Up with Housing Costs Nationwide." Economic Innovation Group. https://eig.org/housing-affordability/.

85 U.S. Census Bureau. 2024. "Phase 4.0 Cycle 01 Household Pulse Survey: January 9 – February 5." February 22, 2024. https://www.census.gov/data-tools/demo/hhp/#/?measures=ENERGYBILL&areaSelector=040.

86 LendingClub. 2022. "Three in Five Americans Live Paycheck to Paycheck: More People Are Living Paycheck to Paycheck but Making Ends Meet Than Not Living Paycheck to Paycheck." https://ir.lendingclub.com/news/news-details/2022/Three-in-Five-Americans-Live-Paycheck-to-Paycheck-More-People-Are-Living-Paycheck-to-Paycheck-but-Making-Ends-Meet-Than-Not-Living-Paycheck-to-Paycheck/default.aspx.

87 Less, B. D., I.S. Walker, and N. Casquero-Modrego. 2021. Emerging Pathways to Upgrade the US Housing Stock: A Review of the Home Energy Upgrade Literature. Energy Technologies Area, Berkeley Lab. https://doi.org/10.2172/1777979.

88 Woody, T. 2023. "How Maine Became the Heat Pump Capital of the US." Bloomberg. https://www.bloomberg.com/news/articles/2023-10-06/how-maine-became-the-heat-pump-capital-of-the-us.

89 Jossi, F. 2021. "Heat Pumps, Already on the Rise in Rural Minnesota, Get Boost from New State Law." Energy News Network. https://energynews.us/2021/06/24/heat-pumps-already-on-the-rise-in-rural-minnesota-get-boost-from-new-state-law/.

90 IPCC. 2022. "Summary for Policymakers." In Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009325844.001.

91 U.S. Environmental Protection Agency. 2023. "Adapting to Heat." https://www.epa.gov/heatislands/adapting-heat.

92 U.S. Department of Energy, Office of Cybersecurity, Energy Security, and Emergency Response and Office of Energy Efficiency and Renewable Energy. 2022. Cybersecurity Considerations for Distributed Energy Resources on the U.S. Electric Grid. https://www.energy.gov/sites/default/files/2022-10/Cybersecurity%20Considerations%20for%20Distributed%20Energy%20Resources%20on%20the%20U.S.%20Electric%20Grid.pdf.

93 U.S. Environmental Protection Agency. 2021. "Climate Change and Social Vulnerability in the United States." https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf.

94 Pacific Northwest National Laboratory, National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, and Department of Energy. 2023. Enhancing Resiliency in Buildings through Energy Efficiency. https://www.energycodes.gov/sites/default/files/2023-07/Efficiency_for_Building_Resilience_PNNL-32727_Rev1.pdf.

95 Li, R., A. Satchwell, D. Finn, T. H. Christensen, M. Kummert, J. Le Dréau, R. A. Lopes, H. Madsen, J. Salom, G. Henze, and K. Wittchen. 2022. "Ten Questions Concerning Energy Flexibility in Buildings." Building and Environment. Volume 223, 109461. https://doi.org/10.1016/j.buildenv.2022.109461.

96 U.S. Environmental Protection Agency. 2021. "Climate Change Indicators: Heat-Related Deaths." https://www.epa.gov/climate-indicators/climate-change-indicators-heat-related-deaths.

97 U.S. Energy Information Administration. 2023. "2020 Residential Energy Consumption Survey (RECS) Microdata." https://www.eia.gov/consumption/residential/data/2020/.

98 U.S. Energy Information Administration. 2023. "2020 Residential Energy Consumption Survey (RECS) Microdata." https://www.eia.gov/consumption/residential/data/2020/.

99 U.S. Department of Housing and Urban Development. 2022. Annual Homeless Assessment Report, Part 1: By the Numbers. https://www.hud.gov/sites/dfiles/PA/documents/HUD-PIT-by-the-numbers.pdf.

100 U.S. Energy Information Administration. 2023. "2020 Residential Energy Consumption Survey (RECS) Microdata." https://www.eia.gov/consumption/residential/data/2020/.

101 U.S. Energy Information Administration. 2022. "2018 Commercial Buildings Energy Consumption Survey (CBECS) Microdata." https://www.eia.gov/consumption/commercial/data/2018/.

102 U.S. Energy Information Administration. 2023. "2020 Residential Energy Consumption Survey (RECS) Microdata." https://www.eia.gov/consumption/residential/data/2020/.

103 U.S. Energy Information Administration. 2022. "2018 Commercial Buildings Energy Consumption Survey (CBECS) Microdata." https://www.eia.gov/consumption/commercial/data/2018/.

104 Denholm, P., P. Brown, W. Cole, T. Mai, B. Sergi, M. Brown, P. Jadun, J. Ho, J. Mayernik, C. McMillan, and R. Sreenath. 2022. Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035. National Renewable Energy Lab. No. NREL/TP-6A40-81644. https://www.nrel.gov/docs/fy22osti/81644.pdf.

105 U.S. Energy Information Administration. 2023. "Reference Case Projections, Tables 4 and 5." Annual Energy Outlook 2023. https://www.eia.gov/outlooks/aeo/tables_ref.php.

106 For additional reference, the latest commercial building model code (ASHRAE Standard 90.1-2019) average site EUI is 46.3 kBtu/ft2 (see https://www.energycodes.gov/sites/default/files/2021-07/Standard_90.1-2019_Final_Determination_TSD.pdf), and the latest low-rise residential model code (IECC-R 2021) is 33.0 kBtu/ft2 (see https://www.energycodes.gov/sites/default/files/2021-07/2021_IECC_Final_Determination_AnalysisTSD.pdf), and the weighted average across the full residential and commercial building stock is 37 kBtu/ft2, so the 42 kBtu/ft2 (45% by 2050) site EUI goal is slightly less aggressive than completely renovating the existing building stock to the performance level of today's latest modeled energy code construction.

107 U.S. Department of Energy. 2021. Opaque Envelopes: Pathway to Building Energy Efficiency and Demand Flexibility. https://www1.eere.energy.gov/buildings/pdfs/80170.pdf.

108 Based on residential building and commercial square footage projections in the AEO 2023 microtables. https://www.eia.gov/outlooks/aeo/tables_ref.php.

109 Reyna, J., E. Wilson, A. Parker, A. Satre-Meloy, A. Egerter, C. Bianchi, M. Praprost, A. Speake, L. Liu, R. Horsey, M. Dahlhausen, C. CaraDonna, and S. Rothgeb. 2022. U.S. Building Stock Characterization Study: A National Typology for Decarbonizing U.S. Buildings. National Renewable Energy Laboratory. NREL/TP-5500-83063. https://www.nrel.gov/docs/fy22osti/83063.pdf.

110 Office of Energy Efficiency and Renewable Energy. "Building Performance Standards." https://www.energycodes.gov/BPS.

111 American Council for an Energy Efficient Economy. 2018. "Commercial and Multifamily Building Energy Benchmarking, Transparency, and Labeling in US Cities." https://www.aceee.org/sites/default/files/pdf/topic-benchmarking.pdf.

112 Natural Resources Defense Council. 2011. "Energy Efficiency Lease Guidance." https://www.nrdc.org/sites/default/files/CMI-FS-Energy.pdf.

113 Institute for Market Transformation. 2023. "U.S. City, County, and State Policies for Existing Buildings: Benchmarking, Transparency, and Beyond." https://www.imt.org/wp-content/uploads/2023/07/IMT-Benchmarking-Map-10132023-CURRENT-1-scaled.jpg.

114 Yale University. 2017. Health and Safety Barriers to Weatherization Study. Health-and-Safety-Barriers-study-final-report3-17-17.pdf (efficiencyforall.org).

115 U.S. Census Bureau. "American Housing Survey Table Creator, Housing Quality, 2021." American Housing Survey (AHS) - AHS Table Creator (census.gov).

116 U.S. Department of State and the United States Executive Office of the President. 2021. The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050. https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf; Larson, E., C. Greig, J. Jenkins, E. Mayfield, A. Pascale, C. Zhang, J. Drossman, R. Williams, S. Pacala, R. Socolow, E. Baik, R. Birdsey, R. Duke, R. Jones, B. Haley, E. Leslie, K. Paustian, and A. Swan. 2021. Net-Zero America: Potential Pathways, Infrastructure, and Impacts. Princeton University. https://netzeroamerica.princeton.edu/the-report; Williams, J. H., R. Jones, B. Haley, G. Kwok, J. Hargreaves, J. Farbes, and M. Torn. 2021. "Carbon-Neutral Pathways for the United States." AGU Advances. https://doi.org/10.1029/2020AV000284; Orvis, R. 2021. "A 1.5 Celsius Pathway to Climate Leadership for the United States." Energy Innovation. https://energyinnovation.org/wp-content/uploads/2021/02/A-1.5-C-Pathway-to-Climate-Leadership-for-The-United-States.pdf; Bistline, J., N. Abhyankar, G. Blanford, L. Clarke, R. Fakhry, H. Mcjeon, J. Reilly, C. Roney, T. Wilson, M. Yuan, and A. Zhao. 2022. "Actions for Reducing US Emissions at Least 50% by 2030." Science. https://doi.org/10.1126/science.abn0661.

117 Lee, M., and S. Billimoria. 2021. "Eight Benefits of Building Electrification for Households, Communities, and Climate." https://rmi.org/eight-benefits-of-building-electrification-for-households-communities-and-climate/.

118 Note that roughly 74 Mt CO_2 of on-site building fossil emissions (~12% of 2022 level) are categorized as "non-building" in the data and assumed to be addressed outside of the context of the 75% reduction target.

119 This contribution could increase with wider use of electric equipment such as heat pumps that may require larger quantities of refrigerant than systems that only provide air conditioning. For example, in Langevin et al., refrigerant emissions are estimated to increase by ~67 Mt CO_2e by 2050, or roughly 60% over HFC levels in 2021. (See https://doi.org/10.1016/j.oneear.2023.07.008.) U.S. Environmental Protection Agency. "Greenhouse Gas Inventory Data Explorer." https://cfpub.epa.gov/ghgdata/inventoryexplorer/#residential/entiresector/allgas/category/all.

120 American Innovation and Manufacturing (AIM) Act of 2020, 42 USC 7675.

121 U.S. Environmental Protection Agency. 2023. "Frequent Questions on the Phasedown of Hydrofluorocarbons." https://www.epa.gov/climate-hfcs-reduction/frequent-questions-phasedown-hydrofluorocarbons.

122 U.S. Department of State. 2016. Pollution: Depletion of the Ozone Layer; Agreement between the United States of America and Other Governments. https://www.state.gov/wp-content/uploads/2023/04/23-129-Kigali-Amendment-to-the-Montreal-Protocol-on-Depletion-of-the-Ozone.pdf.

123 PG&E. 2022. Service Upgrades for Electrification Retrofits Final Study Report. https://pda.energydataweb.com/api/view/2635/Service%20Upgrades%20for%20Electrification%20Retrofits%20Study%20FINAL.pdf.

124 Waite, M., and V. Modi. 2020. "Electricity Load Implications of Space Heating Decarbonization Pathways." Joule. https://doi.org/10.1016/j.joule.2019.11.011.

125 IBISWorld. 2023. "Heating & Air-Conditioning Contractors in the US - Number of Businesses 2004–2029." https://www.ibisworld.com/industry-statistics/number-of-businesses/heating-air-conditioning-contractors-united-states/.

126 Goetzler, W., T. Sutherland, M. Rassi, and J. Burgos. 2014. “Research & Development Roadmap for Next-Generation Low Global Warming Potential Refrigerants.” https://www.energy.gov/eere/buildings/articles/research-development-roadmap-next-generation-low-global-warming-potential.

127 National Renewable Energy Laboratory. 2022. 100% Clean Electricity by 2035 Study. https://www.nrel.gov/analysis/100-percent-clean-electricity-by-2035-study.html.

128 Specifically, VPPs are aggregations of distributed energy resources such as rooftop solar with behind-the-meter (BTM) batteries, electric vehicles (EVs) and chargers, electric water heaters, smart buildings and their controls, and flexible commercial and industrial (C&I) loads that can deliver electrical load balancing and provide utility-scale and utility-grade grid services like a traditional power plant. See also: https://liftoff.energy.gov/vpp/ and https://www.brattle.com/wp-content/uploads/2023/04/Real-Reliability-The-Value-of-Virtual-Power_5.3.2023.pdf.

129 Lawrence Berkeley National Laboratory. “Building Technology & Urban Systems Division: Demand Response Research Center.” https://buildings.lbl.gov/demand-response.

130 Satchwell, A., M. A. Piette, A. Khandekar, J. Granderson, N. M. Frick, R. Hledik, A. Faruqui, L. Lam, S. Ross, J. Cohen, K. Wang, D. Urigwe, D. Delurey, M. Neukomm, and D. Nemtzow. 2021. A National Roadmap for Grid-Interactive Efficient Buildings. https://gebroadmap.lbl.gov/.

131 Smart Electric Power Alliance. 2019. 2019 Utility Demand Response Market Snapshot. https://sepapower.org/resource/2019-utility-demand-response-market-snapshot/.

132 Federal Energy Regulatory Commission (FERC). “FERC Order No. 2222 Fact Sheet.” https://www.ferc.gov/media/ferc-order-no-2222-fact-sheet.

133 U.S. Department of Energy. 2023. Pathways to Commercial Liftoff: Virtual Power Plants. https://liftoff.energy.gov/wp-content/uploads/2023/10/LIFTOFF_DOE_VVP_10062023_v4.pdf.

134 Greenhouse Gas Protocol. 2013. Corporate Value Chain (Scope 3) Accounting and Reporting Standard: Supplement to the GHG Protocol Corporate Accounting and Reporting Standard. https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf.

135 Carbon Leadership Forum (CLF). 2020. “Embodied Carbon 101.” CLF Policy Primer Series. https://carbonleadershipforum.org/embodied-carbon-101/.

136 Advanced Building Construction Collaborative. https://advancedbuildingconstruction.org/. The ABC Collaborative “employs industrialized construction and innovative building technologies with a focus on energy efficiency, reduced greenhouse gas emissions, streamlined project delivery, and high-quality yet cost-effective building techniques and materials.”

137 International Energy Agency for the Global Alliance for Building and Construction, United Nations Environment Programme. 2018. 2018 Global Status Report. https://www.iea.org/reports/2018-global-status-report.

138 Cabeza, L.F., Q. Bai, P. Bertoldi, J.M. Kihila, A.F.P. Lucena, É. Mata, S. Mirasgedis, A. Novikova, and Y. Saheb. 2022. “Buildings.” In Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009157926.011. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter09.pdf.

139 See Figure 9.3 of Cabeza, L. F., Bai, Q., Bertoldi, P., Kihila, J.M., Lucena, A.F.P., Mata, É., Mirasgedis, S., Novikova, A., and Saheb, Y. 2022. Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/.

140 The residential construction portion of this estimate (100–200 Mt CO_2e/yr) was based on two studies: Berrill, P., E. J. H. Wilson, J. L. Reyna, A. D. Fontanini, and E. G. Hertwich. 2022. “Decarbonization Pathways for the Residential Sector in the United States.” Nature Climate Change 12, 712–718. https://doi.org/10.1038/s41558-022-01429-y; and Pauliuk, S., N. Heeren, P. Berrill, T. Fishman, A. Nistad, Q. Tu, P. Wolfram, and E.G. Hertwich. 2021. Global scenarios of resource and emission savings from material efficiency in residential buildings and cars. Nature Communications. https://doi.org/10.1038/s41467-021-25300-4. Berrill et al. estimate 89 Mt/yr for residential construction and 8.6 Mt/yr for residential renovations. Pauliuk et al. estimate 181.1 Mt/yr for the U.S. residential construction sector; the discrepancy is likely due to different assumptions of concrete usage (based on personal communication with an author).

The commercial construction portion of this estimate (100–200 Mt CO_2e/yr) was based on data from 2017 Carbon Leadership Forum 2017 Embodied Carbon Benchmark Study V1, https://carbonleadershipforum.org/lca-benchmark-database/. Analysis of this dataset shows a mean embodied emissions intensity (LCA stage A) for North American commercial buildings of 469 kgCO_2e/m2. Applying this factor to the 2.0 billion ft2/yr of commercial construction forecast by EIA’s Annual Energy Outlook (U.S. Energy Information Administration. 2023. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=5-AEO2023&cases=ref2023&sourcekey=0) yields 87 Mt CO_2e/yr.

Together these estimates yield a the range of 184–268 Mt CO_2e/yr, which was increased to a range of 200–400 Mt CO_2e/yr to account for additional uncertainty in the estimates. The midpoint of this range (300 Mt CO_2e/yr) was used throughout the Blueprint to calculate percentages, such as the 5% listed in Figure 3.

141 Esau, R., M. Jungclaus, V. Olgyay, and A. Rempher. 2021. Reducing Embodied Carbon in Buildings: Low-Cost, High-Value Opportunities. https://rmi.org/wp-content/uploads/dlm_uploads/2021/08/Embodied_Carbon_full_report.pdf.

142 The percentages listed in this paragraph are based on the breakout of buildings-sector related emissions presented in Figure 3 and the *Contributions to U.S. Greenhouse Gas Emissions* section.

143 U.S. Energy Information Administration. 2022. "2018 CBECS Survey Data." Commercial Buildings Energy Consumption Survey. https://www.eia.gov/consumption/commercial/data/2018/.

144 HEET. 2023. "Networked Geothermal: The National Picture." https://heet.org/2023/04/17/networked-geothermal-the-national-picture/.

145 U.S. Department of Energy. 2024. "National Definition for a Zero Emissions Building." https://www.energy.gov/eere/buildings/national-definition-zero-emissions-building.

146 U.S. Department of Housing and Urban Development (HUD). 2023. Press Release HUD No. 23-271. HUD and DOE Announce New Partnership to Decarbonize U.S. Building Sector at COP28. https://www.hud.gov/press/press_releases_media_advisories/hud_no_23_271.

147 Consortium for Energy Efficiency. 2021. 2020 State of the Efficiency Program Industry. https://cee1.org/images/uploads/2020_AIR_Final.pdf.

148 Appliance Standards Awareness Project. 2023. "States." https://appliance-standards.org/states.

149 South Coast Air Quality Management District. 2018. Board Meeting Agenda (No. 26). https://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2018/2018-july6-026.pdf. Appliance Standards Awareness Project. 2023.

150 Dadashi, H., C. Horowitz, and J. Stein. 2022. How Air Districts Can End NOx Pollution from Household Appliances. https://law.ucla.edu/sites/default/files/PDFs/Publications/Emmett%20Institute/PritzkerBrief_NOx.pdf.

151 DiMascia, M. 2021. Five States Set Appliance Efficiency Standards in Banner Year. https://www.aceee.org/blog-post/2021/08/five-states-set-appliance-efficiency-standards-banner-year.

152 Global Electronics Council. 2023. Electronic Product Environmental Assessment Tool (EPEAT) for Solar. https://globalelectronicscouncil.org/epeat-solar-panels-inverters/.

153 Department of Energy. Green Button Open Energy Data. https://www.energy.gov/data/green-button.

154 Gold, R., A. Gilleo, and W. Berg. 2019. Next-Generation Energy Efficiency Resource Standards. American Council for an Energy Efficiency Economy. https://www.aceee.org/sites/default/files/publications/researchreports/u1905.pdf.

155 Hawaii Public Utilities Commission. Performance Based Regulation. https://puc.hawaii.gov/energy/pbr/.

156 U.S. Department of Housing and Urban Development (HUD). 2023. Press Release HUD No. 23-072. HUD Takes Action to Highlight and Research Land Use and Zoning Reforms. https://www.hud.gov/press/press_releases_media_advisories/hud_no_23_072.

157 AHRI. 2023. Twenty Year Graphs. https://www.ahrinet.org/analytics/statistics/historical-data.

158 American Housing Survey (AHS) Table Creator. 2021 National — Home Improvement Costs — Owner-occupied Units. https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html?s_areas=00000&s_year=2021&s_tablename=TABLE16&s_bygroup1=1&s_bygroup2=1&s_filtergroup1=1&s_filtergroup2=1.

159 Building Energy Codes Program. https://public.tableau.com/app/profile/doebecp.

160 EUI is chosen as a more direct indicator of progress on efficiency than overall energy demand. For example, in the past 20 years, overall building demand has remained relatively flat, which masks significant improvements in efficiency that have offset growth in the building stock and are captured by an examination of EUI changes over this period.

161 For example, a 2.6-3.1X increase in power grid generation capacity is projected under the moderate to aggressive grid decarbonization cases in the absence of additional demand-side efficiency and flexibility measure deployment in "Demand-Side Solutions in the US Building Sector Could Achieve Deep Emissions Reductions and Avoid Over $100 Billion in Power Sector Costs," https://doi.org/10.1016/j.oneear.2023.07.008.

162 Hledik, R., A. Faruqui, T. Lee, and J. Higham. "The National Potential for Load Flexibility: Value and Market Potential through 2030." https://www.brattle.com/wp-content/uploads/2021/05/16639_national_potential_for_load_flexibility_-_final.pdf.

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LIST OF ACRONYMS

AEO	Annual Energy Outlook
AFFECT	Assisting Federal Facilities with Energy Conservation Technologies grant (DOE)
AIM Act	American Innovation and Manufacturing Act of 2020
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIL	Bipartisan Infrastructure Law
BPS	Building performance standards
BTO	Building Technologies Office (DOE)
CBECS	Commercial Buildings Energy Consumption Survey (EIA)
CDFI	Community development financial institution
CO2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
DEIA	Diversity, equity, inclusion, and accessibility
DER	Distributed energy resource
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
DR	Demand response
EERS	Energy efficiency resource standards
E&I	Enhancements & Innovations grant (BIL)
EI	Energy Innovation
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPD	Environmental product declaration
EPEAT	Electronic Product Environmental Assessment Tool (EPA)
EUI	Energy use intensity
EV	Electric vehicle
FEMA	Federal Emergency Management Agency
FEMP	Federal Energy Management Program
FERC	Federal Energy Regulatory Commission
GHG	Greenhouse gas
GSA	General Services Administration
GWP	Global warming potential
HFC	Hydrofluorocarbon
HIT	High Impact Technologies catalyst program (DOE)
HUD	U.S. Department of Housing and Urban Development
HVAC	Heating, ventilation, and air conditioning
kWh	Kilowatt-hour
LEED	Leadership in Energy and Environmental Design
LMI	Low-to-moderate income
LTS	Long-Term Strategy of the United States
NH_3	Ammonia
NO_x	Nitrogen oxides
$PM_{2.5}$	Particulate matter 2.5 micrometers or smaller
PV	Photovoltaics
R&D	Research and development
SCEP	Office of State and Community Energy Programs (DOE)
SERC	Sustainable Energy Resources for Consumers grant (BIL)
SO_2	Sulfur dioxide
TEN	Thermal energy network
U.N.	United Nations
VOC	Volatile organic compound
VPP	Virtual power plant
WBLCA	Whole building life cycle assessment

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