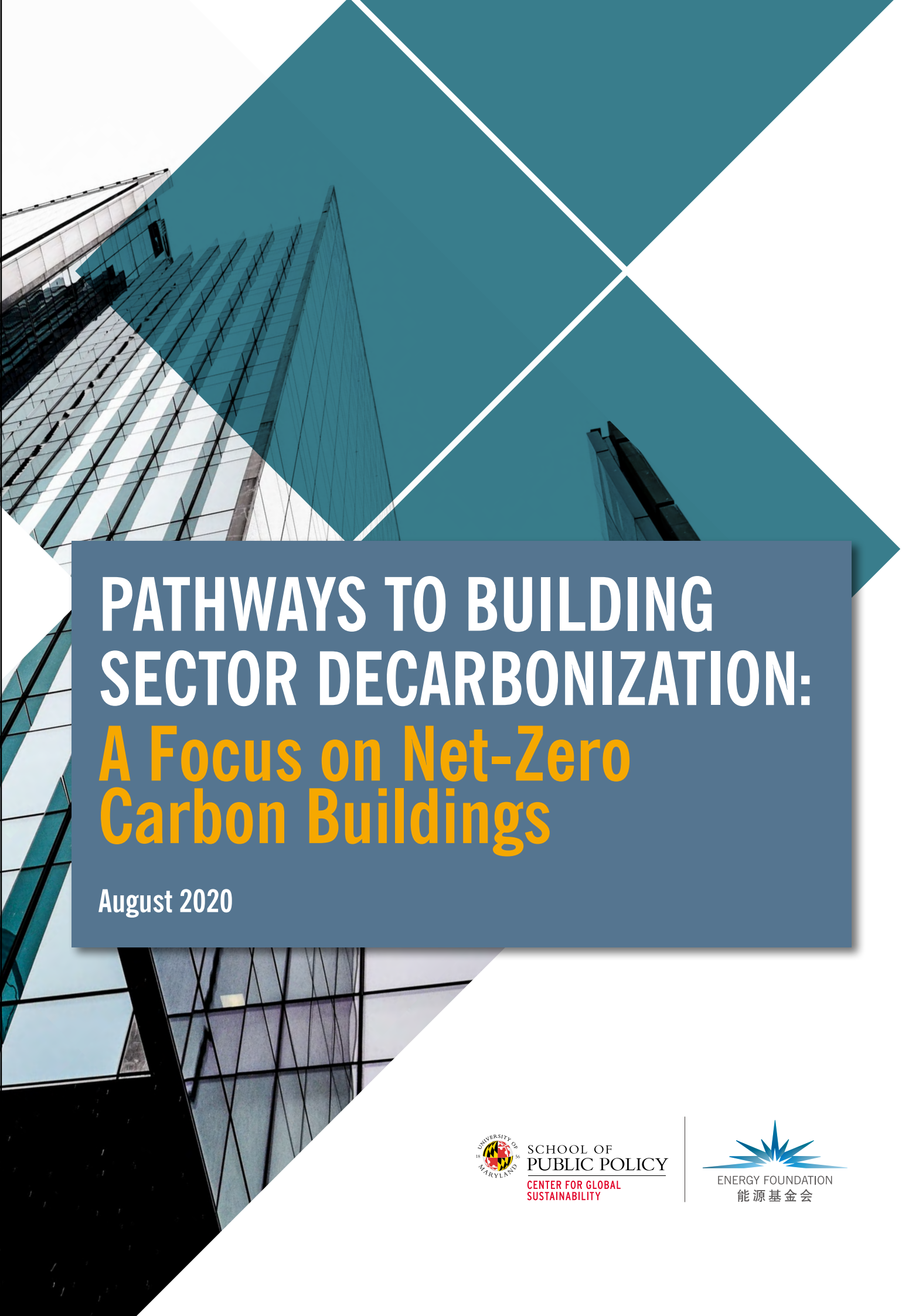

PATHWAYS TO BUILDING SECTOR DECARBONIZATION:

A Focus on Net-Zero Carbon Buildings

August 2020

SCHOOL OF PUBLIC POLICY
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This report was researched and prepared by:

John O'Neill	University of Maryland Center for Global Sustainability
Sha Yu*	Pacific Northwest National Laboratory & University of Maryland
Christina Bowman	University of Maryland Center for Global Sustainability
Jiawei Song	University of Maryland Center for Global Sustainability

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* Corresponding author. Contact: sha@umd.edu.

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LIST OF ACRONYMS AND ABBREVIATIONS

AB	Assembly Bill
ABC	A Better City
ACEEE	American Council for an Energy Efficient Economy
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BEES	Building Energy Efficiency Standards
BERDO	Building Energy Reporting and Disclosure Ordinance
BPDA	Boston Planning and Development Agency
BU	Boston University
BUILD	Building Initiative for Low-Emissions Development
CAL Green	California Green Buildings Standards Code
CARB	California Air Resources Board
CASE	Codes and Standards Enhancement Initiative
CEC	California Energy Commission
CFB	Carbon Free Boston
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CPUC	California Public Utilities Commission
DOE	Department of Energy
ED	Environment Department
EED	Energy Efficiency Directive
EO	Executive Order
EPA	Environmental Protection Agency
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EPS	Emissions Performance Standard
ESCO	Energy Services Company
EU	European Union
EUI	Energy Use Intensity
FEMP	Federal Energy Management Program
GHG	Greenhouse gas
GRC	Boston Green Ribbon Commission
HERS	Home Energy Rating System
HVAC	Heating, Ventilation, and Air Conditioning
ICC	International Code Council
IECC	International Energy Conservation Code
IOU	Investor-owned Utility
ISE	Institute for Sustainable Energy
LED	Light-emitting Diode
LEED	Leadership in Energy and Environmental Design
NBI	New Buildings Institute
NGO	Non-governmental Organization
O&E	Outreach and Education
PACE	Property-Assessed Clean Energy
PV	Photovoltaic
REN	Regional Energy Network
SB	Senate Bill
TAG	Technical Advisory Group
TECH	Technology and Equipment for Clean Heating
ZNC	Zero Net Carbon
ZNE	Zero Net Energy

EXECUTIVE SUMMARY

The global building stock already accounts for 40% of global carbon dioxide (CO_2) emissions, and is still expected to double in size by 2050.[1] Because of their footprint and long lifetimes (60% of the existing building stock will still be in use in 2050), buildings present both a promising opportunity and a daunting challenge in the effort to reduce greenhouse gas (GHG) emissions to net-zero.[2] Though the technologies needed to decarbonize buildings already exist, the sector faces barriers that make effective policy design a challenge, from slow turnover to conflicting incentives. Many new and innovative approaches have arisen in recent years to address these barriers, especially as governments address climate change with increasing urgency.

Countries, states, and cities are exploring options to decarbonize the building sector. This report describes a set of policy opportunities to achieve net-zero carbon/energy buildings that are potentially broadly applicable. It first reviews six approaches to building decarbonization policy in the US and Europe, highlighting best practices and examples from jurisdictions using these approaches to drive transformational change. Next, this report focuses on net-zero building goals as an effective policy framework for sector-wide decarbonization. Building on broad policy pathways, it provides in-depth analysis of two US jurisdictions with ambitious net-zero building goals – Boston, Massachusetts, and the State of California. This report details the motivations, challenges, and strategies of developing, implementing, and enforcing such policies in these two jurisdictions. Based on this analysis, informed by interviews with policymakers and researchers, we present a set of strategies for enhancing building policies in the near term and constructing policy pathways to achieve net-zero building goals.

BUILDING DECARBONIZATION POLICY IN THE US AND EUROPE: AN OVERVIEW

Building decarbonization policies can be grouped into six broad categories: building energy codes and standards; monitoring, benchmarking, and disclosure; building electrification; net-zero buildings; building efficiency retrofits; and financial incentives (see Table ES-1).

These reflect six approaches taken by jurisdictions seeking to decarbonize buildings. The approaches are not mutually exclusive, since some are centered around methods (e.g. codes and standards), whereas others are centered around goals (e.g. net-zero buildings). We summarize best practices from leading jurisdictions that are using these six broad approaches to drive transformational change in the building sector. We elucidate the motivations behind these best practices and provide real-world examples of successfully implemented policies.

TABLE ES-1. POLICY APPROACHES FOR BUILDING DECARBONIZATION

Policy Approach	Best Practices for Transformational Change
Building Energy Codes and Standards	■ Performance-based and/or outcome-based code compliance ■ Offer stretch codes for sub-jurisdictions toward net-zero buildings ■ Mandate stringent (e.g. net-zero) codes for publicly owned buildings ■ Institute net-zero carbon building codes for all new buildings ■ Announce code updates and goals years before they will take effect
Monitoring, Benchmarking, and Disclosure	■ Make building performance data publicly available ■ Use data from disclosure policies to inform future policy design ■ Make disclosure mandatory for most, if not all, buildings ■ Build upon disclosure toward policies that mandate action ■ Track emissions performance instead of just energy performance
Building Electrification	■ Reduce emissions from all energy sources supplying buildings ■ Encourage electrification of building energy loads ■ If feasible, move from incentivizing electrification to mandating it
Net-Zero Buildings	■ Expand the definition of net-zero beyond individual buildings ■ Lead by example: achieve net-zero performance in public buildings ■ Build market capacity for net-zero buildings, then incorporate net-zero standards into mandatory building codes ■ Aim for net-zero in existing buildings as well as in new buildings ■ Account for embodied emissions in net-zero carbon definitions
Building Efficiency Retrofits	■ Combine retrofit incentives with monitoring, benchmarking, and disclosure policies ■ Leverage future energy savings to pay for upfront costs of retrofits ■ Pursue comprehensive retrofits that achieve net-zero performance and electrification ■ Move beyond incentivizing retrofits to mandating them
Financial Incentives	■ Target most financial incentives at existing buildings, not new buildings ■ Leverage future energy savings to pay for upfront costs ■ Invest public finance to leverage private finance ■ Design custom programs to target specific barriers to decarbonization

NET-ZERO BUILDINGS AS A FOCUS FOR ACTION

High-ambition climate action in the building sector has frequently and increasingly focused on net-zero buildings – a trend gaining popularity for several reasons. First, net-zero is ambitious. It is the pinnacle of building design, construction, and operation, integrating efficient performance with renewable energy generation. Second, while not easily defined in practice, net-zero is an intuitive, straightforward, and easily communicated concept. It can be a powerful messaging tool to guide sector-wide policy efforts and mobilize stakeholders toward a single unified goal. Finally, the ambition, but flexibility, of a performance-based net-zero standard inspires innovation in building materials, design, and construction as the industry as a whole works toward net-zero buildings.

The policy tools used to achieve net-zero buildings vary and include mandatory standards, financial incentives, research and development, education and outreach, and lead-by-example programs. A successful approach to net-zero buildings will employ an array of these policies, which may be influenced by a jurisdiction's unique political, economic, and institutional context. Certain policy options may not always be available, and contextual variations can set unique limitations. This unfortunately means there is no universal checklist that guarantees success. However, in analyzing the following in-depth case studies (and drawing from the broad overview of building sector policies), several key strategies emerge for developing net-zero building policies. While these strategies may not guarantee success in all contexts, they are proven strategies that can help any jurisdiction address barriers and achieve its net-zero building goals.

Boston's Policies on Net-Zero Buildings

Boston is one of the United States' leading cities on building decarbonization, and a notable case study for multiple reasons. First, the city's policies are informed heavily by rigorous technical analysis and stakeholder engagement. Second, Boston's net-zero goals are sector-wide, focusing on new and existing buildings alike. Third, the city leads as a "first-mover" by achieving net-zero carbon in city owned buildings. Fourth, the city takes an integrated approach, developing policies to address direct and indirect emissions from buildings. Finally, the city pursues its goals with innovative, unconventional policy tools, such as green building zoning.

Boston's definition of a Zero-Net Carbon (ZNC) building does not account for embodied emissions and includes four tiers: ZNC-onsite, ZNC-offsite, ZNC-ready, and ZNC-convertible, to provide flexibility for different building typologies and encourage buy-in from skeptical developers. The city selects the most stringent tier feasible for new developments.

Boston's decarbonization goals are some of the most ambitious in the country, including net-zero carbon emissions citywide by 2050 and sector-specific targets, like all net-zero new construction by 2030 and net-zero emissions from the entire building sector by 2050. To achieve these goals, the city implements multiple policy tools, outlined in Table ES-2.

TABLE ES-2: KEY POLICY TOOLS FOR NET-ZERO BUILDINGS IN BOSTON

Policies Focused on New Buildings	■ ZNC requirement for new municipal buildings and affordable housing ■ E+ Green Building ZNC demonstration program ■ ZNC requirements for Green Building Zoning (in development)
Policies Focused on Existing Buildings	■ Renew Boston Trust retrofit funding program ■ Building Energy Reporting and Disclosure Ordinance (BERDO), which includes mandatory energy-saving actions ■ Emissions Performance Standard (EPS) (in development)
Additional Supporting Policy Efforts	■ Technical education and training programs to develop a clean energy workforce ■ Working with the state to incorporate ZNC into the Stretch Energy Code ■ Working with the state to set a 100% clean energy commitment by 2050

Stakeholder engagement is a priority in Boston. The Climate Action Plan was developed using the rigorous independent analysis of the Carbon Free Boston (CFB) report. The report's recommendations were thoroughly vetted with extensive citizen engagement, including from marginalized communities, which directly impacted the policy tools Boston chose to prioritize.

City officials still face barriers to effective policy implementation. One is perceived high cost of ZNC buildings. Developers assume they are prohibitively expensive, but CFB analysis indicates they can often be delivered at little additional cost. The city's lead-by-example approach helps demonstrate the cost-effectiveness of ZNC buildings. Natural gas utilities are another barrier. Per CFB analysis, electrification is the most cost-effective way to reach net-zero emissions in Boston's buildings. Natural gas utilities, which might be negatively affected by electrification, propose using renewable natural gas instead. The city is pursuing more analysis to understand the benefits and tradeoffs of renewable gas, but it will likely play a limited role.

Financial incentives at the city and state level focus largely on retrofits since they are often more difficult to finance than new construction. Renew Boston Trust funds comprehensive municipal retrofits and may eventually expand to the private sector. Such deep retrofits are expensive, and the city has limited resources. State and utility incentives generally do not support deep retrofits, but Boston's climate goals call for over 2,000 such projects per year. Achieving this will require a significant increase in state and/or federal investment, plus the mobilization of private capital.

Boston's lead-by-example and workforce development programs are designed to transform the market and make ZNC the norm for new construction. They gradually build to the mandatory commercial standards being developed by increasing demand for high-performance buildings and fostering a workforce capable of meeting the necessary pace of ZNC retrofits and new construction. BERDO contributed to this too by forcing building owners to conduct energy audits and energy-saving actions, which built up a more robust energy services market.

Enforcement and verification are also important to Boston's efforts. State energy codes are enforced locally, and as Boston lobbies for a ZNC Stretch Energy Code, they rigorously enforce the existing code. The state requires energy efficiency training for all local building officials and provides them with free training. Still, buildings often underperform code requirements. BERDO has improved this performance gap somewhat by making building data more accessible and encouraging communication between stakeholders. The city has also promoted green leases to address split incentives. BERDO is enforced with punitive fines, but free training materials and compliance guides help owners achieve compliance. The city is also investigating the legality of using BERDO data to enforce Green Building Zoning Standards based on actual performance.

Boston's future policy priorities are developing an EPS to build upon BERDO and increasing Green Building Zoning requirements to a ZNC standard. Stakeholder engagement and analysis are underway to determine how to implement these policies. One innovative approach under investigation is a carbon linkage fee, which would assess a fee proportional to a development's GHG emissions. Revenue could fund community solar, affordable housing retrofits, or even climate adaptation. The city is also considering an onsite solar mandate for new development.

California's Policies on Net-Zero Buildings

California, the largest state in the US, is another case study that warrants a closer look. First, California spans multiple climate zones, presenting challenges for statewide policy. Second, California's local policy landscape is ambitious and diverse. Third, enforcement of its building code is a top priority. Fourth, the state prioritizes renewable electricity and electrification as part of a broader, economywide decarbonization effort. And finally, the state has adapted its policies over time to respond to changing market conditions.

California's ambitious goals have been approved into binding law by the state legislature. They include net-zero emissions statewide and 100% carbon-free electricity by 2045. New public buildings must already be zero-net energy (ZNE), and the state hopes to retrofit at least 50% of existing public buildings to ZNE by 2025. Embodied energy is not included in California's ZNE definition, though it incorporates flexibility by allowing ZNE portfolios, campuses, and communities. A summary of the state's key policy tools can be found in Table ES-3.

TABLE ES-3: KEY POLICY TOOLS FOR NET-ZERO BUILDINGS IN CALIFORNIA

Policies Focused on New Buildings	■ ZNE requirement for state owned buildings ■ Building Energy Efficiency Standards (BEES), which have been gradually building toward a ZNE standard ■ CALGreen Green Building Standards intended to reduce indirect emissions from the building sector ■ Building Initiative for Low-Emissions Development (BUILD), which incentivizes all-electric new buildings
Policies Focused on Existing Buildings	■ Building Energy Benchmarking program ■ Technology and Equipment for Clean Heating (TECH) Initiative, which develops the market for building electrification technology ■ Miscellaneous programs that support municipalities, universities, schools, and hospitals pursuing high-performance buildings
Additional Supporting Policy Efforts	■ Cap-and-trade emissions pricing scheme ■ Statewide renewable portfolio standard ■ Time-of-use electricity rates

Local policy is a striking feature of California's decarbonization efforts. In California, cities may enact "reach codes," which many have done. Most notably, 20 California municipalities have banned natural gas in new construction, effectively mandating building electrification. Several also have benchmarking ordinances that are stricter than the state Building Energy Benchmarking program. The state works with investor-owned utilities (IOUs) and non-governmental organizations (NGOs) to help municipalities develop their reach codes. Regional energy networks (RENs) are collaborations of local governments that fill gaps in IOU incentive offerings by providing their own incentives and financial products such as Property-assessed Clean Energy (PACE) financing, low-interest loans, and capital equipment lease agreements.

For five years, the state's goal has been to build the BEES toward a mandatory ZNE standard for residential buildings. After extensive stakeholder engagement, the ZNE action plan emphasized using ZNE as a messaging tool to align state and local efforts. A solar mandate was incorporated, though the state did not end up mandating ZNE, since the California Energy Commission (CEC) may only implement cost-effective standards. The latest standards are still quite stringent, and the solar mandate increases statewide renewable generation. But more importantly, the process of mobilizing the entire industry around a ZNE goal spurred advances in local policy, financing, and grid integration, all key elements of a zero-carbon building sector.

California's push to electrify buildings involves addressing various disincentives. The CEC developed all-electric baseline compliance pathways in the BEES for residential buildings, meaning natural gas is no longer the default. Archaic laws that discouraged fuel-switching were modified to encourage building electrification. IOUs are fully decoupled, so their revenue does not depend on energy sales, enabling IOUs to whole-heartedly pursue efficiency programs.

Enforcement of California's BEES is a top priority. The CEC created the BEES Outreach and Education (O&E) Unit to educate stakeholders and local enforcement agencies. The CEC also leverages the resources of IOUs and RENs, which both manage code enforcement programs. The state's Home Energy Rating System (HERS) requires state-approved inspections any time residential HVAC systems are installed or replaced. For commercial buildings, Acceptance Testing must occur at construction to verify proper installation of lighting controls and mechanical systems. New commercial buildings also face an extensive commissioning process.

California's future policy efforts depend in part on legislative authority. The CEC lacks the authority to regulate building standards on the basis of GHG emissions - only energy use and cost-effectiveness. While electrification is typically in line with these goals, in some cases, fossil fuel systems may be cheaper or more efficient. However, there is some expectation that the CEC might be granted this authority in the future. If this happens, California's efforts will likely focus on developing an EPS and may also change the baseline compliance pathway in the BEES to an all-electric model. The CEC has already begun developing a carbon accounting standard which could inform a future EPS. Demand flexibility is another focus of California's future efforts, which may be addressed with higher resolution in time-of-use rates or emissions-based pricing. Finally, policymakers are considering an energy storage mandate. This depends on future prices of home storage systems, as BEES must be cost-effective.

KEY TAKEAWAYS: STRATEGIES TO MOVE TOWARD NET-ZERO BUILDINGS

Countries, states, and cities are considering options to transform their building stock and move toward more efficient, less carbon-intensive buildings. The Boston and California case studies yield valuable insight into how to pursue ambitious building decarbonization policies. Based on these case studies, and drawing from the overview of building policy in the US and Europe, we identify several policy tools to promote net-zero buildings. We also present supporting strategies to optimize policy design and implementation.

There is no shortage of policy tools that can be used to encourage the proliferation of net-zero buildings, as this report elucidates. Below are a select few that have been proven to be among the most impactful, though it should be noted that in certain contexts, other policies may be equally effective or more feasibly implemented.

TABLE ES-4: POLICY TOOLS FOR ACHIEVING NET-ZERO BUILDINGS

Tool 1: Net-Zero Building Codes	While building codes are traditionally "backstop" policies that ensure bare minimum performance, jurisdictions should rethink these policies and increase their stringency to net-zero. Well-established enforcement infrastructure and strong stakeholder relationships make building codes a powerful tool to transform the building sector.
Tool 2: Emissions Performance Standards	A well-designed Emissions Performance Standards should be outcome-based and ratchet down predictably over time toward net-zero emissions to allow building owners to pursue the most cost-effective path to required emissions reductions. Emissions-based policies also encourage electrification, an essential strategy for building decarbonization.
Tool 3: Green Zoning Requirements	In jurisdictions without authority to set building codes, zoning policies can be used to decarbonize buildings. This could take many forms, from prescriptive actions (e.g. new developments must undergo a net-zero carbon feasibility study) to financial incentives (e.g. density bonuses for new net-zero buildings). The approval process can be treated as a negotiation, where policymakers can convince developers to implement net-zero buildings.
Tool 4: Benchmarking and Disclosure	A comprehensive disclosure policy provides data that can inform future net-zero policy design and can be used to monitor policy outcomes and manage enforcement.
Tool 5: District Energy Systems	District energy systems are highly efficient and make communities more resilient. Expanding these systems can significantly reduce emissions in the short run. However, it is essential to develop a long-term plan for decarbonizing district energy using renewables, carbon-neutral fuels, or carbon capture, or district energy could lead to lock-in of future emissions.

Policy does not exist in a vacuum; its effectiveness depends on far more than just the words included in a rule or ordinance, such as the political context, implementation and enforcement mechanisms, and capacity of stakeholders to act. Therefore, these policy tools should not be implemented without careful consideration of the following supporting strategies.

TABLE ES-5: POLICY STRATEGIES TO SUPPORT NET-ZERO BUILDINGS

Strategy 1: Lead by Example	Jurisdictions should require net-zero performance in their own buildings before demanding the same of private buildings. This helps develop the market and demonstrates to private developers the benefits and achievability of net-zero buildings.
Strategy 2: Net-Zero as a Messaging Tool	Net-zero is an intuitive, easily communicated concept, which can be effective at aligning the many stakeholders in the building sector behind a common goal.
Strategy 3: Flexible Approach	Incorporating flexibility into net-zero definitions (such as a tiered or portfolio-wide definition of net-zero) increases cost-effectiveness, stakeholder buy-in, and compliance.
Strategy 4: Stakeholder Engagement	Engagement must be comprehensive, begin early, prioritize underrepresented communities, and occur continuously throughout policy implementation. It is a constant responsibility, not a step to complete once.
Strategy 5: Prioritize Compliance	Policies are only effective if they are well-enforced. Stakeholder engagement, training and education, and compliance mechanisms, such as rigorous inspection and commissioning, can maximize compliance.
Strategy 6: Integrated, data-driven policy design	Policy should be grounded in robust analysis to ensure the most cost-effective and direct pathway to decarbonization is being pursued. Analysis must recognize the building sector's linkages to other sectors, such as transportation and power generation.
Strategy 7: Policy Alignment	Aligning policy at all levels of government (and even within a single government) can eliminate contradictory incentive structures that hinder building decarbonization.
Strategy 8: Mandatory Programs	Mandates are preferable to voluntary programs, though mandates may require enabling policies (e.g. workforce development, market transformation, education/outreach, and financial assistance) to build capacity for compliance.
Strategy 9: Just Transition	The benefits of a decarbonized building sector must be shared by all. Among other things, housing must remain affordable, energy burdens must be minimized, a robust clean energy workforce must provide employment opportunities.
Strategy 10: Financing	Financing should be designed to use future energy savings to pay for upfront costs. Incentive programs should be promoted to maximize their impact and should be designed to target specific barriers like split incentives and energy poverty. Limited public resources can be maximized by using public investment to leverage greater private investment.

The policies and strategies recommended above should not be viewed as a comprehensive checklist that guarantees success. Policy effectiveness is heavily dependent on context, such as political will, jurisdictional authority, existence of other policies, and many other factors. In some cases, different tools and strategies may be more effective than those listed here. However, these tools and strategies have yielded significant results in Boston and California and will be effective in most jurisdictions. The policy tools are transformative mechanisms that can help jurisdictions build upon existing policy frameworks to reach net-zero building goals. The policy strategies provide necessary support to ensure these tools are designed, implemented, and enforced effectively. By following this framework, jurisdictions worldwide can become leaders themselves in the global effort to decarbonize the building stock.

1. INTRODUCTION

Construction and operation of buildings already account for 40% of global CO_2 emissions – and the building stock is still expected to double by 2050.[3] Although there is no single emissions pathway to reaching a particular climate goal, the Intergovernmental Panel on Climate Change has stated that preventing a >1.5°C increase in global mean temperature will require global CO_2 emissions to reach net-zero by roughly mid-century.[4] Reducing emissions from buildings is thus critically important to meeting global climate change mitigation goals. However, achieving net-zero carbon in the building sector represents unique challenges, and in most places, there is not a sufficiently ambitious policy framework in place to achieve this goal. This report studies some of the most ambitious and impactful examples of building sector decarbonization policies throughout the US and Europe.

One challenge is that building turnover is typically slow, meaning the energy efficiency of new buildings is locked in for decades after construction. Realizing this, some jurisdictions have implemented policies targeting “net-zero” buildings (see Box 1) to avoid locking in an energy-intensive building stock. Given slow turnover, it is crucial that when new buildings are constructed, they are as efficient as possible to minimize emissions.

BOX 1: DEFINING NET-ZERO BUILDINGS

There is no universally accepted definition for the term “net-zero building.” Net-zero can refer to net-zero energy or net-zero carbon, but the exact definition depends on temporal and spatial boundaries which must be defined when designing net-zero building policies.

For example, can building owners purchase off-site renewables or carbon offsets to reach net-zero carbon, or does the definition strictly apply to the building site? Are embodied emissions and energy from the building’s entire life cycle considered, or only day-to-day operations? Does net-zero refer to individual buildings exclusively, or can a campus or district be considered net-zero? Because there is no consistent choice of boundaries, it is not even immediately clear when comparing two different policies whether net-zero carbon or net-zero energy is a more stringent standard!

In most cases, a jurisdiction chooses either net-zero energy or net-zero carbon, but the definitions are often similar. Most often, net-zero refers to individual buildings that, over the course of a year, produce at least as much onsite renewable energy as they consume. Energy efficiency standards are also included in many net-zero definitions. Inclusion of embodied emissions or energy is uncommon since accounting for and mitigating those emissions is challenging. Throughout this report, unless otherwise specified, net-zero carbon or net-zero energy refers to a policy that uses this definition (or something very similar). Significant deviations from this definition will be indicated.

Since many definitions exist, clearly defining “net-zero” is essential when implementing policies. The choice of definition has significant implications for the impact of net-zero buildings goals. Choices like whether to allow offsite generation greatly influence how developers will construct buildings and whether or not jurisdictions will meet their climate goals.

Net-zero buildings bring many additional benefits besides lower GHG emissions. By reducing energy demand, net-zero buildings lower energy bills, mitigating household energy burdens and reducing operating costs for businesses and governments. Besides saving money, this makes communities more resilient to changing energy prices and even natural disasters. Net-zero buildings can also improve both indoor and outdoor air quality, improving health outcomes for communities. Indoor air quality is improved by reducing or eliminating fossil fuel combustion used for space and water heating. Outdoor air quality is improved because efficient buildings reduce how much electricity demand must be met using polluting, fossil fuel-based sources of electricity. Net-zero buildings usually provide greater comfort too, for example by reducing air leakage or preventing occupants from having to sacrifice comfort for energy affordability. Net-zero buildings also offer an opportunity to address inequality, as many of these burdens (energy cost burdens, poor air quality, and uncomfortable buildings) are often borne most heavily by low-income communities.

A robust net-zero building sector creates jobs in a diverse range of industries and skill levels including research and development, manufacturing, engineering and design, and construction and installation. Net-zero buildings integrate cutting-edge technologies such as smart meters and thermostats or electric vehicle charging, advancing markets for these technologies.

Energy efficient, net-zero buildings are an asset for energy providers too. Often, energy efficiency is the lowest-cost way to meet increasing energy demand (rather than investing in additional energy generation and distribution infrastructure). In fact, net-zero buildings often include distributed generation, which reduces a utility’s need to build out additional transmission infrastructure. Reduced demand increases system reliability and provides demand management opportunities for utilities, which allows for greater integration of renewable energy.

Overall, the objective of this report is to provide insight on how to expand upon existing policy frameworks to decarbonize the building sector. To do this, a broad overview of building sector policies in the US and Europe is presented. Citing examples, this overview summarizes best practices from leading jurisdictions who have built upon existing policy frameworks to drive transformational change in the building sector and explores the motivations behind these best practices. Additionally, a closer look at net-zero building goals explores some of the most ambitious and innovative policy approaches to net-zero buildings, largely informed by two in-depth case studies. These case studies detail the motivations, challenges, and strategies of developing, implementing, and enforcing net-zero building policies. Finally, the report synthesizes the findings from the policy overview and case studies into a set of recommended policy tools and supporting strategies to maximize the impact of net-zero building policies.

2. BUILDING DECARBONIZATION POLICY IN THE US AND EUROPE: AN OVERVIEW

A wide variety of policy tools in the United States and Europe are intended to decrease GHG emissions in the building sector. These policies can generally be classified into the following approaches:

1. Building energy codes and standards
2. Monitoring, benchmarking, and disclosure of building energy use
3. Building electrification
4. Net-zero building policies
5. Building efficiency retrofits
6. Financial Incentives*

It should be noted that policies rarely fit neatly into one of these six categories. Because some approaches center around methods, whereas others center around goals, policies may fit into multiple categories. For example, some building energy codes mandate net-zero performance. Nevertheless, sorting policies thusly organizes them based on approaches used by leading jurisdictions. Each section summarizes best practices from ambitious jurisdictions using these approaches to transform the building sector and discusses the motivations behind these practices (i.e. why additional ambition is necessary). Each section also provides real-world examples of cities, states, and countries that have implemented ambitious building sector policies.

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* In addition to these six categories, appliance standards are important to building energy consumption. They are not discussed here, as they are often developed and implemented separately from other building energy policies.

2.1. BUILDING ENERGY CODES AND STANDARDS

Best Practices	Motivations
Provide performance-based and/or outcome-based paths to code compliance	■ Performance paths vs. prescriptive paths provide flexibility ■ Lowers compliance costs ■ Fosters innovation in building design ■ Outcome-based compliance minimizes the “performance gap”
Offer stretch codes for sub-jurisdictions	■ Allow ambitious cities to lead on building energy efficiency and decarbonization ■ Cities may have the workforce capacity, motivation, and technical capability to decarbonize the sector sooner than the rest of a state or country
Mandate stringent (e.g. net-zero) codes for publicly owned buildings	■ Lead by example: demonstrate to the private sector the affordability and benefits of highly efficient buildings ■ Foster market development for the materials, technology, and workforce required to transform the building sector
Institute net-zero carbon building codes for all new buildings	■ Mandatory programs are preferable to voluntary ones ■ It is more cost-effective for new buildings to reach net-zero carbon performance than existing buildings
Announce future code updates and goals years before they will take effect	■ Guarantee companies a market for high-performance technologies, materials, and construction methods so they have incentive to develop and invest in them ■ Allows developers to plan ahead, encourages early compliance

Building energy codes are sets of rules that apply to new buildings (and additions), requiring them to achieve a minimum level of energy efficiency. Codes may be voluntary or mandatory and may apply to all buildings in a jurisdiction or only certain ones - all public buildings, for example. Different codes usually apply to different building typologies.

Traditionally, building energy codes have been used as a “backstop” policy, intended to ensure that all buildings within a jurisdiction achieve at least a bare-minimum level of energy performance. They were not used to pursue highly efficient buildings, but rather to prevent exceptionally inefficient buildings. But increasingly, leading jurisdictions have turned to codes as a policy tool to achieve more aspirational building sector goals, even net-zero goals.

Codes are either prescriptive- or performance-based. Prescriptive codes outline specific standards for individual building components, while performance codes require a building’s total energy usage to meet some threshold. Typically, this requires modeling software to predict a building’s energy use before construction. Unfortunately, buildings do not always perform as designed in practice. For that reason, some leading jurisdictions have implemented outcome-based performance requirements into their energy codes.

A single code often provides multiple paths to compliance: a building may either meet all the requirements of a prescriptive code, or it can demonstrate that its total energy use is at least as low as a building constructed according to the prescriptive code. Performance-based compliance therefore affords builders flexibility – since every single component does not need to meet exact requirements, some over-performing elements may be combined with some under-performing elements to meet the overall performance standard. This flexibility encourages building designers to innovate and develop new high-performing building technologies. With a prescriptive code, there is little incentive to innovate. Innovation can also be spurred by announcing code updates years in advance, which provides long-term market signals to industry. It promises companies a future market for new technologies, materials, and construction methods, giving them reason to invest in research and development.

In some cities or counties, political will for building decarbonization is stronger than in the state or country in which those cities reside. As a result, localities might enact a “stretch code” which by design is more stringent than the state-level or country-level energy code. States and countries are usually open to this and may even develop their own stretch codes that localities within their borders have the option of implementing. Offering an optional stretch code allows ambitious cities to lead the way and develop the market for highly efficient buildings.

In leading jurisdictions, it is common for publicly owned buildings to face a more stringent set of code requirements than private buildings, like net-zero carbon. The goals of this are twofold. First, net-zero public buildings serve as a proof of concept to the private sector, proving the feasibility and cost-effectiveness of similar projects. Secondly, this helps develop the market for advanced building technologies, lowering costs for the private sector in the process.

Building codes in the US and Europe are a mixture of voluntary and mandatory, as well as prescriptive and performance, and they vary widely in scope depending on the jurisdiction. Below are some examples of how ambitious jurisdictions have used building energy codes as transformational policy tools.

United States

In the US, there is no mandatory federal building energy code. Cities and states may develop their own codes for residential and commercial buildings, but more commonly, they adopt the national model codes. These are developed and regularly updated by private organizations, often with input from many stakeholders, including the US Department of Energy (DOE). The US model code for commercial buildings (ASHRAE Standard 90.1) is created by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE); the US model code for residential buildings (International Energy Conservation Code) is created by the International Code Council (ICC). These model codes are updated every three years, but states (or cities) do not necessarily update their own codes as frequently. As a result, buildings across the US face an uneven patchwork of codes of various stringency. In fact, not all buildings in the US are subject to a code at all.[5]

In some states with a mandatory state code, cities may enact a stretch code that is designed to be more stringent than the state-level base code. Stretch codes are often developed on the state level, with states allowing cities or counties within their borders to use the stretch code instead of the base code. For example, Massachusetts and New York state have designed stretch codes which cities in those states have the option of enacting.

Several states and cities have begun to use building energy codes as ambitious decarbonization policies. California’s latest residential BEES are the first in the country to require that all new homes install rooftop solar photovoltaic panels.[6] In an effort to reduce the performance gap (where buildings fail to perform as designed), Seattle offers an optional compliance pathway for its commercial building code, which offers slightly less stringent prescriptive requirements in exchange for opting into outcome-based compliance. Failure to perform as designed results in fines.[7]

The US federal government also operates voluntary building efficiency codes and certification programs. One such program is ENERGY STAR, run by the US Environmental Protection Agency (EPA), which has certification programs for homes, commercial buildings, and industrial facilities. Additionally, the ENERGY STAR label is added to appliances, building products and electronics that meet energy-saving requirements.[8] Voluntary private-sector certifications like the Green Building Council’s Leadership in Environmental Design (LEED) are also commonly used in the US. While mandatory codes are preferable, since they impact more buildings, voluntary codes often help lay the groundwork for future mandatory standards by strengthening stakeholder relationships and developing the market and workforce necessary for stringent (i.e. net-zero) code updates. For example, Boston’s current efforts to increase its local zoning code to a net-zero standard first began by requiring LEED-certified performance.

Europe

In the EU, the Energy Performance in Buildings Directive (EPBD) was originally enacted in 2002, then recast in 2010.[9] It was expanded further in 2018 by Directive 2018/844, which amended aspects of both the EPBD and the Energy Efficiency Directive (EED, first enacted in 2012). Together, EPBD and EED are the most important EU-wide policies related to building energy efficiency.[10] The original EPBD required member states to set minimum energy performance requirements for new buildings. The directive allows flexibility in how member states calculate energy performance and set targets. Member states have the freedom to set more ambitious targets, which enables ambitious countries to lead transformation of the building sector.[11] When EPBD was recast in 2010, member states were further required to develop national action plans to achieve "nearly zero-energy" performance in all new buildings by the year 2021. For public buildings, this requirement took effect in 2019.[12]

Several European countries have chosen to adopt building energy codes that are quite innovative and ambitious. Denmark, for example, routinely updates its building code with voluntary, low-energy classes of buildings, while announcing that these standards will become mandatory several years later. This has sparked innovation and market development, as companies have time and incentive to invest in and develop new energy-efficient technologies, materials, or construction methods since they know there will be a market for them in several years. When announced in advance, compliance with low-energy building classes is gradually implemented, and partial compliance is achieved even before standards become mandatory.[13]

As buildings become more efficient and approach net-zero operations, it is increasingly important to consider embodied emissions. Net-zero buildings have similar embodied emissions as buildings built to older standards, and embodied emissions can account for up to half of the lifecycle emissions of net-zero buildings.[14] To address this, France aims to define its building performance metrics from a lifecycle perspective beginning in 2020. All building developers would need to complete a lifecycle analysis accounting for the embodied emissions of the building. A process is underway to develop cost-effective targets for lifecycle emissions.[15]

Sweden has gone a step farther than the EPBD requirement for performance-based codes and implemented outcome-based codes. Compliance is determined with measured energy performance, not designed performance. This helps minimize the performance gap. Buildings in Sweden may be subject to fines, mandatory retrofits, or even revocation of building permits if measured energy use does not meet design levels.[16]

2.2. MONITORING, BENCHMARKING, AND DISCLOSURE

Best Practices	Motivations
Make building performance data publicly available	■ Use transparency to leverage public shame and competition to encourage energy-saving actions
Use data from disclosure policies to inform future policy design	■ Data-driven analysis helps determine least-cost pathways to achieving decarbonization goals ■ Policies can be designed to prioritize the most under-performing buildings
Make disclosure policies mandatory and increase coverage to most (if not all) buildings	■ Disclosure policies are only as effective as the number of buildings they cover
Use disclosure policies as a foundation to build toward policies that mandate action, like an EPS	■ Disclosure policies encourage, but do not require, building owners to take energy-saving actions like retrofits. ■ Tying disclosure policies to mandatory action prioritizes under-performing buildings (i.e. mandate energy saving actions for buildings that do not meet performance standards)
Track emissions performance instead of just energy performance	■ Emissions are a more directly relevant metric to climate change mitigation ■ Emissions performance goals can more directly incentivize building electrification

Monitoring, benchmarking, and disclosure policies gather information about the energy performance of buildings and make it available to building owners, developers, tenants, policymakers, or even the public. By improving imperfect information, these policies can influence stakeholder behavior. Building owners that are forced to compare their energy use to peer buildings may be encouraged to plan an energy saving retrofit. Prospective commercial tenants may seek out high performing buildings. And developers may be more likely to construct efficient buildings to attract tenants willing to pay a premium for performance.

Normally, the market fails to adequately value energy efficient buildings. Benchmarking using simple, easy to understand performance metrics helps correct this problem, making the value of energy efficient buildings more transparent. Efficient buildings command higher rents, higher market values, higher occupancy rates, and lower operating expenses.[17]

Programs may be voluntary (perhaps encouraged by financial incentives) or mandatory. They may apply to all buildings in a jurisdiction or only some, for example only public buildings or only commercial buildings above a certain size. Reporting requirements also vary widely. Some policies simply require average monthly energy usage or costs, while others mandate the use of a benchmarking tool that rates energy performance on a dimensionless scale. In some cases, this information must be disclosed to the government alone, but more extensive policies require disclosure to tenants, buyers, or even the general public. Some policies require performance disclosure only when a building is sold or leased, while others require it annually.

Benchmarking policies are only as effective as their coverage. For that reason, mandatory policies are preferable to voluntary ones, and requirements should cover most of the building stock. A common approach is to begin mandating disclosure for only public buildings, or commercial buildings over a certain size, then expanding the scope over time to include a greater share of buildings.

An additional benefit of disclosure policies is that

they increase accountability amongst the public and policymakers. With relative performance data, under-performing buildings or sectors can be targeted when designing other efficiency policies, such as financial incentives for retrofits. Disclosure can also use competition and public shame to nudge developers toward higher energy efficiency in buildings. Disclosure data can even be used to monitor compliance with outcome-based policies and levy fines.

A weakness of traditional disclosure policies is that they encourage, but do not require, additional investment in energy efficient buildings. Leading jurisdictions have combined such policies with mandatory requirements to make energy efficiency upgrades or undergo full-scale energy audits if buildings do not meet certain performance requirements. Jurisdictions should also consider moving from energy performance requirements to emissions performance requirements, as this is a more relevant metric to the goals of decarbonizing the building sector and does not run the risk of disincentivizing building electrification.

United States

Many states and cities have enacted monitoring, benchmarking, and disclosure policies, which vary widely in scope. Some apply only to public buildings, some apply to all private buildings above a certain size, and some apply to large commercial buildings, but not residential buildings. Reporting and disclosure requirements vary widely too.

Only two states (Washington and California) have mandatory statewide benchmarking policies in place for commercial buildings, though fourteen states have mandatory benchmarking policies in place for public buildings.[18] Much of the leadership on benchmarking policies in the US has come from cities. Of 86 cities tracked by the American Council for an Energy-Efficient Economy (ACEEE), 22 have mandatory benchmarking policies that apply to commercial and/or multifamily buildings, while 9 more have voluntary programs.[19] Cities with mandatory benchmarking include the three largest American cities (New York, Los Angeles, and Chicago).[20] Additionally, some large cities like San Diego have no local policy but fall under the jurisdiction of statewide policies.

Most cities with a commercial building benchmarking requirement, like Washington D.C., require annual benchmarking and make data publicly available online.[21] Some cities, including Boston, San Francisco, and Seattle, have combined mandatory actions with their benchmarking policies. Boston's BERDO requires that commercial buildings who are not already certified as "highly efficient" must perform an energy-saving action (generally retrofits) or complete a comprehensive energy audit every five years until certain energy performance standards are achieved.[22] The San Francisco and Seattle policies are similar. Minneapolis, Portland, and Austin (among several other cities) have disclosure policies for single-family residences that require sellers to provide an energy disclosure report at the time of sale.[23]

A logical progression for many disclosure policies is an EPS, such as the one recently passed in New York City. Buildings must not only report building emissions performance, they must also meet certain thresholds, which gradually ratchet down over time toward net-zero carbon. This forces building owners to either reduce their emissions or face fines.[24] Boston is also considering an EPS to replace BERDO, its existing energy disclosure ordinance.[25]

While there is no federal requirement in place to benchmark energy use in commercial buildings, the federal government plays a key role in state and local policy. ENERGY STAR Portfolio Manager is an online tool developed by EPA to monitor energy use, water use, and GHG emissions for buildings, and calculates a standardized energy performance score. While not quite universal, Portfolio Manager is used by most of the city and state policies mentioned above. EPA reports that Portfolio Manager is used by twelve of fourteen state benchmarking policies, and 40% of the US commercial building sector.[26]

Europe

The EPBD outlines requirements for member states to certify the energy performance of buildings. Per the directive, an energy performance certificate (EPC) must be made available upon the construction, sale, or rental of any residential or commercial building.[27]

Buildings which are "frequently visited by the public" must prominently display their EPC.[28] EPCs are formatted differently in different member states, but all must contain certain information including energy consumption information and recommendations for cost-effective upgrades to improve energy efficiency. Many member states rate buildings on a scale from A to G, making this grading system a de facto standard across the EU.[29] By 2013, all member states had implemented the benchmarking requirements of the EPBD.[30]

Some countries and cities have gone even further with this class of policies. In the UK, EPCs help address the split incentive problem between landlords and tenants. Beginning 2018, landlords can no longer rent out property unless it has an energy rating of E or above, effectively forcing them to make energy-saving renovations to poor-performing buildings.[31] Ireland has a well-maintained and publicly available EPC database, the data from which is used extensively to design, market, and implement financial incentives for building retrofits. The government also uses the data to analyze the effectiveness of other building sector policies.[32] Copenhagen utilizes an hourly digital monitoring system on most of its municipal buildings that automatically compares energy use to expected values based on weather, enabling unusually high energy consumption to be flagged to the city immediately.[33]

2.3. BUILDING ELECTRIFICATION

Best Practices	Motivations
Reduce emissions from the energy sources supplying buildings	■ Decarbonizing the electricity, district heating, and combustion fuels supplied to buildings lowers emissions, even if buildings use the same amount of energy ■ Decarbonizing these systems also reduces emissions outside the building sector
Encourage electrification of fossil fuel energy loads in buildings (i.e. use electric heat pumps over natural gas boilers)	■ Wide-scale electrification is often the most cost-effective way to decarbonize buildings ■ The electric grid is easier to fully decarbonize than other building energy sources (natural gas, district heating) ■ Electric heat pumps are extremely efficient
If feasible, move from incentivizing electrification to mandating it	■ Mandatory policies may be necessary if building owners are hesitant to use unfamiliar technology

Some leading jurisdictions have taken a more systematic approach to decarbonizing buildings. Rather than considering building energy efficiency separately, they consider buildings within a larger decarbonization context. Buildings must not only use less energy, the distribution networks that supply that energy (the electric grid, natural gas lines, or district heating) must be decarbonized. Reducing emissions from these energy streams necessarily reduces the emissions of the buildings which rely on them. However, this is not a distinct approach that ignores the role of efficiency in reducing overall emissions. Rather, they are complementary.

More energy is consumed as electricity than any other form and building electricity consumption is expected to increase rapidly in the coming decades, so decarbonizing electricity is crucial to overall building sector goals.[34] Compared to other methods of delivering energy, the electricity grid is relatively easy to decarbonize - making building electrification the most cost-effective way to decarbonize buildings in many jurisdictions (compared to carbon neutral fuels like renewable natural gas). And even in the absence of fully carbon-free electricity, the efficiency of electric heat pumps is high enough to reduce lifecycle emissions compared to natural gas furnaces. This is the case in

about 99% of US homes – all but the locations where the electricity mix is most carbon-intensive.[35]

Despite the benefits, there is likely to be resistance to electrification for several reasons. First, in most cases, electric heat pump systems are more expensive than fossil fuel systems, which are far more developed technologies. Incentivization is thus an important consideration. And even when electrification is cost-effective, some may avoid it due to a lack of familiarity. For this reason, mandatory electrification may be necessary to prevent lock-in of fossil fuel emissions.

United States

As renewables become cheaper and public demand for clean energy grows, it is no surprise that renewable energy or clean energy portfolio standards have been instituted in many states. 29 of 50 states (plus the District of Columbia) have a renewable portfolio standard that legally requires a certain percentage of a utility's electricity come from renewable sources. Seven more have a carbon-free energy standard. Eight more states have voluntary goals for their electricity profiles.[36] Seven states (plus D.C. and Puerto Rico) have even implemented 100% renewable or clean electricity goals to be met by no later than 2050.[37] Financial incentives on the state and federal level also incentivize renewable electricity generation. For example, a tax credit for residential solar systems can partially subsidize the upfront installation costs of photovoltaics.

As the electricity grid gradually decarbonizes, the emissions benefit of electrifying buildings becomes more pronounced. This has led many states, cities, and utilities to offer financial incentives to encourage the electrification of space and water heating. For example, the Mass Save program in Massachusetts offers rebates for heat pumps that scale base on technology type - the incentive is greater if customers replace a furnace that burns heating oil rather than natural gas, since there is a greater reduction in emissions.[38]

Several local governments have moved beyond the voluntary approach and implemented mandatory electrification policies by completely banning natural gas installations in new buildings. This recent trend is rapidly gaining in popularity; Berkeley was the first US city to enact such a ban in 2019, and has since been followed by twenty cities and counties in California, plus Brookline, Massachusetts.[39] This is not feasible everywhere if electrification is prohibitively expensive or if the political will for decarbonization efforts is not sufficiently high. But when possible, a mandatory approach is preferable. Given the choice, many customers may still install fossil fuel heating systems out of convenience or familiarity (or if they cannot afford the upfront cost of a heat pump) - even if they are a costlier lifetime investment.

Europe

In the EU, the 2018 recast of the Renewable Energy Directive (RED) requires the EU to obtain 32% of its energy from renewable sources by 2030.[40] Besides this commitment, several European countries have set more ambitious goals for their electricity sectors. For example, Germany has a goal of 65% renewable energy by 2030[41], Denmark 50% by 2030 (and 100% by 2050)[42], and Sweden 100% by 2040.[43] Like the US, some European cities have their own renewable electricity goals which are more ambitious than the country they reside in. Paris, for example, is targeting 100% renewable electricity by 2050.[44]

Some local European governments strive for low or net-zero carbon by targeting the other energy streams being supplied to buildings too. Copenhagen, Denmark has set a goal of providing 100% carbon neutral electricity and district heating by 2025.[45] The advantage of decarbonizing existing district heating infrastructure (rather than transitioning to full-scale building electrification) is that the distribution infrastructure is already in place, and is often extremely efficient provided the density of energy demand is high enough. In Denmark, almost ⅔ of homes rely on district heating, and analysis indicates that decarbonizing district systems using large-scale electric heat pumps could have a payback period of less than 7 years.[46]

Heidelberg, Germany looks to do the same by 2050 via distributed solar and various renewable district heating sources, including solar thermal and thermal storage.[47] To maximize the system's efficiency and potential emissions reductions, the city requires all new development in certain high-density areas to connect to its district heating system.[48] Stockholm, Sweden aims to be carbon-neutral by 2040, and recognizes district heating as the biggest obstacle. Stockholm already sources over 50% of its district heating energy from renewable sources (including biomass) and plans to increase this further by transitioning fossil fuel plants to biomass or renewably powered heat pumps.[49]

2.4. NET-ZERO BUILDING POLICIES

Best Practices	Motivations
Expand the definition of net-zero beyond individual buildings to consider net-zero on a portfolio or district basis	■ This offers flexibility for building typologies with different energy needs, making it more cost-effective and achievable than individual building requirements
Lead by example to achieve net-zero performance in publicly owned buildings	■ Demonstrate to the private sector the affordability and benefits of net-zero buildings ■ Foster market development for the materials, technology, and workforce required to transform the building sector
Build market capacity for net-zero buildings, then eventually incorporate net-zero standards into mandatory building codes	■ Transforming the building sector requires a sizable and well-trained workforce ■ When feasible, use mandatory policy to achieve the highest level of performance possible in all new buildings ■ New buildings are cheaper to decarbonize than existing buildings ■ Aspirational net-zero policies incentivize innovation in building technology
Focus on achieving net-zero performance in existing buildings as well as in new buildings	■ Most buildings that will be in use in 2050 have already been built - those buildings must be decarbonized too
Account for embodied emissions when defining net-zero carbon	■ Emissions from the production of building materials (steel, concrete) account for almost a third of total sector emissions

The policies discussed here are diverse in scope and style because net-zero is a goal rather than a method. Cities use a variety of strategies to achieve net-zero buildings, including net-zero building codes, financial incentives, design contests, "lead-by-example" policies, or education, outreach, and training efforts.

Crucial to any effective net-zero policy is a consistent definition of what net-zero means; there is no consensus definition. The first question is choosing net-zero energy or net-zero carbon. While both are still used, net-zero carbon is becoming more common for leading jurisdictions, as emissions are a more relevant metric to climate mitigation goals. The second is setting temporal boundaries. For example, are only building operations considered, or are embodied emissions/energy from the building's entire lifecycle included? Finally, the third question is setting spatial boundaries. Are buildings allowed to purchase off-site renewables or does all renewable power need to be produced onsite? Can owners purchase carbon offsets to eliminate residual emissions?

Typically, the term net-zero applies to single buildings, but a growing number of jurisdictions are realizing it is more practical and effective to consider net-zero targets on a district or portfolio level. Like the difference between a prescriptive and performance-based building

code, the district level approach provides flexibility. Some buildings (e.g. hospitals) are energy intensive and difficult to fully decarbonize, but when considered alongside buildings with low energy intensity (e.g. warehouses), there may be opportunities to reach overall net-zero emissions far more cost-effectively than considering each building separately.

Net-zero goals are useful because they unify many different policy areas under one common goal. Theoretically, a jurisdiction could decarbonize their building sector by independently pursuing stringent building codes, electrification, renewables, and aggressive retrofitting programs - but this might be a difficult process to manage. With a net-zero goal, all relevant stakeholders are pursuing the same goal, and can all be convened and managed using the same process. Net-zero buildings are inherently aspirational, meaning they often inspire innovation in building design.

Typically, achieving net-zero carbon in new buildings is easier than in existing buildings, as they can be designed to use the most efficient building materials and technologies from the start. But since most of today's buildings will still be in use decades from now, achieving net-zero performance in existing buildings is just as important as achieving it in new buildings.

Finally, net-zero standards should eventually incorporate embodied emissions rather than solely operational emissions. Doing so too soon may be counterproductive, as stakeholders may become discouraged by a goal that is not yet achievable. But these emissions must be reduced as well, and incorporating them into net-zero requirements may help encourage innovation in low-carbon building materials.

United States

There is no national goal for net-zero buildings, though the DOE provides resources to states, cities, and organizations looking to develop net-zero construction. The Energy Security and Independence Act of 2007 established the ZNE Commercial Buildings Initiative.[50] Design guides for certain building types are published online and various DOE studies investigate challenges to net-zero design and how to overcome those challenges, from tenant-landlord split incentives to master planning for zero-energy districts.[51]

On the state level, California is the clear leader in net-zero policy in the US. The state developed a Net Zero Action Plan to achieve the goal of all net-zero energy for new residential construction starting in 2020. The intent was to develop the market for net-zero construction over several years, then formally require net-zero designation in the BEES.[52] While this goal was not formally realized, all new homes must be "highly efficient" and are required to install solar panels.[53] The net-zero goal served to unify stakeholders, sparking innovation in home energy systems like energy storage and raising public awareness. This may have contributed to the ambitious local policies in California, such as the natural gas bans in Berkeley and elsewhere. California also leads by example - all new state owned buildings must be ZNE, and at least 50% of all state owned buildings must achieve ZNE performance by 2025 (including existing buildings).

Multiple American cities have net-zero goals too. Overall, 8 have signed the World Green Building Council's Net Zero Carbon Buildings Commitment, which aims for 100% net-zero carbon for new construction by 2030 (and for existing buildings by 2050). These cities are Washington, Boston, New York, Seattle, Los Angeles, Portland, San Francisco, Santa Monica, San Jose, and Newburyport.[54] Washington D.C. plans to implement a mandatory net-zero building code, using incentives, education, training, and public sector leadership (i.e. first requiring public buildings to be highly efficient) to gradually build toward that goal.[55] Boston's goal of achieving citywide net-zero carbon emissions already includes a requirement for new municipal buildings and city-funded affordable housing to be net-zero carbon. The city is also developing a net-zero carbon standard for the zoning approval process for large developments (since they cannot directly impact the statewide building energy code).[56] Impressively, the city of Santa Monica, California has already implemented a mandatory net-zero energy standard for new residential construction.[57]

Europe

The EPBD requires new construction throughout the EU to be "nearly zero-energy." The stated goal of the amended EPBD is to fully decarbonize the EU's building stock by 2050, and member states are expected to develop long-term plans to get there.[58] The EU also funds the World Green Building Council's Build Upon 2 initiative, a collaboration with eight European pilot cities that are developing long term commitments to reach net-zero building stocks by 2050. These are Velika Gorica, Budaörs, Dublin, Padova, Wroclaw, Madrid, Eskişehir, and Leeds.

Several other major cities have also signed on to the Net Zero Carbon Buildings Commitment, including Copenhagen, Heidelberg, Helsinki, London, Oslo, Paris, Stockholm, and Valladolid. All have declared citywide initiatives intended to achieve 100% net-zero carbon new buildings by 2030 and 100% net-zero carbon for all buildings by 2050. Similar commitments have been made by several regions in Europe: Baden-Württemberg, Catalonia, Navarra, and Scotland.[59] Each has crafted a unique approach, focusing on the particular needs of the city or region. Paris leads by example by targeting 100% renewable municipal power purchases and requiring all new municipal buildings to be net-zero carbon. Oslo requires all new municipal buildings (e.g. nursing homes, schools) be net-zero energy, has banned heating oil, and runs a Climate and Energy Fund that provides financing for both renovations and new energy efficient solutions like heat pumps and increased insulation.[60]

2.5. BUILDING ENERGY RETROFITS

Best Practices	Motivations
Combine retrofit incentives with monitoring, benchmarking, and disclosure policies	■ Disclosure provides the information to encourage retrofits; incentives provide the capacity to complete them ■ Data from disclosure policies can be used to target financial incentives to under-performing buildings or sectors
Leverage future energy savings to pay for upfront costs of retrofits	■ Retrofits can be expensive, but often save money long term by reducing energy bills ■ By structuring financial incentives to leverage future energy savings to pay for upfront costs, retrofits can be encouraged
Pursue comprehensive retrofits that achieve net-zero performance and electrification	■ Comprehensive, full-building retrofits yield more energy savings than marginal efficiency improvements ■ Incentivizing electrification now prevents long-term lock-in of emissions from natural gas use
Move beyond incentivizing retrofits to mandating them	■ Financial incentives alone may not drive the rate of retrofits necessary to achieve mid-century decarbonization goals

Retrofits are crucial to decarbonizing the existing building stock, which is essential to achieving the ambitious goals set by many cities, states, and countries. An estimated 60% of the existing global building stock will still be in use in 2050, so without addressing existing buildings, there are severe limits to how effectively the building sector can be decarbonized.[61]

Building efficiency retrofits may refer to a variety of building upgrades that improve the energy performance of a building. Examples include:

- Replacing HVAC systems, boilers, or water heaters with more modern, efficient equipment (and/or electrifying those systems)
- Replacing windows, roofing, walls, or insulation with higher-performing materials
- Replacing light fixtures with highly efficient LEDs
- Replacing appliances and electronics with more efficient models
- Sealing the building envelope to minimize wasted energy
- Installing energy management equipment (e.g. motion-sensing lights, smart thermostats)
- Installing on-site renewable generation like rooftop solar panels or geothermal wells

This list is certainly not comprehensive but illustrates the range of projects that can enhance building energy efficiency. This can make it challenging to design policies to encourage retrofits, since there are so many different types. The high upfront costs of many projects also discourage retrofits, even if they will save building owners money in the long run. This often requires finding creative financial incentives that leverage future savings to pay for upfront expenses. Often, retrofit incentives take the form of rebates, tax credits, or low-interest loans.

Common partner policies for such retrofit incentives are energy monitoring/benchmarking programs. These programs educate building owners on available opportunities for energy savings, quantify them, and often provide specific retrofit recommendations. This combination of policies provides both the awareness (benchmarking) and capacity (incentives) for widespread implementation of energy-saving retrofits.

Future efforts in retrofit policies must become more ambitious. Policies should move beyond voluntary retrofits encouraged by financial incentives to programs that mandate building owners to retrofit their buildings until they achieve minimum performance standards. This could be done on a regular schedule (e.g. every five years) or could be required at time of sale. Additionally, the scope of projects should expand from traditional efficiency improvements (which are often less capital intensive, but have limited energy savings potential over the project lifetime) to comprehensive, full-building retrofits (which are more expensive, but usually maximize energy savings and financial benefit).[62] Electrification should also be a focus of retrofit programs to avoid lock-in of future emissions.

United States

Several federal programs in the US encourage building retrofits. Aimed at residential retrofits, DOE's Home Performance with ENERGY STAR is administered via sponsors (e.g. states, municipalities, and utilities) who recruit contractors to perform whole-home efficiency assessments and provide recommendations for homeowners to lower their energy use. Sponsors typically offer a variety of incentives (rebates, financing, etc.) to encourage retrofits. For commercial buildings, DOE's benchmarking program, Building Performance with ENERGY STAR, rates buildings so building managers understand the performance of their assets. To incentivize adoption of recommendations, commercial buildings can access a $1.80/ft tax credit for certain retrofitting projects.[63]

For federal buildings, the Federal Energy Management Program (FEMP) uses business models such as energy savings performance contracts and utility energy service contracts, to facilitate retrofits in federal facilities. FEMP also has standardized and streamlined project development and implementation processes to remove institutional barriers and reduce transaction costs.

Retrofit initiatives are plentiful at the state and local level too. Programs are extremely diverse - states, cities, utilities, NGOs, and other organizations provide incentives in the form of rebates or tax credits to encourage retrofits. Other programs focus on outreach and education, informing consumers of the benefits of efficiency upgrades. Washington state does both. - the Community Energy Efficiency Program provides consumer education and financial support for retrofits. The program targets low-income housing, rental housing, and small businesses.[64] New York City is also a leader in retrofitting policy. The city's Climate Mobilization Act includes an EPS which requires all buildings over 25,000 sq. ft to meet increasingly strict emissions limits (starting in 2024) or they must pay fines. This inherently forces building owners to undergo retrofits to maintain compliance, but offers them flexibility in designing and scheduling retrofits.[65] Buildings are also required to replace inefficient lighting systems by 2025.[66] Boulder, Colorado also requires mandatory retrofits of rental housing if energy efficiency requirements are not met.[67]

Europe

The importance of building retrofits is recognized in the EED, which requires all member states to annually renovate 3% of all government buildings to meet minimum energy performance requirements outlined by the EPBD. Member states must also develop a long-term strategy for mobilizing investment into building renovations.[68] The updated EBPD/EED lists several suggested policy tools member states can use to encourage investment in renovations, including financial incentives, public-private partnerships, advisory tools and one-stop-shop renovation services.[69]

Many cities and countries have made retrofits a priority well beyond the EED requirements. Paris for example provides public financial support for the energy retrofitting of social housing units and condominiums, and is renovating hundreds of municipal facilities like schools and swimming pools.[70] In the UK, the Energy Company Obligation is one of the main tools for incentivizing residential retrofits. This policy requires energy providers to reduce energy use by subsidizing retrofit projects for their customers, the cost of which is generally passed through to consumers on energy bills.[71] France, recognizing the importance of mandatory retrofits over voluntary ones, requires any home rated lower than an E on its Energy Performance Certificate to undergo retrofits to improve energy performance before it can be sold.[72]

The European Green Deal highlights building retrofits and aims to start a "renovation wave". The European Commission is planning to launch an open platform to develop innovative financing mechanisms and promote investment in energy efficiency retrofits, with the goal of at least doubling the current rates of renovation in public and private buildings.[73]

2.6. FINANCIAL INCENTIVES

Best Practices	Motivations
Target most financial incentives at existing buildings, not new buildings	■ Existing buildings are more costly to decarbonize than new buildings
Leverage future energy savings to pay for upfront costs	■ Often, energy savings surpass the upfront cost of a retrofit ■ Structure financial incentives that minimize risk for building owners by using expected future savings to fund upfront costs
Invest public finance for retrofit programs and leverage private investment	■ Energy savings may not always pay back the cost of a retrofit ■ Public finance is necessary to guarantee retrofits will get done at the scale necessary to reach net-zero carbon emissions ■ Use public investment to leverage additional private investment
Design custom programs to target specific barriers to decarbonization	■ The building sector faces various unique challenges, such as the landlord-tenant split incentive, the temporal split incentive, and energy poverty ■ Design specific programs and incentives to address particular challenges - a "one-size-fits all" approach will not be successful

Financial incentives drive the implementation of many building energy efficiency policies in the US and Europe. Often the most significant barrier to the implementation of energy efficiency technologies is high upfront cost. It may be pointless to design mandatory policies that do not increase the capacity of building owners and developers to afford these costs.

While achieving high energy performance can be expensive, the money saved on future energy bills is often more than enough to pay back upfront costs. A well-designed financial incentive leverages the expected future energy savings to pay for these initial costs. Incentives are distributed using a variety of methods, including tax relief, rebates, grants, low-interest loans, and many others. However, in some cases, retrofits will not be cost-effective, even in the long run. Old buildings may be extremely expensive to retrofit and the energy savings may not be sufficient to overcome the upfront costs. Public investment to subsidize energy efficiency is thus incredibly important.

Public investment may be difficult to secure on a large scale, making it essential for governments to maximize their resources. Generally, it is easier to design buildings to be highly efficient from the start than it is to retrofit an existing building to reach the same level of performance, so incentives should focus primarily on retrofits rather than new construction. Another strategy to maximize the impact of public investment is to leverage limited public financing to secure private sector funding. For example, public money could be used to guarantee payments for future energy savings of retrofits, reducing some of the perceived risk that hinders large-scale private sector investment.

Finally, incentives should be customized to target specific barriers in the building sector. The landlord-tenant split incentive refers to the fact that landlords incur the costs of energy efficiency improvements, but tenants receive the benefits (lower energy bills, greater comfort, etc.). The temporal split incentive refers to the fact that building owners may be unwilling to invest in expensive retrofits if they are not confident that they will still own the building by the time an investment in energy efficiency is repaid. Energy poverty is another huge challenge. Low-income families do not have the cash (or access to credit) necessary to undertake retrofits, even when financial incentives lower costs somewhat. Yet these same people would benefit the most from more efficient homes, since a greater share of their income is dedicated to energy costs. Financial programs must be carefully designed to address specific barriers - simple rebates and tax credits will not suffice for many building owners because of these challenges.

Financial incentives are offered by many different entities, including banks, utility providers, governments, and NGOs. They are also vastly diverse in style, purpose, and structure. For this reason, this section is far from comprehensive, but provides examples of some creative approaches taken in the US and Europe to address these barriers.

United States

On the federal level, several financial incentives exist for implementing building energy efficiency projects. Many of these come in the form of tax credits. Builders of new energy-efficient homes can receive a $2000 tax credit.[74] And homeowners who install renewable energy products on their homes (solar photovoltaic, geothermal heat pumps, etc.) can receive a tax credit for up to 26% of the installation cost.

Federal incentives come in other forms too. The Weatherization Assistance Program provides grants to states to help low-income homes improve their energy efficiency to alleviate energy poverty.[75] The Fannie Mae Green Initiative offers lowered-interest loans for energy and water saving measures in multifamily buildings.[76] And the Federal Housing Administration Energy Efficient Mortgage lets homeowners finance energy efficient retrofits by adding the costs to their mortgage.[77] This reduces the risk of borrowers failing to repay debts incurred by energy efficiency investments, since mortgages are often the top priority bill for most households.

State and city efforts offer financial incentives too. One useful financing method for energy improvements to both commercial and residential properties is a PACE program, which allows building owners to spread the cost of efficiency projects over 10-20 years, repaying the debt by paying increased property taxes. This way, debt is tied to the property, not the owner, addressing the temporal split incentive. Such a program in California was utilized by 47,000 residential customers.[78]

The City of St. Paul, Minnesota offers interest-free loans for energy efficiency upgrades through its Energy Smart Home program.[79] Utilities play a role as well. Many offer ratepayer-funded rebate programs for customers who install energy efficient equipment or otherwise minimize their energy usage, like the New York State Electricity and Gas Corporation.[80]

Another strategy for financing energy efficiency projects is the establishment of green banks. This has only happened on the state and local level in the US so far. Traditionally, green banks are financial institutions which leverage limited public capital to mobilize private capital toward “green” investment like renewables, energy efficiency, or other green infrastructure.[81] At least nine states have established green banks in the US, as well as four municipalities (New York, Washington D.C., Baltimore, and Montgomery County).[82] Green bank funding structures vary widely: the Connecticut Green Bank is funded by a $0.001/kWh surcharge on electricity rates, the Montgomery County Green Bank was funded through a $14 million grant, and the Nevada Clean Energy Fund was not granted any public money upon startup (the board of directors raised startup capital through grants and foundational support).[83] Recent trends show green banks slowly moving toward a model similar to Nevada Clean Energy Fund, with less government involvement at startup and more diverse funding sources. Non-profit green banks have become more common (which do not require legislation and do not receive public funding). And business models are evolving to utilize private sources of capital as well as public sources like grants and foundations.[84]

Green banks may provide a range of financial services to encourage the deployment of green infrastructure and technology, including energy efficiency. They may directly loan to end users, as the DC Green Bank will through a PACE program to fund upgrades to lighting and building envelopes.[85] They may work with utilities to provide creative financing structures for efficiency projects. The Hawaii Green Infrastructure Authority runs the Green Energy Money Saver program, which provides on-bill financing for energy efficiency upgrades - customers pay nothing up front but forego energy savings until the debt is paid off.[86] This too helps address the split incentive - even if a customer moves, the utility can still recover the cost of the investment by charging it to the next tenant.

Green banks may also incentivize private investment by taking on some of the lending risk. The Connecticut Green Bank has a loan loss reserve fund which encourages local banks to lend to residential customers for efficiency upgrades by promising to cover a portion of potential losses those banks might face. This enables private investors to offer more favorable terms to consumers for their financial products since they are partially protected from loss.[87] Another key service green banks provide to leverage private investment is warehousing services for the energy efficiency loans they provide. With warehousing, many individual loans are combined into a diversified, low-risk portfolio, which is more attractive to private investors than many small, scattered individual loans whose risk is hard to characterize. The Green Bank sells these portfolios off, effectively using only private capital for the projects in that portfolio. New York Green Bank is one example that offers warehousing.[88]

Europe

EU financial institutions like the European Structural and Investment Funds and European Fund for Strategic Investments provide public financing for energy efficiency and sustainable energy projects. In addition to public finance, the European Commission’s Smart Finance for Smart Buildings Initiative aims to unlock private investment by accepting some of the risk. For example, the initiative guarantees the value of energy savings for retrofits, so financiers who are unsure if they will recoup their investment will be more willing to fund such projects. The initiative also develops tools to educate private lenders about the relatively low risk of energy efficiency investments.[89]

Individual countries have implemented financial incentive programs too. Several have programs which utilize government owned financial institutions to fund building efficiency projects. An example of this is the federally owned KfW development bank in Germany. They administer the CO_2 Buildings Rehabilitation Programme which offers subsidized, low-interest loans (and to a lesser extent, grants) for energy retrofits.[90] Other countries may offer tax incentives; in Ireland, the Energy Investment Allowance lets companies deduct the value of energy efficiency investments from their taxable profits.[91] And in Sweden, grants are provided to

small and medium businesses to help pay for energy audits that enable businesses to target energy saving opportunities.[92]

A variety of private institutions offer financing too. In some cases, governments offer incentives to banks to offer certain products. For example, in the Netherlands, Rabobank receives tax deductions from the Dutch government in exchange for offering lower interest rates on mortgages for “nearly zero” energy homes. Other institutions offer incentives unprompted by government intervention, like green mortgages or lowering interest rates on existing loans after energy efficiency improvements are completed. Banks are beginning to realize that energy efficient buildings are often low-risk investments and have begun to find ways to monetize the potential energy savings.[93]

As stated at the outset of this report, this summary of building sector policies in the US and Europe is far from comprehensive. States, cities, and countries have taken vastly different approaches to decarbonizing the building sector, and rather than attempting to fully characterize this policy landscape, this report instead highlights some of the more creative, unique, and/or successful approaches in the US and Europe. Certainly, no one has found the perfect solution yet. But the varied experiences of leading jurisdictions can provide insight into how existing policy frameworks can be expanded to pursue transformational building sector decarbonization.

3. NET-ZERO BUILDINGS AS A FOCUS FOR ACTION

Net-zero buildings are growing in popularity in cities, states, and countries across the US and Europe. There is increasing awareness of the importance of fully decarbonizing the building sector, which by some accounts is responsible for nearly 40% of global CO_2 emissions.[94] Robust policies that encourage the widespread adoption of net-zero buildings are instrumental to achieving ambitious decarbonization goals. Since turnover of the building stock is slow, achieving these goals requires the construction of new net-zero buildings and the retrofitting of existing buildings to reach net-zero performance. But several barriers discourage the adoption of net-zero buildings, including imperfect information, split incentives, financing challenges (both real and perceived), and a diverse, fragmented industry.

Local, state, and national governments take many different strategies to address these barriers, utilizing a variety of policy tools. There include both mandatory policies, such as introducing net-zero performance requirements into building codes, and voluntary policies, such as financial incentives or energy performance competitions. Some governments try to inform stakeholders about the benefits of net-zero buildings through transparency and education programs, like energy performance disclosure programs or the publication of educational materials. Others use a “lead-by-example” approach and require all public (government owned) buildings to meet net-zero carbon performance to demonstrate the feasibility and affordability of net-zero buildings. Almost all jurisdictions pursuing net-zero carbon use a mixture of all these policies.

Analyzing individual case studies may be the most instructive way to study net-zero policies. Cities, states, and countries face very different challenges in decarbonizing their building sector. Certain policy options may be available to one but not the other. For example, in the US, many cities do not have the authority to institute a mandatory energy code, as that authority often lies with

the state. Cities typically have limited access to financial resources compared to states and countries. Yet smaller jurisdictions may have a greater ability to engage stakeholders and may be better equipped to monitor and enforce policies than a larger jurisdiction. The politics, culture, economy, and existing policies all impact the development and implementation of net-zero building policies.

The following US case studies (Boston, Massachusetts, and the State of California) illustrate two unique approaches toward net-zero buildings. Each case is characterized by highly ambitious goals for the building sector, though their goals and approaches are slightly different. The cases span multiple levels of government and jurisdictional sizes, and they occupy different climate zones. Each uses a slightly different definition of net-zero and utilizes a different set of policy tools to achieve their goals.

In these case studies, we explore the following issues in detail: how net-zero buildings are defined, what goals have been set and how they are framed, what policy tools have been developed to meet those goals, how policies are enforced, what inputs inform policy development and implementation, how stakeholder engagement is managed, what barriers exist and how to overcome them, and what lessons have been learned that can inform future policy development and implementation. The answers are different in each case, which implies that there is no single recipe for achieving a net-zero carbon building sector. However, through the study of these two jurisdictions, several key strategies have emerged that form the basis of a strong approach to developing and implementing a robust portfolio of net-zero carbon policies. These are:

- Allow flexibility when defining net-zero. This could mean broader spatial boundaries (portfolio/district level), allowing off-site renewables, and setting varying stringency levels. This increases the achievability, cost-effectiveness, and stakeholder buy-in and compliance of net-zero carbon policies.
- Use net-zero carbon (rather than net-zero energy), as it is a more relevant metric to climate mitigation. Framing policies in this way allows them to be integrated more easily into broader emissions reductions goals and avoids conflicting incentives such as disincentivizing building electrification.
- Lead-by-example policies provide multiple benefits. They stimulate the market for net-zero buildings and demonstrate to the private sector the achievability, cost-effectiveness, and benefits of net-zero buildings.
- Stakeholder engagement is crucial to both policy design and implementation.
- Monitoring and disclosure policies are useful both for correcting the market's failure to adequately value highly efficient buildings and for providing data to inform later iterations of the policymaking process
- Focus on enforcement of building energy policies. Well-designed policies mean little if they are not adequately enforced.
- Align incentives among levels of government to remove barriers that undermine the effectiveness of new policies.
- Prioritize a just transition to ensure that the benefits of decarbonizing the building sector are experienced by all. This might include ensuring housing affordability for low-income communities, providing widely accessible financial incentives, or developing the necessary clean energy workforce to provide employment opportunities.

This list is not comprehensive, nor does following these recommendations guarantee success. Each case is too unique to craft a universal approach to net-zero carbon. But by using this guide as a framework, common pitfalls can be avoided, and the ambitious net-zero carbon goals in any city, state, or country will be significantly more achievable.

3.1 BOSTON'S POLICIES ON NET-ZERO BUILDINGS

The City of Boston is widely considered a leader in clean energy and energy efficiency in the United States. Boston perennially receives first place in the City Clean Energy Scorecard, a ranking of US cities' energy policies published by the American Council for an Energy Efficient Economy.[95] The city's latest Climate Action Plan calls for achieving net-zero carbon emissions citywide by 2050. Advancing net-zero buildings is integral to that goal.

Citywide, Boston has already made significant progress toward decarbonization in the last decade or so, reducing total emissions by 21.7% from 2005 to 2017 (latest available data). It is on track to meet the initial carbon reduction goal of 25% below 2005 levels by 2020. Over the same period, combined building sector emissions (commercial, residential, and industrial) decreased by 26.9% (see Table 1 for achievement on sector-specific targets), largely driven by reduction in emissions from electricity generation and the replacement of heating oil use with cleaner, low-carbon alternatives.[96] Despite this progress, ambitious policy action is still required to achieve net-zero emissions citywide by 2050. Boston's approach to net-zero carbon warrants deeper attention for several reasons. First, the city's net-zero policies are heavily informed by rigorous technical analysis and broad stakeholder engagement. Second, Boston's net-zero carbon goals are sector-wide, focusing on new and existing buildings alike. Third, the city exhibits exemplary leadership by acting as a "first-mover" and piloting net-zero carbon technology in city owned buildings to prove the feasibility to the private sector. Fourth, the city takes an integrated approach, developing policies addressing both direct and indirect emissions from buildings. And finally, the city's building policies are innovative, allowing the city to pursue aggressive decarbonization goals using creative and unconventional policy tools, such as green building zoning.

TABLE 1. BOSTON'S PROGRESS ON SECTOR-SPECIFIC ENERGY TARGETS

2020 TARGETS	ACHIEVED TO DATE
72,000 completed home energy audits	56,714 audits (79% of target) completed through Mass Save between 2009 and Q2 of 2019
36,000 weatherizations, heating system replacements or other significant upgrades	27,631 projects (77% of target) completed through Mass Save between 2009 and Q2 of 2019
7% energy use reduction across all BERDO buildings	7% average energy use reduction across the first cohort of BERDO buildings from 2013 to 2017
15% of energy use from cogeneration	125 MW of cogeneration installed through 2018
10 MW of commercial solar	15 MW of commercial solar installed since 2015
Improved fuel economy	17% improvement in fuel economy between 2005 and 2017
5.5% below 2005 vehicle miles travelled (VMT)	Total VMT increased 14% while VMT per capita decreased 14% between 2005 and 2017

Source: City of Boston Climate Action Plan 2019 Update

BOX 2: BOSTON'S POLICIES TO ACHIEVE NET-ZERO CARBON BUILDINGS

In Place

- All new municipal buildings must be built to a ZNC standard.
- All new city-funded affordable housing must be built to a ZNC standard.
- Renew Boston Trust funds energy efficiency retrofits in public buildings. It is self-funded by the energy savings gained by the retrofits.
- E+ Green Building program demonstrates the feasibility of ZNC multifamily residences.
- BERDO requires large- and medium-sized buildings (>35,000 square feet) to disclose their energy performance yearly and undergo an energy audit or retrofit every five years.
- Miscellaneous workforce training/development programs build capacity to facilitate the implementation of building sector policies.

In Progress

- Convert existing green zoning requirements for large buildings to a ZNC standard.
- Develop a building emissions performance standard (EPS) requiring building owners to annually report their emissions and take steps to reduce them. This would replace BERDO.
- Expand the scope of Renew Boston Trust's funding to the private sector.
- Work with the Commonwealth of Massachusetts to implement policies consistent with Boston's climate goals (e.g. ZNC building code, statewide 100% renewable electricity standard, expanding statewide retrofit financing programs like Mass Save).

BOX 3: STRATEGIES FOR POLICY IMPLEMENTATION

- Develop a broad and ongoing stakeholder engagement process
  - Guarantee broad support for policies when they are enacted
  - Avoid surprises: stakeholders should be informed on coming policies so they can plan for the future
  - Encourage discussions between building tenants, owners, managers, developers, and builders to improve actual energy performance to match designed levels
  - Ensure stakeholders understand how to comply with policy requirements and inform them of the benefits of voluntary programs through targeted outreach
- Provide financial incentives for retrofits
  - Eventually work toward standards and mandates rather than voluntary programs
- Emphasize workforce development to create an enabling environment for future policy implementation
- Require regular reporting of energy usage from buildings
  - Provide valuable data to inform policy design
  - Provide mechanisms for verifying compliance/performance
- Align policies at all relevant levels of government where possible

Net-Zero Goals in Boston

BOX 4: BOSTON'S NET-ZERO GOALS

- Citywide net-zero carbon by 2050
  - 50% reduction in citywide emissions by 2030 (2005 baseline)
- Net-zero carbon building sector by 2050
  - All new construction reaches net-zero carbon standard by 2030

The City of Boston has an overall goal of achieving citywide carbon neutrality across all sectors by the year 2050. Every five years (most recently in 2019), Boston updates its Climate Action Plan, which highlights several policy priorities across multiple sectors, including the building sector, intended to achieve this goal.

The Plan also outlines intermediate goals the city has set to gauge progress toward the 2050 goal. Boston aims to reduce citywide emissions by 25% (compared to a 2005 baseline) by 2020, which the city expects to achieve. A 50% reduction is the goal for 2030.

As buildings are responsible for over 70% of the city's emissions, eliminating emissions from the building sector is essential. The Plan aims to achieve a net-zero carbon building stock by 2050 using a three-pronged approach:

1. Construct highly efficient buildings
2. Electrify most building thermal loads
3. Supply buildings with only carbon-free electricity

This applies to both new and existing buildings. The Plan calls for all new construction to meet a ZNC standard by 2030 at the latest, though explicitly recognizes that realizing this goal even sooner would lead to substantial cumulative emissions reductions. The city also expects to retrofit and electrify at least 80% of existing buildings by 2050.[97]

Defining Net-Zero Buildings

For both citywide and building-level calculations, Boston considers Scope 1 and Scope 2 emissions,* but not embodied emissions.[98] Boston has defined a four-tiered designation system for net-zero carbon buildings and requires all new municipal buildings to achieve one of the four tiers, shown in Table 2. The city evaluates projects individually and "target[s] the most stringent tier possible" for each.[99]

* The Greenhouse Gas Protocol is a standardized emissions accounting method which classifies GHG emissions into three categories, or scopes, when performing an emissions inventory. Scope 1 includes on-site, "direct" emissions (e.g. emissions from combustion of natural gas for space heating). Scope 2 includes off-site emissions from energy used on-site (e.g. emissions from electricity generation or district heating). Scope 3 includes all other off-site emissions caused by on-site activity (e.g. emissions from manufacturing the steel and concrete used to construct buildings, also known as embodied emissions)

TABLE 2: BOSTON'S ZERO-NET CARBON (ZNC) STANDARD FOR MUNICIPAL BUILDINGS*

ZNC-onsite: a ZNC-onsite building is one that is optimally efficient, has no onsite fossil fuel combustion, and over the course of a year, generates renewable energy onsite in a quantity equal to or greater than the total amount of energy consumed onsite.
ZNC-offsite: in contrast to ZNC onsite, this option allows for energy from offsite renewable sources to be included. Such fuel sources could include the purchase of renewable energy credits (RECs), or participation in a clean power purchase agreement (PPA).
ZNC-ready: a building that is ZNC-ready would become ZNC (either onsite or offsite) when its electricity is supplied by 100 percent renewable sources.
ZNC-convertible: a building that uses electricity supplemented with some onsite fossil fuel use, for example combined heat and power (CHP), but that can be readily changed over to 100 percent renewable energy sources upon availability.

There are two main reasons for using a tiered approach. First, it recognizes that different buildings have different energy demands, so it makes little sense to hold them all to the same standard. Second, it acts as a "safety net" to encourage buy-in from stakeholders who may be skeptical about the technological feasibility of a full zero-carbon standard.

Policy Tools

New Buildings

Boston is rapidly constructing new buildings, adding approximately 4-6 million square feet of new building space every year since 2014.[100] This building boom means achieving high energy performance in all new buildings is crucial, hence the 2030 goal of net-zero carbon for all new construction. To get there, Boston has implemented (or is currently developing) several key policy tools to encourage the construction of new ZNC buildings:

1. Municipal Building ZNC Requirement: This policy requires any new city owned building to meet one of the tiers of the ZNC standard (the city chooses the most stringent feasible tier after assessment). This policy was chosen partly out of opportunity: while the state sets the building code, the city can require city owned buildings to meet higher standards in line with local targets. The city also recognizes the importance of leading by example, piloting the ZNC standard in city buildings to demonstrate to the private sector the feasibility, affordability, and benefits of ZNC buildings. Furthermore, this fosters the market for ZNC construction, helping to develop the local ZNC-workforce and lowering costs of materials and technologies used in ZNC construction. One challenge to implementing a net-zero standard is ensuring it is stringent yet achievable for all building typologies. This is the logic behind using a flexible, tiered standard. Different tiers afford more energy-intense buildings (e.g. hospitals) some flexibility, while ensuring adequately high performance in others. The municipal building requirement was instituted via executive order in December 2019, so it is still too early to have demonstrated significant results.
2. Affordable Housing ZNC requirement: All new city-funded affordable housing must meet one of the tiers of the ZNC standard. This is another "lead-by-example" policy and much like the municipal building requirement, the most stringent feasible tier is selected after assessment. A unique challenge faced by this policy is that it is particularly important to ensure ZNC buildings are cost-effective and do not introduce undue financial burdens on affordable housing developers. This policy is also partially motivated by opportunity (the city can set standards for affordable housing since they help fund it) and partially because it increases equity by ensuring the benefits of ZNC construction (air quality, low energy bills, comfort, etc.) are enjoyed by low-income residents. The city has found that ZNC buildings are indeed cost-effective; small multifamily housing units typically cost less than 2.5% more to construct compared to buildings constructed to code, even before incentives or the energy savings of ZNC buildings are considered.[101]
3. E+ Green Building Program: This is a demonstration program intended to prove the feasibility and affordability of energy positive buildings, much like the above two programs. Over 14 new multifamily residences have been constructed through this program. Each produces at least as much energy as they consume over the course of a year. The program is a joint initiative of the Environment Department, Boston Planning and Development Agency (BPDA), and Department of Neighborhood Development. The city issues requests for proposals for contractors to build energy positive homes and promotes their performance.
4. ZNC Green Building Zoning: New buildings or additions over 50,000 square feet are subject to the Large Building Review process outlined in Article 80 of the Boston Zoning Code. Article 80 projects are also subject to Article 37, which seeks to minimize adverse environmental impacts of a project. One requirement of Article 37 is that all such projects must be designed to achieve at a minimum LEED-certified energy performance. During the review process, developers are expected to complete a Zero Carbon Building Assessment to identify measures needed to achieve a ZNC building and use this assessment as a starting point for zoning negotiations with BPDA. Developers are expected to take full advantage of whatever utility, state, and federal incentives and technical assistance for energy efficiency that are available and cost-effective. Most projects in fact have achieved higher than the minimum performance standards. For example, more than 75% of large buildings achieved LEED Gold or above after going through the review process. This demonstrates that developers are willing to take additional steps toward more efficient and sustainable buildings and build momentum for market transformation and more stringent zoning requirements. The above features of the green building zoning are already in place – the next step currently under development is to elevate these minimum requirements to a ZNC standard. The motivation for taking this approach is predominantly out of necessity. Because the city is preempted from developing its own ZNC energy code, Boston has used its zoning authority as a creative work-around to achieve its goals.*

To this point, Boston has focused on leading by example. The first three policies develop the market by increasing demand and convince private developers that ZNC buildings are not only achievable, they are valuable. The next major goal for the city is updating the Green Building Zoning requirements to a ZNC standard, which would apply to large buildings only.

Existing Buildings

When it comes to existing buildings, Boston also has several policies in place to encourage energy retrofits that drive the existing building stock toward net-zero carbon. They include:

1. Renew Boston Trust: This is a program that funds retrofits in Boston's municipal buildings. The program is entirely self-funded, meaning retrofits are paid for with the energy savings they provide. The city contracts an energy service company (ESCO) to conduct comprehensive energy audits to recommend efficiency improvement measures. The contractor guarantees the anticipated energy savings. Projects are intended to be comprehensive, addressing multiple aspects of energy use in buildings. Examples include installing lighting controls, sealing the building envelope, replacing boilers, and installing solar panels. In the first phase (currently underway), the

* A note on terminology: Boston's Climate Action Plan uses both "Zero-Net Carbon" and "net-zero carbon." The former is typically used when specifically referencing the standard defined here, while the latter is used more generally to refer to sector-wide or citywide carbon neutrality goals. For clarity, this case study attempts to mirror this convention.

* The municipal building ZNC requirement, affordable housing ZNC requirement, and E+ Green Building Program are already in place. Green building zoning is partially in place – some minimum zoning requirements already exist, and the process of augmenting them to a ZNC standard is underway.

program has approved 14 municipal buildings for inclusion in the program, including police stations, community centers, and libraries, with expected electricity savings up to 56% for some projects. In total, Phase 1 projects are expected to lower municipal GHG emissions by 1%.[102] In time, this program will hopefully be expanded to a greater share of municipal buildings as well as private sector buildings. The program is administered by the Environment Department, Budget Office, and Public Facilities Department. The verification of energy savings will be done using data from Energy Star Portfolio Manager, which is also the tool Boston uses for BERDO (see below). One of the main challenges to implementing such a program is gaining the necessary internal expertise to properly model the program and how to structure the guarantees to achieve maximum energy savings.[103]

2. Building Energy Reporting and Disclosure Ordinance (BERDO): This ordinance requires all buildings over 35,000 square feet to report and publicly disclose their energy performance annually. Additionally, buildings must demonstrate highly efficient performance (defined as Energy Star Certified, LEED Silver Certified, or zero-net carbon or energy as defined by various certification systems). If they do not, they must instead undergo an energy audit or perform an energy-saving retrofit every five years that achieves at least a 15% reduction in energy consumption, energy use intensity (EUI), or GHG emissions. Alternatively, increasing the building's Energy Star score by 15 points qualifies. The city does not count emissions reductions due to the changing energy mix of the electricity grid.[104] The goal of the program is to increase transparency and make building owners more aware of their buildings' energy performance. Through mandatory reporting of audit results, building owners acknowledge their potential energy savings and the pathway to achieve them. And mandatory retrofits ensure progress toward the city's decarbonization goals from the largest emitters – large buildings. The program is administered by the Environment Department. Building owners use the Energy Star Portfolio Manager tool to report their energy performance, which ensures all data is reported in the same manner and makes it easier to compare performance data across buildings. One challenge is how to guarantee that audits will translate into action – in other words, making sure that building owners follow through with recommendations from audits. This can be addressed by working closely with utilities, who provide financial incentives for customers, and ESCOs, who perform retrofits. Auditors make owners aware of incentives once an audit is completed, for example. To address the challenge of workforce development, the city supports training and education programs to ensure there is an adequate workforce to perform the necessary 2000-3000 retrofits per year. Another challenge is compliance. Boston outreach and support efforts have led to 90% compliance.[105] Additionally, non-compliers may face fines of up to $3000 per building per year.[106] From 2014 to 2017, the first cohort of buildings subject to BERDO requirements achieved 7% energy savings on average.[107]
3. Emissions Performance Standard (EPS): Boston is developing a building EPS that would set emissions performance thresholds that ratchet down over time and require buildings to annually report their emissions. This would take the place of BERDO energy reporting requirements. The goal is to move toward an EPS instead of energy performance standard because reducing emissions is the ultimate the goal. An EPS would also allow building owners flexibility. If they are informed of future emissions thresholds in advance, they may decide for themselves what schedule and set of projects will be the most cost-effective path to compliance. Implementing such a standard is challenging and must be informed by technical analysis and a robust stakeholder engagement process. Boston has a technical advisory group consisting of architects, engineers, ESCOs, utilities, and contractors providing input on the technical analysis. Crucial to the policy design is grouping buildings into fair typologies, measuring emissions metrics appropriately, and ratcheting down performance requirements in a way that is ambitious yet feasible. After this process, Boston is planning large stakeholder working groups that routinely meet to discuss impacts on various communities or sectors.*

* The Renew Boston Trust and BERDO programs are operational. The emissions performance standard, envisioned as the next evolution of BERDO, is still being developed.

Other

Alongside these policies, the City of Boston recognizes the necessity of working with the Massachusetts state government to implement additional policies that support and enable Boston to achieve its decarbonization goals. For example, building energy codes are determined at the state level, so Boston legally cannot institute energy performance requirements for all city buildings. Massachusetts does have a Stretch Energy Code (which Boston has implemented), but it is no longer as aggressive as it used to be. The Base Energy Code has become increasingly stringent with subsequent updates, effectively catching up to the stretch code. Boston will encourage the state to implement a stretch code with a mandatory ZNC standard. Additionally, achieving citywide decarbonization requires an all-clean electricity mix. Currently, Massachusetts has targeted 80% clean energy in the state by 2050, and Boston will encourage the state government to increase this target to 100%.

Boston also recognizes the importance of developing a sufficient workforce to support the impending transformation of the building sector and is pursuing a variety of programs to ensure this. There are Career and Technical Education courses at several Boston high schools which provide students with skills necessary for careers in construction trades, facilities management, engineering, and environmental science. The city has organized Building Operator Certification training sessions to teach municipal facilities managers how to maximize energy performance. These and other policies will be developed further to ensure that there will be a sufficiently large and well-trained workforce to perform retrofits and build ZNC buildings at a fast enough rate to achieve the city's climate goals.

Policy Strategies

Stakeholder Engagement

Extensive stakeholder engagement has been a crucial part of Boston's process of developing building efficiency policies. There are several standing organizations in Boston that serve a convening function to bring together stakeholders on this issue (Figure 1). The Boston Green Ribbon Commission (GRC) consists of a diverse collection of city leaders who are committed to meeting the goals of the Climate Action Plan broadly. This includes leaders in real estate, higher education, technology, government, health care, utilities, and cultural institutions. A Better City (ABC) also convenes a diverse group of community and private sector leaders to influence policy related to environment and energy, transportation and infrastructure, and land use and development.

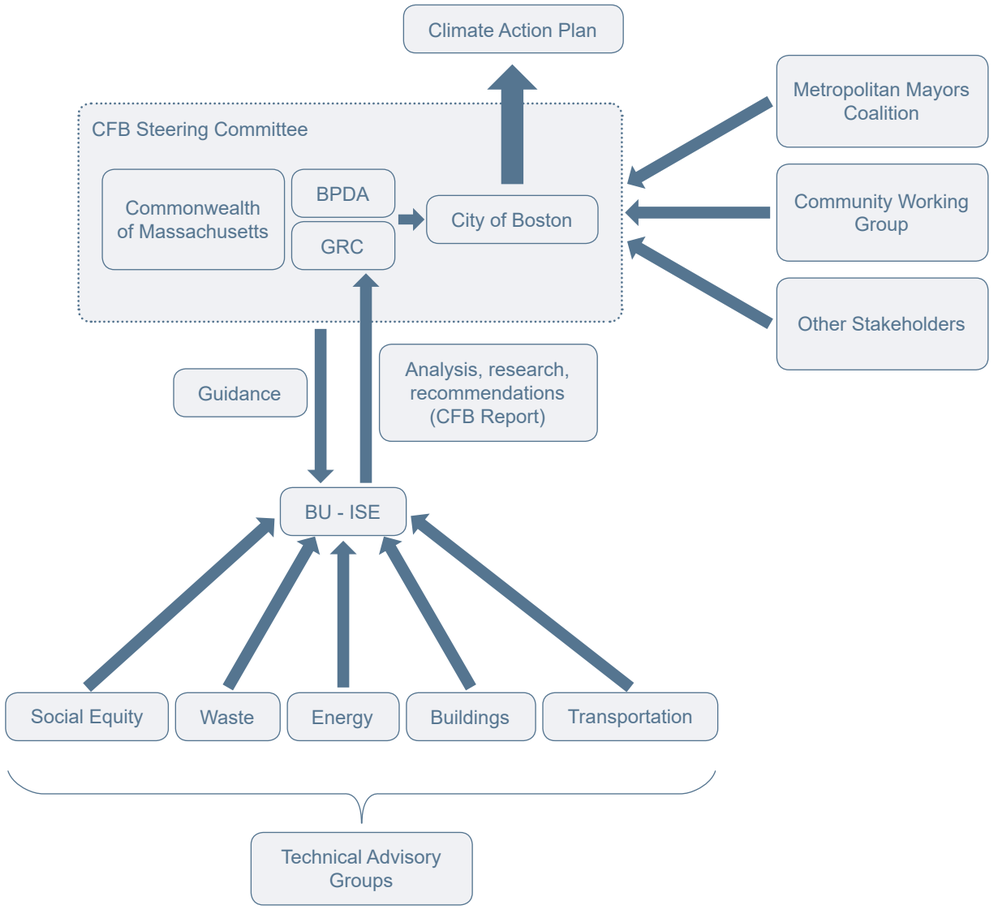
Also, worth noting is the CFB report, a joint effort by the Green Ribbon Commission, the City of Boston, and Boston University's Institute for Sustainable Energy (ISE). This report completed an independent technical analysis to inform the update of the Climate Action Plan. Based on the findings of this report, the Boston city government designed decarbonization policy following an extensive stakeholder engagement process. This public engagement process solicited input from a wide range of community groups to ensure the policies in the Plan are equitable to all citizens, including low-income and minority communities.

This process is evident in the policies Boston has chosen to prioritize. For example, BERDO data have shown clear differences in energy usage across building types, and this was well aligned with stakeholders' inputs.[108] A standard that is easily achievable by one building type may be prohibitively expensive for another. By adopting a tiered ZNC standard, the city incorporates diversity that allows for more flexibility and leads to a more cost-effective pathway to overall emissions reductions goals. And by requiring affordable housing to meet the ZNC standard, the city gives more low-income residents access to the benefits of energy efficient homes, like lower energy bills and improved air quality and comfort.

Boston has enjoyed relatively high buy-in from most relevant stakeholders. Public awareness and concern about climate change are high and there is a strong environmental advocacy presence in Boston. Within this context, the City of Boston has prioritized energy efficiency and clean energy. Beyond the general public, most stakeholders in the building sector are generally supportive of citywide efforts to achieve carbon neutrality. Even building owners, developers, and operators who will ultimately be faced with additional responsibilities or costs because of stricter policies are typically willing to engage in open, honest discussions about the unique challenges they face.

For example, affordable housing units are often on 15-year capital refurbishment cycles, making it difficult to fund renovations or retrofits outside of that schedule. How to navigate affordable housing toward net-zero carbon within its refurbishment cycle becomes critical and requires active involvement of stakeholders. And as mentioned earlier, different building types have specific energy needs and challenges.

FIGURE 1. EXTENSIVE STAKEHOLDER ENGAGEMENT IN BOSTON



BOX 5: SUMMARY OF KEY EXTERNAL ORGANIZATIONS

Green Ribbon Commission: The GRC is a group of leaders (governmental, business, community, etc.) throughout Boston with a goal of fulfilling the goals of the city's Climate Action Plan. The GRC was represented on the CFB steering committee. As a standing organization, Boston maintains a relationship with GRC and works with them on policy development and implementation.

Commonwealth of Massachusetts: This is the state in which Boston is located. Boston lobbies the Commonwealth to develop state-level policies that are conducive to Boston's own climate goals. The Commonwealth was represented on the CFB steering committee.

Metropolitan Mayors Coalition: This group is a collaboration of Boston and 14 surrounding cities and towns. They have collectively committed to net-zero carbon emissions by 2050, and they work to implement climate change mitigation and adaptation solutions that are best solved at a larger community level.

Community Working Group: This is the key stakeholder engagement group convened specifically for the development of the Climate Action Plan. Over 70 organizations were involved, including environmental justice/advocacy groups, labor unions, student associations, developers, construction companies, religious organizations, cultural institutions, and many more. The group met 4 times over the course of the Climate Action Plan's development to develop roadmaps for key strategies.

Boston University (BU) – Institute for Sustainable Energy (ISE): ISE is a BU center that performs research, policy analysis, and collaborative engagement to facilitate a sustainable global energy system. It is a self-described "think-and-do tank" which specifically aims to leverage research to contribute to society. ISE performed the analysis for CFB.

Advisory Groups: Specifically created to inform the CFB report, the technical advisory groups (TAGs) are specialized groups of representatives from a range of organizations with specialized knowledge in four categories: buildings, transportation, waste, and energy. Additionally, a specialized Social Equity Advisory Group was convened to integrate social equity into technical analysis and implementation, as well as assess the impacts of specific policy suggestions on social equity issues. Social equity experts were also included in each TAG.

A Better City (ABC): ABC is another standing stakeholder organization in Boston. It convenes business leaders who seek to cooperate with the public sector and provide technical expertise, research to influence policy in three areas: transportation/infrastructure, land use/development, and environment/energy. ABC was represented on the Climate Action Plan working group and continues to serve in an ongoing collaborative role with the city.

Others: Boston Climate Action Network, investor owned utilities, and many more. See Boston's Climate Action Plan Update for a more comprehensive list.[109]

BOX 6: SUMMARY OF KEY CITY AGENCIES AND DEPARTMENTS

Boston Planning and Developing Agency (BPDA): Tasked with economic planning and development, BPDA is responsible for the green building zoning review process. BPDA was represented on the CFB steering committee.

Boston Housing Authority: This agency oversees affordable housing and assisted with developing affordable housing requirements.

Environment Department (ED): ED carries out the mayor's environmental protection vision, including addressing climate change. ED administers nearly every policy discussed above.

Department of Neighborhood Development: This agency aims to create housing options and manages the city's real estate, and was involved with the affordable housing and municipal building performance requirements.

Others: Other agencies involved include the Board of Building Regulations and Standards, Department of Economic Development, the Department of Workforce Development, and the Health Commission.

Addressing Barriers

The city enjoys generally high public support for emissions reductions efforts, though that is not to say there are no roadblocks to achieving stakeholder buy-in. One of the biggest challenges of promoting ZNC buildings is their perceived high cost. Too often, building developers incorrectly assume that achieving ZNC is prohibitively expensive. In reality, technology has now developed to a point where new ZNC buildings can often be delivered for "little or no additional cost" [110] compared to buildings constructed to code. The additional costs of a high-performance building envelope are largely offset by cost savings from smaller heating and cooling systems to meet the building's lower energy demand. This is especially true for small, multi-family residential buildings which are common in Boston. The city's analysis indicates a price premium of just 2.5% for such buildings.[111]

So-called "first-mover" policies are particularly important for convincing building developers that ZNC is not only achievable, but affordable. First-movers are simply building owners and developers that are the first within a jurisdiction to pursue ZNC projects, before such construction becomes commonplace throughout the industry. The ZNC requirement for municipal buildings is an important example of such a first-mover policy. The city, by constructing all municipal buildings to the highest standards of energy performance, can prove to the rest of the real estate community that ZNC is cost-effective. Adopting a ZNC standard for all low-income, city-funded housing serves the same purpose. Another example is the E+ Green Building Program, run by BPDA. This is a proof-of-concept program to demonstrate that small multifamily residences could achieve ZNC status affordably.

Universities in Boston have been early adopters of net-zero building technology too. For example, Boston University's Center for Computing and Data Science will be a 19-story, ultra-efficient, all-electric building that derives almost all of its heating and cooling energy from geothermal wells onsite, and will make up the balance with offsite solar and wind power, making it ZNC. Innovative, cutting-edge projects like this are tremendously powerful in changing the industry's mindset about project costs. One developer entered a meeting about this building with preconceived notions about the high cost of ZNC buildings but walked out with a desire to demo geothermal wells in his own developments.

One stakeholder group that has expressed resistance to ZNC standards is natural gas utilities. Due largely to CFB analysis, the City of Boston has chosen to pursue widespread electrification, which they see as the most cost-effective path to a net-zero building stock. Electrifying building heating threatens the business model of natural gas utilities. In response, such utilities have questioned the cost-effectiveness of electrification, proposing instead that renewable natural gas (produced from anaerobic digestion of organic waste) or synthetic natural gas (produced from renewable power-to-gas systems) could be more cost-effective. The CFB report acknowledges the possibility of such systems playing a future role in Boston's net-zero carbon building sector, but claims they are not yet cost-effective.[112] They are also not currently scalable to meet the required demand, though these solutions could be practical in certain niche applications. More analysis of higher-resolution spatial data was recommended to effectively determine the most cost-effective solutions for individual applications (district heating, for example).

BOX 7: DISTRICT HEATING

District energy systems provide heating for 10% of the floor area in Boston.[113] Vicinity Energy owns the main district heating system, though several smaller, distinct systems are in place at several university and hospital campuses in Boston. District systems are extremely efficient at generating steam via fossil fuel combustion due to economies of scale. Overall efficiencies of CHP are even higher. District-level heating therefore offers significant emissions reductions over single-building systems. BPDA encourages developers to approach district-level solutions as part of the Article 80 Large Project Review using its Smart Utilities policy. Projects over 1.5 million square feet must perform a feasibility study for a CHP system, which must have the ability to island itself and continue providing local heating and power in the event of a power outage.

However, the emissions benefits of district CHP systems will diminish as grid electricity is decarbonized. CFB analysis indicates this break-even point could occur as soon as 2032 unless district energy systems are powered by carbon-free fuels, a difficult task. The CFB analysis did not include a deeper analysis of decarbonizing district heating systems. However, the bordering city of Cambridge undertook a Low Carbon Energy Supply Study which analyzed various scenarios to achieving a carbon neutral energy system. The report found that by integrating water-based district energy systems with thermal storage, the city could achieve its goals more cost-effectively than in a complete electrification scenario. District energy solutions can meet emissions goals if heat is provided by biomass that is proven to be carbon neutral. These systems, as well as district cooling systems were found to be viable in only certain areas of the city with high enough demand density.

District systems could have other benefits too. CHP systems are resilient; they can continue to provide power in the event of grid outages. Thermal storage could be used to store excess renewable electrical energy, helping to stabilize the grid and maximizing the use of renewable sources of power. Using water-based rather than steam-based systems also opens the opportunity to make use of low-temperature waste heat streams from sectors such as industry, water treatment, data centers, and more.[114]

CFB did not undertake a detailed analysis of decarbonizing existing district energy systems within Boston proper, though expressly acknowledged that if this issue is not addressed, residual emissions will remain in Boston's energy sector. This could be an area for future work. The CFB report references sustainable natural gas, solid biomass, and hydrogen generated from renewable electricity as potential solutions for decarbonizing district heating.

Financing and Market Transformation

Policy change requires incentivizing new behavior and building capacity to attain policy goals. For ZNC buildings, this typically involves financial incentives. Most financial incentives at the city and the state level are focused largely on retrofits, for the simple reason that retrofits are often more expensive and challenging to finance than new buildings that are designed to be ZNC from the start. Often, new ZNC buildings carry only a modest price premium compared to buildings built to code, as mentioned earlier.

At the city level, Boston hopes to expand the Renew Boston Trust program to the private sector. On the state level, the Mass Save program provides incentives, mostly in the form of rebates, to homes and businesses to fund energy efficiency projects. The program has some resources available for new construction, but much of the program's focus is on improving existing buildings. Additionally, both programs focus on what might be termed "traditional" efficiency upgrades: weatherization, LED lighting replacements, switching to highly efficient appliances, etc. These are generally characterized by relatively low capital costs and short payback periods. But there is still a lack of funding specifically aimed at achieving ZNC retrofits, leading to lock-in of future emissions that could be saved by more aggressive retrofits.

One reason for this gap is that the payback periods for retrofits necessary to get to ZNC are typically long, on the order of 20-30 years. For example, building envelope improvements are often capital-intensive, requiring decades for the energy savings to pay back the initial investment. Most private developers demand much shorter payback periods of 5 years or less (typical of "traditional" efficiency upgrades).

A possible solution is to undertake comprehensive building retrofits, leveraging the savings from low-capital upgrades to mitigate excessively long payback periods of more capital-intensive measures. Although this means much higher upfront capital investment, it can also unlock greater energy savings (and thus emissions reductions) over the project's lifetime and justify longer payback periods.[115] However, the longer payback periods and higher upfront costs associated with ZNC retrofits still exist, which necessitates the mobilization of funding on a far greater scale than the current level (federally funded programs, for example) and finding innovative ways to finance projects that capture the value of ZNC retrofits. To address this issue, cities and states have experimented with various innovative financing mechanisms, e.g PACE, sustainable energy utility, energy and managed services agreements, and green banks.

Aside from simply providing financial incentives, it is crucial to ensure that the market for ZNC buildings is developed enough to handle the scale that will be required. An estimated 2,000 - 3,000 buildings will need to undergo deep retrofits (to achieve ZNC status) every year in Boston to achieve its climate goals by 2050. And with 4-6 million new square feet of buildings being built every year in Boston, new construction faces similar challenges. Advanced building materials must be affordable and accessible at a large scale, and design and construction workforce must be large enough and adequately trained to support this transition. Boston's first-mover policies should help stimulate these markets by creating demand. Boston is also prioritizing workforce development through training programs and career and technical education programs in public schools.

BERDO also helped lay the groundwork for market transformation. This ordinance requires large commercial buildings to undergo energy saving retrofits or energy audits every five years and requires them to report energy performance annually. This provided a wealth of data on building performance, making stakeholders at all levels more aware of energy use in buildings and ways to improve it. While the requirements applied only to certain buildings, and buildings could choose an audit rather than an efficiency improvement, it led to greater interest in performing energy retrofits as building managers got a better understanding of their energy usage.

Enforcement and Verification

While the design of ZNC buildings is straightforward, it is a greater challenge to ensure those designs are fully implemented and buildings are also constructed and operated in accordance with their design. Facing this challenge, the City of Boston is trying to put together the necessary legal and regulatory framework to handle this task. While Boston hopes to convince the state to implement a ZNC Stretch Energy Code (the Board of Building Regulations and Standards plays a large role in these efforts), the city is focusing on zoning as the best available tool to set up this framework at the moment.

Building codes in Massachusetts are enforced at the local level – in Boston, that is under the purview of the Building Division of the Inspectional Services Department. The Massachusetts Board of Building Regulation and Standards requires all building officials be trained in energy efficiency. The state's Mass Save energy efficiency program provides an Energy Code Technical Support Initiative, jointly sponsored with the state Board of Building Regulation and Standards and Department of Energy Resources, on building energy code and Stretch Code compliance. It is offered throughout the state for free for buildings officials and is open to the public for a fee so that other buildings stakeholders can participate as well (builders, architects, contractors, etc.).[116] Overall statewide code compliance was estimated to be between 85-95% in a 2014 study.[117] It is estimated this is 5-6% higher than it would have been without the state's Code Compliance Support Initiative.[118]

Evidence shows that even under the current building energy code, buildings often end up performing at a lower level of energy performance than they are designed for. But it is difficult to allocate blame amongst developers, builders, owners, and tenants. Likely all share some responsibility. By implementing BERDO, Boston helped open lines of communication between different stakeholders regarding building energy use by making data more widely available. By upgrading BERDO to an EPS, Boston hopes to incentivize further communication between parties that could come up with ways to achieve required emissions reductions goals and increase compliance with building performance standards. For example, the city has promoted green leases between building owners and their tenants to help solve the split incentive problem and encourage building owners to undergo ZNC retrofits.

Enforcement of BERDO is accomplished through a mixture of punitive measures (fines of up to $3000 per building per year for failure to report energy performance data) and outreach efforts. The City Energy Project, a joint initiative from the National Resources Defense Council and the Institute for Market Transformation, helped support initial outreach and implementation efforts by providing on-site staff. The Environment Department published a host of training materials on its website including checklists, compliance guides, and tutorial videos.

BERDO also serves as a compliance mechanism for Boston's other building sector policies. Municipal buildings must report their energy usage (which is then published by the city). This holds the city accountable for the adequate design and operation of its buildings to a ZNC standard. BERDO (eventually the EPS) is also being investigated as a tool to ensure buildings that undergo Article 37 Green Building Zoning review are performing at the level they were designed to achieve. The city is still investigating legal options for using this as an enforcement mechanism and what possible consequences for non-compliance could be. For now, the city's work in the zoning process ends at project approval.

Currently BPDA has two tiers of project review for permitting large development projects. The larger of the two, which applies to developments over 50,000 square feet, requires that buildings achieve LEED-certified status (not required to obtain 3rd-party verification). While city authorities cannot modify the building code, Article 80 of the Boston zoning code allows the city to conduct a comprehensive review process of large developments, avoiding adverse impacts on the environment. This workaround enables the city to work toward some of its climate goals without having to wait for the state to update the Stretch Energy Code. The goal is to eventually update the zoning code for large buildings to a ZNC standard.

It should be noted, however, that while the zoning code defines LEED-certified as the minimum performance standard for large buildings, nearly all large projects ultimately end up achieving a higher energy performance standard. This is because the permitting process is less of a checklist and more of an ongoing dialogue. BPDA can encourage developers to achieve even higher performance standards, highlight the importance of reducing emissions, and point out the financial value of highly efficient buildings. In almost every case, developers end up constructing buildings to a higher standard than the bare minimum.

Future Policy Directions

Boston's main policy priorities now are the EPS and updating the Green Building Zoning to a ZNC standard. Both are being thoroughly vetted in an analysis process soliciting input from technical advisory groups and will utilize stakeholder working groups to discuss potential impacts of the policies. This process ensures the city develops a workable and effective policy with broad stakeholder support before introducing an ordinance for the public hearing process. One possible tool that is being investigated is a carbon linkage fee. Linkage fees seek to "link" commercial development with the impact it has on the community. Boston already assesses two linkage fees – one for housing and one for jobs. These two fees are assessed proportional to the floor area of the commercial development, with the revenues added to funds that finance affordable housing and job training programs in the city. The carbon linkage fee would assess a fee tied to the emissions performance of the development, and revenues could potentially fund community renewable energy development, climate adaptation and resilience measures, or even retrofits of affordable housing. The idea is still in its early stages and the city is attempting to determine whether or not it is an appropriate tool, but it is yet another example of Boston's innovation and commitment to achieving its climate goals despite lacking the authority to directly modify the building code. Another priority for zoning requirements could be requiring onsite solar photovoltaic (PV) for all developments, or at least buildings that are designed to be "PV-ready" or optimized to use onsite PV once it is installed.

Another approach the city may take is instituting a graduated performance threshold. For example, the E+ Green Building program demonstrated that 4-5 story multi-family residences are relatively easy to decarbonize at little additional cost. Such buildings might be subject to stricter requirements right away, while larger projects may have a less stringent performance standard to meet, at least at first. Ultimately, the goal is to set up a review process that ensures new buildings are highly efficient, fully electric, and designed to make maximum use of onsite renewables.

Additionally, the city will continue to work with the state to develop a ZNC stretch code and increase the ambition of the state's renewable portfolio standard. Certainly, a building code update would be simpler than creating complicated legal workarounds such as the green building zoning to address this issue. But the City of Boston also recognizes the need to act now, regardless of the state's actions – so they are utilizing the tools they already have at their disposal to take immediate action.

Remaining Challenges

The most critical policy barrier yet to be fully addressed is not surprising: financing. This is especially true for retrofits. While there are growing opportunities for financing, challenges remain. Financing against future energy savings can work – but not all investors are comfortable with it, especially not for projects with longer payback periods (e.g. ZNC-level retrofits). Investors prefer to see a large body of evidence that similar projects (especially local projects) will yield stable returns, which simply does not exist yet on a large enough scale. "Lead-by-example" policies like Renew Boston Trust for municipal building retrofits help, but these are often for different building typologies than large commercial buildings and so do not directly translate.

Urgency is another challenge – only three decades remain to retrofit most of the existing buildings in the city. That means existing buildings likely have limited opportunities to undergo a comprehensive retrofit between now and then. If they are not done correctly, the city may fail to achieve its climate goals. Quickly developing a large enough and well-trained workforce to perform these retrofits will be difficult, though the city does prioritize workforce development. Additionally, the city will strive to provide long-term signals to the private market about future policy requirements and goals. For example, the EPS, once developed, is expected to have performance requirements that over time ratchet down the allowable emissions intensity of buildings. Building owners can then plan for future requirements and make the best decision for their own situation about when and how to undergo a comprehensive retrofit. Incorporating flexibility (e.g. allowing offsite renewable power purchases for temporary compliance) further enables developers to make cost-effective decisions that meet long-term emissions goals.

Additionally, achieving ZNC may not necessarily be purely cost-effective for 100% of projects, especially retrofits. Even with creative financing that effectively unlocks future savings to pay for current costs, certain projects will not break even – and to pay for those projects, public investment will be required on a scale larger than the city alone can provide. State- or federal-level solutions may be necessary. This does not currently seem to be a priority of the federal government, and state-level spending may be difficult to secure given the budgetary stress brought on by the COVID-19 response, meaning this may remain a challenge for the foreseeable future.

Some technoeconomic barriers remain as well. For example, the low cost of natural gas makes it more difficult to convince customers to electrify their buildings. And certain energy-dense applications like hot water in large residential buildings do not yet have an obvious path to electrification.

Policy Recommendations and Lessons Learned

The City of Boston is unequivocally a leader in US energy and climate policy, especially in the building sector. Studying their policies and the intent behind them has provided valuable insight into what has enabled the city to be so successful with its building policies. Some of the key takeaways are listed here.

Utilize extensive stakeholder engagement: Stakeholder engagement should begin early, cover all relevant stakeholders, and be an ongoing process. Engaging stakeholders early ensures that policy goals and barriers are understood from the start. Gathering input from all relevant stakeholders (especially underrepresented communities like the poor, minorities, elderly, etc.) helps ensure no group is surprised or disproportionately affected by new policies. And by treating engagement as an ongoing process (rather than something to be done once), compliance can be enhanced.

Mandates are preferable to voluntary programs: Mandates are generally more effective at achieving bold climate goals than voluntary programs. However, when mandates are not achievable, they are not effective. Enabling policies are therefore crucial, such as workforce development (e.g. training programs), market transformation (e.g. demand-boosting programs like public building leadership), or financial incentives/assistance (to ease the burden of upfront capital costs).

Utilize energy/emissions performance requirements: This is beneficial for two reasons. First, it provides a large amount of data that can and should be used to inform future policy design. Second, this is a way to manage compliance with mandatory policies, since it is apparent when buildings are not meeting necessary performance levels.

Use robust analysis to inform policy development: Boston's latest policy efforts stem from rigorous analysis. Such analysis is crucial because it allows governments to understand the most affordable and achievable long-term pathways to achieving emissions reduction goals. For example, Boston found that "traditional" energy efficiency measures, while valuable, are limited in their effectiveness. Comprehensive retrofits are necessary – in particular, electrification retrofits. That fundamentally alters a government's approach to energy efficiency and heavily informs its policy choices. Boston's choice to move to an emissions performance standard (rather than an energy performance standard) is an example. Such a standard inherently incentivizes electrification, while energy performance standards might only incentivize marginal improvements (more efficient natural gas boilers, for example) that could lead to lock-in of future emissions.

Align policies at all levels of government: While Boston has shown remarkable leadership in building policy, there are limitations to what can be done. The city has no jurisdiction over the building code, for example. They have been creative in finding ways to work around this as much as possible, but a far more straightforward, simple, and efficient solution would be for the Commonwealth of Massachusetts to increase the stringency of the state building code. The state can enact renewable portfolio standards for utilities, which would create an enabling environment to achieve net-zero carbon in cities like Boston. And programs should properly align incentives to synergize action - it is much harder for Boston to encourage ZNC retrofits when there are no state/federal incentives specifically targeted at achieving this standard.

These lessons can help inform other cities in their approach to achieving a net-zero carbon building sector. While each city, state, and country is different and faces a unique set of challenges, Boston's leadership proves that with some creativity and commitment, even highly aspirational climate goals are achievable. Broad engagement of stakeholders and a data-driven approach ensure well-designed, achievable, and enforceable

policy. Approaching climate goals from a sector-wide perspective allows for flexibility and cost-effectiveness. And finally, the importance of the government acting as a "first-mover" cannot be understated, as this proves to the private sector the feasibility, affordability, and financial value of ZNC buildings.

3.2 CALIFORNIA'S POLICIES ON NET-ZERO BUILDINGS

California boasts both the largest population[119] and the largest state economy in the US.[120] Fortunately, California has also consistently been a leader in climate and energy efficiency policy and has long championed some of the most aggressive decarbonization goals in the country. California's current goal of reducing statewide GHG emissions 80% by 2050 (measured from a 1990 baseline) has been in place since 2005.[121] The state has made steady progress toward that goal; as of 2017, emissions had decreased 13% from 2005 levels (or about 1.6% below 1990 levels).[122]

California is an instructive case study for several reasons. First, besides the state's size, California spans multiple climate zones and geographies. Second, a diverse and ambitious local policy landscape provides state policymakers a unique opportunity to interact with and encourage local policy efforts. Third, the state prioritizes enforcement of its building energy code, which it uses as a transformational tool. Fourth, California emphasizes renewable electricity and electrification, addressing buildings as part of an economywide decarbonization effort.

Finally, California's building sector goals and policies have shifted over time in response to changing market conditions. In 2008, California set a goal to require all new residential construction to be net-zero energy by 2020 by updating Title 24, Part 6 of the state's mandatory BEES.[123] But the most recent version of the standards did not explicitly call for a net-zero requirement. Instead, it requires stringent energy performance and requires all new homes to be equipped with rooftop solar panels. Understanding how and why these goals shifted over time is instructive to pinpointing the barriers to building sector decarbonization, especially in the residential sector, and highlights the importance of evolving policies over time to address these barriers.

BOX 8: CALIFORNIA'S POLICIES TO ACHIEVE NET-ZERO CARBON BUILDINGS

- Building Energy Efficiency Standards
- Building Energy Benchmarking Program
- Public building ZNE requirement
- BUILD and TECH: building electrification programs
- California Advance Home Program (new residential construction)
- Savings by Design (new commercial construction)
- Energy Design Rating Score
- Home Energy Rating System and Acceptance Testing

BOX 9: STRATEGIES FOR POLICY IMPLEMENTATION

- Use energy codes and building standards as transformational tools
  - Utilize pre-existing stakeholder engagement structures
  - Mandatory policies are preferable to voluntary ones
- Prioritize compliance as much as policy design
  - Ambitious policy is useless without compliance
  - Build capacity through outreach and training programs
  - Require physical inspection and testing of key building systems
- Cooperate with other governments and organizations to align policies
  - Utilities, local governments, or other organizations have expertise, data, and knowledge that can improve policy design and compliance
  - Ambition may be higher locally - remove barriers and allow cities to lead
- Approach building decarbonization within the context of economywide decarbonization
  - Integrate building-specific policies into broader decarbonization efforts (e.g. decarbonizing the grid electricity mix)
  - Revenue-generating programs (e.g. carbon pricing, fines) can be used to fund pilot programs to further advance decarbonization goals
- Align incentives to accomplish end goals
  - Provide financial incentives to encourage building decarbonization
  - Remove policies that discourage compliance with policy goals

Net-Zero Goals in California

BOX 10: CALIFORNIA'S NET-ZERO GOALS

- Statewide net-zero carbon by 2045
  - 80% reduction of all GHG emissions by 2045; 40% by 2030 (1990 baseline)
  - 100% clean electricity by 2045; 60% by 2030
- Publicly owned buildings must all be ZNE
  - Retrofit at least 50% of existing publicly owned buildings to ZNE by 2025

California has long set strong climate goals. The target of reducing GHG emissions by 80% (from 1990 levels) by 2050 has been in place via executive order (EO) since 2005.[124] In 2006 the legislature passed SB-32 (Senate Bill 32), writing that goal into state law and adding an intermediate goal of 40% reduction by 2030.[125] California's legislature also passed SB-350 in 2015, which established goals for renewable energy procurement (50% by 2030) and the amount of energy saved via energy-efficient measures or practices (100% increase by 2030).[126] California went even further in 2018 with the passage of SB-100 and EO B-55-18, both passed in 2018. The former requires 100% zero-carbon electricity by 2045 and ups the 2030 goal to 60%.[127] The latter calls for statewide carbon neutrality by 2045.[128]

Legislative action is a defining feature of California's energy and climate goals. Many governors across the country have issued executive orders to establish similar goals to California for emissions reductions or renewable portfolio procurement in their states, but relatively few states have these goals written into law. Executive orders can be revoked unilaterally by a future administration, but legislation is much more difficult to overturn. This sends a more consistent and predictable market signal and is more enforceable than an executive order.

For the building sector specifically, AB-3232 (Assembly Bill 3232) called for the CEC to complete a study analyzing the feasibility of reducing building sector emissions by 40% by 2030 (though this is not yet mandated).[129] As of 2017, all new publicly owned buildings must qualify as ZNE. Finally, by 2025, all state agencies must conduct retrofits to achieve ZNE for at least 50 percent of the total existing floor area managed by that agency.[130]

Originally, the CEC aimed to implement net-zero energy requirements into the BEES (residential by 2020 and commercial by 2030).[131] However, the last triannual update took effect on January 1, 2020 with no residential net-zero requirement. That is not to say the standards are not ambitious. The standards require all new residential buildings in California to be built with rooftop solar panels and achieve highly efficient energy performance. The code stops short of a strict net-zero requirement though. Such a requirement might be preferable for its ambition and because the certainty it would provide could encourage innovation. However, the prescriptive rooftop solar requirement is simpler to enforce than a net-zero performance requirement. Furthermore, the rooftop solar requirement lays the groundwork for a net-zero standard in the future.

The Building Decarbonization Coalition (a buildings stakeholder group engaging in research and policy) recommends California refocus on these goals and institute net-zero requirements into the residential and commercial building standards by 2025 and 2028, respectively, though these goals have not been implemented by the state government.[132]

Defining Net-Zero Buildings

The California Department of General Services provides the following definitions for ZNE buildings, campuses, portfolios, or communities:

"An energy-efficient [building, campus, portfolio, or community] where, on a source energy basis, the actual annual consumed energy is less than or equal to the on-site renewable generated energy." [133]

The definition does not include embodied energy, only operational energy. This provides some flexibility to account for the fact that different buildings have different energy needs. For example, a typical hospital's EUI is around four times higher than a typical office building.[134] California's approach to dealing with this challenge was to broaden the spatial boundaries of net-zero (though notably, on-site generation is still required). This is consistent with research that finds expanding the definition of net-zero beyond individual buildings makes net-zero goals more achievable.[135]

Policy Tools

New Buildings

It is estimated that ⅓ of California's 2045 building stock has not yet been built.[136] Because it is much easier to decarbonize new buildings than existing ones, this represents a huge opportunity for the state - it is crucial to achieve outstanding energy performance in these new buildings. The state has not expressly instituted a decarbonization goal specific to the building sector but is aiming for economywide carbon neutrality by 2045. Reducing the emissions impact of new buildings will be a necessary part of that effort. The policies below are a few of the most important steps California policymakers have taken to decarbonizing new buildings.

1. State Owned Building ZNE Requirement: As of 2017, all new state owned buildings must be constructed to the ZNE standard outlined above.[137] This was motivated by a desire to lead by example and help develop the market for net-zero construction. According to New Buildings Institute (NBI), 31 publicly owned buildings have been certified as ZNE, while another 129 are listed as ZNE "emerging," which generally means a building that is either incomplete or has not been occupied long enough to verify ZNE performance over the course of a year.[138] (Note that the NBI definition allows for off-site renewable energy generation, the California definition does not).
2. Building Energy Efficiency Standards: Arguably the most effective policy tool California uses to lower building sector emissions is the state's aggressive building energy code, developed by the CEC. Title 24, Part 6 of the California Code Regulations outlines the state's BEES, which are some of the most stringent in the country -the 2016 standards were approximately 29%more stringent than the national model code (IECC 2015).[139] The 2019 standards (which took effect Jan. 1, 2020) are even more impressive. Besides more stringent efficiency requirements, the residential code is also the first in the country to require all new residential buildings to install solar panels. The motivation for this was the state's goal of requiring ZNE for all new construction by 2020. However, the required amount of solar capacity falls short of the amount needed to achieve ZNE. This is because the CEC cannot implement any standards which are not deemed cost-effective for consumers. Solar panels can meet the cost-effectiveness requirement by saving customers on future energy bills, but continued expansion of solar capacity to completely offset annual residential energy usage would not have been cost-effective. The Title 24 Standards also restrict new natural gas hookups - they are allowable only if their installation does not require an extension of the main gas pipeline. Natural gas hookups are not outright banned, however.[140]
3. California Green Building Standards Code: In addition to Title 24, Part 6 (BEES), Title 24 Part 11 (CALGreen) is a set of standards intended to reduce emissions from buildings. There are versions for both residential and non-residential buildings. They do not regulate building energy performance; they include a variety of measures intended to encourage decarbonization more broadly. For example, they mandate a minimum amount of bike parking and EV charging stations that each building must include, limit water usage via maximum flow rates for faucets and toilets and mandatory water reuse systems, and limit the volatile organic compound content of paints and coatings used. Life-cycle measures are also included: construction must include a commissioning process, at least 65%of construction waste must be recycled, and use of high global-warming potential refrigerants is restricted. More ambitious voluntary measures are also included which municipalities have the option of making mandatory.[141] The emissions associated with buildings go well beyond their energy usage, and this is how California has chosen to address these indirect, life-cycle emissions.
4. BUILD Program: With the passage of SB-1477 in 2018, the California legislature allocated $200 million over four years to support two new zero-carbon building pilot programs. One is the BUILD program, which targets new residential buildings.[142] The BUILD Program provides direct incentives for the construction of new, all-electric buildings (new buildings with gas hookups will not be eligible for funding).[143] SB-1477 points to the lack of uptake of near-zero emissions construction practices despite "favorable economics of achieving deep emissions reductions in new buildings" as the motivation for the creation of the BUILD program.[144] Results from this program are not yet available. Funding for the program is provided by revenue from the sale of emissions credits to the state's natural gas utilities under the Cap-and-Trade Program.

Existing Buildings

In any jurisdiction's building sector decarbonization efforts, existing buildings are critical. The challenges unique to retrofitting existing buildings require innovative policy measures. Some of California's approaches are listed below.

1. Building Energy Benchmarking Program: California's Building Energy Benchmarking Program requires all buildings over 50,000 square feet to annually report their EUI (benchmarked using ENERGY STAR Portfolio Manager) to the CEC. This information is made available to the public.[145] Additionally, all state owned buildings must report their EUI.[146] Failure to comply is enforced with fines of $500-$3000 per day (beginning 30 days after being informed of the violation).[147] Compliance is further improved via online resources such as frequently asked questions, training videos, and checklists.[148]
2. TECH Initiative: The TECH Initiative is the second pilot program authorized by SB-1477, and it is focused on market development for low-emissions space and water heating equipment, primarily for existing buildings, though not exclusively. The program will provide (rulemaking in progress) consumer education, contractor/vendor training, and upstream/ midstream incentives. It will target promising decarbonizing technologies in early stages of market development. The program will also develop evaluation metrics, outreach strategies for hard-to-reach customers, and job training and employment opportunities.[149] The SB-1477 legislation states that "clean heating technologies are not widely available in the marketplace" as the motivation for the TECH program.[150] Recognizing the need for policies that are tailored to specific market segments and to the state of technology deployment, the TECH initiative takes an upstream approach rather than a direct incentive approach. Furthermore, widespread implementation of

such technologies requires a well-trained and educated workforce to sell, install, and maintain them, hence the program's focus on workforce development. Funding for the program is provided by revenue from the sale of emissions credits to the state's natural gas utilities under the Cap-and-Trade Program.

Other

Several policies are notably important to the building sector but do not specifically target new or existing buildings (or even the sector specifically, in some cases). The examples listed below are reflective of California's strong, multifaceted approach to decarbonization policies. The state operates one of the largest carbon pricing schemes in the world and is making a concerted effort toward decarbonizing the electricity supply. These efforts are combined with policies aimed at electrifying space and water heating to reduce emissions from the building sector.

1. Cap-and-Trade Program: AB-32 authorized the California Air and Resources Board (CARB) to adopt "market-based compliance mechanisms" to achieve the state's GHG emissions targets, which led to the development of the California Cap-and-Trade Program.[151] The program applies to large electricity generators and industrial facilities as well as distributors of transportation fuels and natural gas, covering about 85% of GHG emissions in the state.[152] The legislation is obviously consequential to the building sector because it incentivizes the decarbonization of electricity and reduced natural gas usage in buildings. It is also impactful because the revenue generated from the sale of emissions credits to natural gas utilities is the funding source for the BUILD and TECH programs created by SB-1477.[153]
2. Renewable Portfolio Standard: This standard requires that load-serving entities (utilities, electricity service providers, and community choice aggregators) procure a certain percentage of their energy from renewable energy sources (the CEC certifies renewable energy facilities). The targets are 33% by 2021, 44% by 2025, 52% by 2028, and 60% by 2031.[154]
3. Time-of-Use Electricity Rates: All industrial, agricultural, and commercial utility customers must pay a rate that varies depending on the time of day. Rates are highest during peak demand hours and lowest during off-peak hours. The purpose is to incentivize customers to shift energy usage to times of the day when renewables are most plentiful, but demand is not as high. This increases the overall usage of renewables and minimizes the need to use fossil fuel energy during high demand, low renewable times of the day. Residential customers may voluntarily participate to save energy on their bill. The CEC develops these pricing mechanisms, which are subject to approval via a California Public Utilities Commission (CPUC) rate-setting procedure.

Interaction with Local Policy

A striking feature of California's building policy landscape is the interaction between state and local policy. While the state maintains stringent building policies that apply statewide, many municipalities have instituted their own even more stringent requirements for the energy or emissions performance of buildings. California is unlike some other states in that municipalities are free to independently enact BEES (reach codes, essentially) that are more stringent than the state-level standards.

At least 21 California cities or counties have passed local energy ordinances that are more stringent than state requirements outlined in Title 24.[155] Thirteen require higher levels of solar PV installation than state standards. Sixteen have additional energy efficiency requirements, like exceeding energy performance requirements by a certain margin or installing some other prescriptive measure, such as cool roofs. Three require EV-readiness in new construction. And possibly most impressive - in 20 different municipalities, natural gas hookups for new construction have been banned outright, requiring full building electrification, which the CEC stopped short of requiring in Title 24. The CEC does not do any outreach or expressly encourage municipalities to institute more stringent requirements (it is not within their authority) but does provide support to cities and counties who have chosen to pursue more ambitious policies. While the CEC cannot (yet) regulate building standards based on GHG emissions, some cities have found legal workarounds to expressly regulate emissions, and the CEC works with those cities to ensure proposed measures are cost-effective.

That is not to say cities and counties are alone in developing their own standards. Many organizations work statewide to push local ordinances. Investor owned utilities have developed studies for municipalities to analyze the cost-effectiveness of certain building provisions that local authorities are interested in pursuing. (This is the one requirement that local ordinances must meet: cost-effectiveness. However, the definition of "cost-effective" is left up to the local jurisdiction itself, so there is some latitude even with that requirement and municipalities have a great deal of freedom to set local ordinances). Large non-governmental organizations (NGOs) such as the National Resources Defense Council, Sierra Club, and others attend public hearings for local ordinances to offer support and influence local policy. Towns in similar climate zones and/or with similar building stocks collaborate and share challenges to implementation and best practices.

Another important resource for municipalities is the three regional energy networks (RENs). Located in the Bay Area (BayREN), Southern California (SoCalREN), and Tri-County Area (3-C REN), these are collaborations between local governments that provide energy efficiency programs to their regions. This can take many forms, including financing tools (rebates, PACE financing, loan programs), code development, code compliance outreach, training, and education, and even project delivery assistance (auditing, financial support, technical assistance) for public agencies implementing energy efficient projects. Some produce templates for local ordinances (reach codes) to make it easier for municipalities to implement their own. RENs can provide a level of support that a single county or city cannot provide, and a level of flexibility and customizability that a utility might not be able to achieve. RENs are to undertake activities that utilities "cannot or do not intend to undertake... where there is no current utility program offering and where there is potential for scalability to a broader geographic reach…[or] in hard to reach markets, whether or not there is a current utility program that may overlap."[156] They also serve a convening role for stakeholders - BayREN, for example, hosts quarterly forums to share best practices on local energy policy.[157]

Besides local energy ordinances, cities may use other measures to pursue more aggressive building policies. For example, six cities (including the four most populous) are exempt from the statewide building energy benchmarking program because they have their own more stringent disclosure policies that set a lower square footage threshold for reporting and/or require periodic energy saving measures or audits that go beyond standard benchmarking.[158]

The ambition of municipalities is a significant asset of California's energy policy landscape and state-level policymakers. With cities and counties pushing for more and more ambitious building policies (some have instituted net-zero carbon goals, for example), state policy makers are able to be more ambitious than they may otherwise have been. Local policies help to develop a workforce and a market for low-emissions buildings, which will eventually reach a tipping point to make ultra-efficient buildings commonplace throughout the state.

Policy Strategies

Stakeholder Engagement

When updating the Title 24 standards, the CEC runs a rigorous process designed to solicit input from many relevant stakeholders and ensure that proposed changes are indeed cost-effective and in the best interests of Californians before they are added to the code. It is also a completely transparent and open public process.

IOUs play a significant role in the code development process. Through the Codes and Standards Enhancement (CASE) Initiative (a collaboration of the three IOUs and two publicly owned utilities) they help identify possible changes to the code that would improve energy efficiency. With research and analysis, they develop CASE reports that determine the energy, emissions, and/or money savings of various proposals. The CEC is constrained by the limitation that code updates must be cost-effective for consumers. Proving this is the case requires a large body of evidence which IOUs can readily provide. As the process is completely public, any individual or organization can propose changes to the standards - IOUs are simply best suited to meet the burden of evidence. CASE also engages stakeholders to understand the impacts of proposed code changes before they are even presented to the CEC.

Back in 2015, the CEC and the CPUC set out to achieve the goal of ZNE in all new residential construction by

2020. The Residential Zero Net Energy Action Plan emphasized the importance of stakeholder engagement and consistency between local and state policies, highlighting the ZNE goal as a framework for these crucial tasks. The goal was to build up a robust market for ZNE buildings using a variety of policies (education/outreach programs, workforce development, financing tools and incentives, and technological innovation), ultimately building up to a ZNE requirement that would be added to the Title 24 standards. This framing was intentional: "the goal for ZNE to be regulated by Codes and Standards beginning in 2020 provides the coordination" necessary to achieve the end goal and "encourages the alignment of state goals with local policies and planning."[159]

It should be noted that the CEC did not ultimately add the ZNE requirement to the 2019 Title 24 update (which took effect on January 1, 2020; the code is updated every three years). The intention was to reduce energy use in new homes by increasing the stringency of various efficiency requirements, then have homes install enough solar panels to compensate for the remaining energy use. However, as the code update approached, it became clear that a ZNE mandate could not be considered cost-effective. At first, solar panels reduce the electricity bills of customers, thus meeting the cost-effectiveness requirement. But beyond a certain point, additional capacity would just be overgeneration, so without net metering (which is not in effect beyond a customer's actual usage), customers would no longer see marginal financial benefit, but would incur the additional cost of the panels.

However, the fact that the ZNE requirement did not materialize should not necessarily be viewed as a failure. First, the latest standards are still quite stringent. Buildings built to comply with the 2019 standards are expected to use approximately 7% less energy than the 2016 standards, or 53% when the required solar power is deducted.[160] Second, the process of striving for the ZNE mandate spurred advances along the way in financing, local policy, grid integration of distributed generation to further develop a low-carbon building sector. Besides, requiring homes to install higher solar capacity may lead to overcapacity. The grid, historically designed to be a one-way distribution network, could hardly absorb all the additional capacity; and could undermine grid stability.

BOX 11: SUMMARY OF KEY STATE AGENCIES AND DEPARTMENTS

California Energy Commission: The CEC is responsible for much of California's energy policy. It develops the building standards (Title 24) and appliance standards, supports energy research and development, helps the state plan its path to achieving its future energy goals, and runs important programs like the Acceptance Test Technician Certification Program, Building Energy Benchmarking Program, Renewable Fuel Portfolio Standard (and many more).

California Public Utilities Commission: The CPUC regulates utilities in California (including natural gas and electricity utilities) to protect consumers and the environment and works to improve the reliability and resiliency of utility services. The CPUC determines allowable revenue and sets electricity rates (including time-of-use rates) for IOUs in the State of California.

California Air Resources Board: CARB is the authority responsible for regulating air pollutants, including GHG emissions, in California. CARB runs the Cap-and-Trade program.

California Building Standards Commission (CBCC): The CBCC is heavily involved with the implementation and enforcement of the Title 24 building standards, including Part 6 (BEES) and Part 11 (California Green Buildings Standards, or CALGreen).

BOX 12: SUMMARY OF KEY NON-STATE ORGANIZATIONS

Regional Energy Networks (BayREN, SoCalREN, and 3-C REN): RENs are ratepayer-funded organizations that fill an important niche in energy efficiency policy. They are collaborations of local governments that undertake energy efficiency efforts on a regional level. The scope of the RENs' work includes financing, education and outreach for code compliance, workforce development, professional services like auditing and technical support for local governments, stakeholder engagement efforts, and even local code development. RENs leverage the resources of an entire region while providing services that utilities cannot easily provide.

Local Government Sustainable Energy Coalition: This is a coalition of municipal governments that supports sustainable energy. They collectively influence state-level policy and convene local energy leaders to share information on best practices and successful programs.

Codes and Standards Enhancement Initiative: The CASE team consists of the three IOUs in California, plus two publicly owned utilities. CASE plays an important role in the CEC's rulemaking process, though it is a distinct entity. They identify possible changes to the energy code, perform research and analysis, and convene stakeholders to generate CASE reports outlining the expected outcomes of proposed code changes (energy/cost/emissions savings, for example). CASE also works with the CEC throughout the rulemaking process and helps incorporate newly implemented code changes. CASE maintains code compliance reference manuals and software.[161]

Addressing Barriers

California has made significant progress in addressing some of the typical barriers to decarbonizing the building sector. The CEC has recognized the importance of electrification of building space and water heating, as evidence has shown it to be the cheapest, most technologically feasible means to decarbonize the sector.[162] But certain barriers have made electrification challenging to achieve. High upfront cost is one such barrier, which policymakers have attempted to address through a variety of financial incentives (see next section).

Incentivizing electrification alone is insufficient to spur electrification - regulatory disincentives (intentional or not) must also be removed. Two measures added to the 2019 BEES did just this. First, language requiring natural gas appliances in new homes was removed, allowing for all-electric buildings. Second, an all-electric prescriptive compliance path for homes was established. All-electric baselines for multifamily and common commercial building types are being developed for the 2022 update.[163]

Another example of removing an unintentional disincentive is the "three-prong test." In 1992, a law was passed in California that required fuel substitution measures to pass a three-prong test to ensure the measure did not increase energy consumption, increase total costs, or adversely impact the environment. At the time, when grid electricity was far more carbon-intensive than it is today and electric equipment was far less efficient than natural gas-powered equipment, disincentivizing electrification was beneficial from an emissions perspective. However, as more renewables were integrated into the grid and heat pumps became more efficient, electrification became the lower-emission option. This rule then became a barrier to beneficial electrification. It was modified to remove this disincentive in 2019.[164] It is crucial to understand the existing policy environment deeply or unintended interactions with other policies could neutralize new policy efforts.

Another barrier that needed to be addressed was removing disincentives for IOUs to pursue energy efficiency measures. As the entity selling energy to consumers, utilities would not naturally support efficiency programs, because that would mean lower

energy demand, thus decreasing sales and revenue. California addressed this issue with utility decoupling, which basically means the CPUC determines a utility's allowable revenue on multiple metrics besides volume of electricity sold. Examples of metrics include the cost of providing service and the capital and operating expenditures associated with energy infrastructure investments. Additionally, the CPUC adopted the Efficiency Savings and Performance Incentive (ESPI) mechanism which provides additional incentives for utilities to pursue energy efficiency. The CPUC sets energy efficiency goals for each IOU in the state. If an IOU meets its goals because it operates successful energy efficiency programs, the CPUC will grant it additional allowable revenue. Utilities can also earn additional revenue for codes and standards advocacy programs or non-resource energy efficiency programs (e.g. marketing, training, education, etc.).[165] This gives utilities a strong incentive to pursue energy efficiency measures, enabling the state to leverage the resources and expertise of IOUs to their benefit.

Public support is generally high for clean energy and energy efficiency in California, though even in this context the framing of energy efficiency measures must be carefully considered. One key recommendation that emerged from this research is the importance of framing energy-saving measures as “efficiency” rather than “conservation.” The former implies delivering the same performance using less energy, while the latter implies compromising performance to use less energy. It is a minor distinction, but it makes an outsized difference. Improvements to building envelopes to eliminate drafts do not just save energy and money - they increase the quality and comfort of buildings. Framing it this way may make building owners more willing to pursue retrofits or developers to construct more efficient buildings.

Financing and Market Transformation

High upfront cost is always the primary barrier that prevents the widespread adoption of energy efficiency in buildings. Large upfront capital costs can often lead to substantial future energy savings, but the risk of those savings never fully materializing (or simply the lack of available upfront capital) makes it difficult to convince building owners to move forward with energy efficiency upgrades or building developers to pursue highly-efficient construction. California’s state agencies, IOUs, and RENs run several impactful programs that seek to minimize the financial burden of investing in energy efficiency. Other programs seek to transform the market for high-performance buildings via workforce development, training, or outreach and education on the benefits of efficiency and related technologies.

The CEC runs several programs that incentivize the retrofitting of schools. The Bright Schools Program provides free support services to schools planning energy retrofits, such as energy audits to identify energy-saving opportunities and reviewing proposals and designs. Additionally, the Energy Conservation Assistance Act provides schools with zero-interest loans to finance their energy efficiency projects.

Other state-run policies facilitate energy efficiency projects at the local level. Analogous to the Bright Schools Program, the Energy Partnership Program provides free support services to municipalities, universities, and hospitals pursuing energy efficiency for existing buildings and new construction alike. The Energy Conservation Assistance Act also provides low-interest loans for such projects. Projects with payback periods of up to 17 years are eligible (and even longer can receive partial funding), which allows for the pursuit of deep retrofits characterized by longer payback periods but greater overall energy savings. The Local Government Challenge is a competitive grant program that has awarded over $10 million for efficiency and renewable energy projects across the state. With the support of this program, three projects have been completed so far (grants were awarded in 2017) and the remaining ten are expected to finish this year. Several of the selected projects involved efficiency upgrades in municipal facilities. One condition of the grants was that winners had to share best practices to inform and encourage further action throughout the state.

IOUs have huge slates of “traditional” ratepayer-funded energy efficiency financing tools including rebates and zero-interest on-bill financing for equipment installations or building retrofits, available to all customers: homeowners to large businesses. Besides these typical measures, the IOUs offer a robust portfolio of other energy- and money-saving programs to customers. Businesses that use above a specified amount of electricity can receive incentives if they reduce their demand during peak hours. Homes and businesses can receive incentives for installing battery systems intended to optimize the usage of solar installations. By charging batteries with excessive solar generation and discharging the batter during peak hours, customers can save money on energy bills by reducing peak energy usage from the grid.

RENs offer their own suite of financing tools as well, such as residential PACE financing (offered by BayREN and SoCalREN). This financing mechanism prevents homeowners from having to put a down payment on energy efficiency and clean energy home improvements - instead, the cost of the improvements gets assessed on property tax bills for the property. The liability thus stays with the property, rather than the homeowner, which helps address the temporal split incentive (when homeowners do not pursue energy saving measures because they fear they will move out before recovering the upfront costs). Through BayREN, multifamily residences can access zero-interest matching funds to reduce the overall interest rate for loans used for energy efficiency upgrades. SoCalREN offers capital lease agreements for equipment replacement projects. In such an agreement, the lender owns the equipment financed by the program and transfers ownership to the borrower once the loan is paid off. They also offer energy service agreements, where property owners can repay contractors for project costs based on actual future savings. This helps reduce hesitancy on the part of building owners that energy savings will be sufficient to repay a loan.

Market transformation is also crucial to the success of the policies discussed throughout this report, and various efforts are underway from state agencies, local governments, IOUs, and RENs.

The TECH initiative is an example. Authorized by SB-1477, the initiative is expressly intended to advance the market for low-emission heating technologies (heat pumps, mainly). On the demand side, the initiative focuses on consumer education about low-emission heating equipment (many consumers are unfamiliar with these emerging technologies). On the supply side, the initiative provides training and incentives for vendors and contractors to sell/install low-emission heating equipment (both in new and existing buildings). The CEC is accepting proposals for a third-party to implement the program and will develop metrics to evaluate the success of the program, as well as assist in the development of outreach strategies and job training and employment development.[166]

Workforce development is an important task that the RENs have taken a leading role in addressing. For example, 3-C REN provides a series of workforce development workshops to train building professionals on a variety of topics, including how to use energy modeling software and how to perform certain retrofits. SoCalREN provides workforce education, training, one-on-one technical assistance, and even paid apprenticeships for contractors.

Enforcement and Verification

While California’s BEES are some of the most stringent in the country, that means little if the standards are not effectively enforced. Achieving high levels of compliance with building standards is extremely difficult due to the number of market actors involved, varying levels of regulation, and variety of building types. Strong enforcement and verification efforts exist to ensure California’s ambitious policies are carried out.

Recognizing this challenge, the CEC created the BEES O&E Unit, which is responsible for educating buildings stakeholders and enforcement agencies. Building codes are enforced by local agencies in California. If a building fails to comply with state building regulations like BEES, cities should refuse to issue local building permits. The O&E unit is currently holding several seminars a month (remote now, but usually held across the state) to inform local enforcement agencies of updates to the standards and other programs. Compliance forms, fact sheets, training videos, and links to compliance software and external organizations with educational materials can be found on the CEC website.

The CEC leverages the resources of other organizations too, such as IOUs and RENs. Incentivized by the ESPI mechanism (utility decoupling), IOUs participate in various code enforcement strategies. All IOUs offer training programs in person and most offer online options and/or on-demand training videos on a range of topics related to the BEES. EnergyCode Ace is a program funded by four IOUs (supervised by the CPUC) that provides a wealth of compliance tools, including installation guides, step-by-step code navigation guides, checklists, and tools to help users find what forms, products, and compliance actions will be needed for their project. Live and pre-recorded training classes and webinars are also available.

BayREN runs a Codes & Standards program that aims for full compliance of the California Energy Code through targeted training and forums to share best practices. The organization also encourages municipalities to institute reach codes. 3-C REN offers "Energy Codes Coaches," expert consultants that help building professionals understand and comply with building codes.

Enforcement efforts go beyond just education, training, and outreach. Building systems must be inspected during construction (and construction cannot continue until the inspection is completed) to ensure they are installed correctly and will operate as efficiently as designed. This maximizes the impact of updating the BEES. For residential buildings, the HERS requires that whenever HVAC systems are installed or replaced, ducts must be inspected and sealed by state-approved technicians.[167] For non-residential buildings, Acceptance Testing must be performed at construction to verify the proper installation of lighting controls and mechanical systems to ensure they operate efficiently.* Most commercial buildings (mixed use buildings of any size and all types over 10,000 square feet) must go through a commissioning process during construction that includes design review, functional performance testing of building components, and training of maintenance staff tasked with operating building components once construction is complete.[168]

Future Policy Directions

The direction of future building sector policies in California depends on how the CEC's authority is defined. The CEC does not technically have the authority to regulate on the basis of GHG emissions - just energy use and cost-effectiveness. But much of the CEC's energy policy is really intended to decarbonize the building sector. In many ways, the two goals go hand-in-hand: decarbonizing generally means using less energy. But they diverge slightly. For example, while the CEC understands that electrification is the most cost-effective way to achieve net-zero emissions in the building sector, it may not always be the lowest-cost or lowest-energy option, meaning they have limited ability to expressly pursue electrification.

This may change, however. With the passage of SB-49, the legislature expanded the CEC's authority to expressly regulate appliance standards based not only on energy and cost savings, but also on GHG emissions. There is hope that soon, the legislature will similarly expand that authority to building standards, giving the CEC more freedom to pursue emissions-reducing measures. Whether or not this authority is granted will have a significant impact on how future decarbonization will play out in California and what role building codes and the CEC in general will play in that effort. Possible future efforts might include an emissions performance accounting/reporting standard or switching the baseline assumptions in the building energy code to an all-electric baseline. Again, these efforts could be constrained if the CEC's authority is not expanded, though based on the expansion of authority for appliance standards, there is expectation this will happen. In fact, the CEC has already begun to develop a GHG accounting standard for buildings in hopes the legislature will act.

Demand flexibility is a key focus of future energy policy in California, as this will be essential to enabling a high-renewable grid. In 2010 the CPUC authorized IOUs to install millions of "smart" meters to better inform customers (and utilities) about their energy usage. Customers can better manage their energy usage (e.g. avoid peak hours) using smart meters and even automate their air conditioning to reduce operation during peak hours. The CEC is now examining ways that demand flexibility can be built into both appliance and building standards (such as energy storage, automation, etc.).[169] Time-of-use rates may also be altered to better manage loads. Current design of time-of-use rates varies somewhat between utilities, but currently, the smallest block of time for time-of-use rates is two hours long. There are also only 2-4 different price levels (e.g. peak pricing, off-peak, mid-peak, etc.) and the levels change only a few times per year (e.g. in some cases, rate structures are the same for 8 months out of the year). By introducing higher resolution to time-of-use rates (perhaps even real-time pricing that constantly updates based on the demand on the grid at any given time), there could be a greater incentive to shift energy usage away from periods of highest demand and toward the periods of lowest demand. The CEC is examining possible modifications to existing time-of-use rates, and even considering the possibility of explicitly incorporating emissions intensity into rate structures.

Other future policy directions may depend on advances in technology since the CEC is constrained by cost-effectiveness. That means technologies like home battery storage cannot be expressly required in Title 24 standards, though as the cost of such systems drops, that may change. As soon as storage can be considered cost-effective, there is a desire to implement a mandatory storage requirement for new buildings. Likewise, as the cost of solar panels falls, it may be considered cost-effective to increase the mandated capacity of solar panels that homes must install (possibly to the point of ZNE), and the requirement may also be expanded to commercial buildings. "Smart" building technology and automation could also be required in future code updates.

Remaining Challenges

As is often the case, high upfront cost remains the greatest challenge facing widespread innovation in the building sector. With good reason, the CEC is constrained by cost-effectiveness requirements, and it is likely that this will remain the case for the foreseeable future, especially in the context of retrofitting existing buildings. Significant investment is still needed (possibly on the federal level) to address situations where the cost-effectiveness criteria cannot be met, even by leveraging future energy savings.

Likewise, the oft-cited barrier of split incentives (renters see the benefits of energy saving retrofits while owners bear the costs) remains a challenge. Although some of California's innovative financing tools like PACE financing and on-bill financing help address this, the challenge remains. Future efforts could include incentivizing green leases that allow for the benefits of retrofits to be shared by both landlords and tenants.

Improving load management and demand flexibility remain high priorities for state policymakers. California's renewable electricity goals are highly ambitious - 60% renewables in just a decade will be a difficult task to manage and will require a flexible and resilient "smart" grid. Already state utilities have taken important steps toward this vision such as widespread smart meter installation and a variety of demand reduction programs, but this will remain a challenge. The addition of new solar rooftops on all new homes will make it even more challenging to maintain a reliable grid.

Policy Recommendations and Lessons Learned

California stands out as a leader in energy and climate policy not only in the US, but worldwide. It operates one of the largest carbon pricing schemes in the world and maintains bold emissions reductions and renewable energy targets which have been codified into state law. The state's efforts in the building sector are inspiring and instructive. Some of the key lessons learned from this case study are:

Leverage leadership and policy efforts on local/regional scales: Cities and regions may vary widely in their desire and capacity to undertake ambitious building sector policies. Though seemingly a hindrance, this can be an opportunity if leveraged correctly. Where possible, institute a regulatory and legal framework that allows local and regional governments to pursue policies that are more ambitious than can reasonably be demanded statewide. Support local efforts via education and outreach and financial resources and facilitate information-sharing between municipalities with similar goals.

Use codes and standards as transformational policies: Traditionally, codes and standards for buildings and appliances serve the role of a "backstop" policy by simply setting a bare minimum level of performance. But viewing codes differently, they can be incredibly powerful tools to revolutionize the industry. Building energy codes (reach codes) in several jurisdictions go beyond the traditional approach of minimum energy efficiency requirements and can address electrification, renewable energy integration, and other decarbonization issues.
Mandatory codes are almost always preferable to voluntary ones. A mandatory performance-based code requires action from the whole industry and spurs innovation and creativity, whereas a voluntary program could simply receive low interest and lead to little results. Furthermore, the process of developing and implementing building energy codes generally already engages an extensive stakeholder network consisting of exactly the actors needed to transform the industry. Using this pre-

* The mechanical systems provision is not yet enforced. It does not activate until the CEC approves a certain number of Acceptance Test Technicians to ensure the workforce is sufficiently robust before mandating compliance.

existing infrastructure may be easier than creating a stakeholder engagement process from scratch.

Compliance is key: A policy is only as effective as its compliance. Well-designed and ambitious standards do little if they are not enforced properly. Engage stakeholders constantly; during policy development, so they understand new standards before they are instituted, and during implementation, to strengthen industry knowledge and build capacity for compliance. Provide education, training, and outreach resources for free, and make use of the expertise of utilities, local governments, or other organizations with the expertise to provide this service. Build in checkpoints early and often throughout the design, approval, and construction process of buildings to catch errors while they can still easily be solved.

Align incentives: It is important to ensure incentives are aligned properly to encourage desired behaviors. This goes for homeowners, developers, utilities, and local governments. Providing incentives alone is insufficient. Removing disincentives that discourage action can be just as impactful.

Net-zero as a messaging tool: Net-zero (energy or carbon) buildings goals are extremely useful for mobilizing the sector toward a single, intuitive goal. For a building to achieve net-zero performance, it requires intelligent design, high-performance materials, on-site renewable energy generation, high-quality construction, and efficient operation (most likely utilizing "smart" building technologies). Announcing the goal of a net-zero energy code in the future necessitates innovation from all those industries, and will lead to better ideas, practices, materials, and technologies along the way. Similarly, it helps align multiple levels of policy (e.g. state and local) and provides a framework for integrated policy design from different approaches. Decarbonizing buildings requires not just changing building policies, but also changes to the electricity system and electricity market design. In California's case, net-zero goals helped drive the creation of programs and policies such as time-of-use rates, utility decoupling, and demand flexibility that are not necessarily specific to buildings. But California's experience also shows that individual net-zero buildings may not be the most effective way to decarbonize buildings. Decarbonization requires widespread change of how energy is supplied to buildings as well as how they use it. At a high penetration of renewables, the amount of energy used may become less important than when it is used or the source of the energy, which a net-zero standard does not capture. Nevertheless, net-zero goals are incredibly useful as messaging tools to catalyze action and innovation.

California's success in reducing its GHG emissions over the last decade or so is impressive, especially considering the state's economy has continued to grow while it makes such ardent strides. The lessons drawn from studying California's path to decarbonizing the building sector in part using ZNE goals can help inform other states and countries seeking to do the same. Leveraging the ability and ambition of local governments can eventually spur action throughout a state/country. Incorporating ambitious goals into codes and standards can be one of the most transformational approaches to decarbonization. A focus on compliance is essential to maximize the benefits of building decarbonization policies. And net-zero energy (or carbon) buildings, though they may not universally be the most effective decarbonization strategy at present, they are aspirational and ambitious targets that can catalyze necessary transformation in the building sector.

4. KEY TAKEAWAYS: STRATEGIES TO MOVE TOWARD NET-ZERO BUILDINGS

Countries, states, and cities are considering options to transform their building stock and move toward more efficient, less carbon-intensive buildings. The Boston and California case studies yield valuable insight into how to pursue ambitious building decarbonization policies. Based on these case studies, and drawing from the overview of building policy in the US and Europe, we identify several policy tools to promote net-zero buildings and present supporting strategies to optimize policy design and implementation.

Policy Tools

Many different policy tools may be used to facilitate net-zero buildings. The effectiveness of any policy depends heavily on context. Factors like jurisdictional size and authority, political will, and market capacity may mean some policies are simply not feasible or effective in certain contexts. With this in mind, the tools summarized here have been found over the course of this research to be effective options for encouraging the proliferation of net-zero buildings.

Tool 1 - Net-Zero Building Codes: Building codes can drive the sector to net-zero emissions by maximizing efficiency, prioritizing electrification, and integrating renewables. Codes should gradually build to net-zero and be announced years in advance to allow stakeholders to prepare and the market to develop. Even if political will is insufficient for statewide or nationwide net-zero codes, stretch codes can be developed to support more ambitious sub-jurisdictions.

Tool 2 - Emissions Performance Standards: A technology-neutral, performance-based emissions standard for existing buildings gives owners flexibility as they

reduce building emissions. This allows them to find the most cost-effective path to compliance. An EPS should be predictable. As emissions limits ratchet down, new thresholds should be announced years in advance to enable building managers to perform retrofits when it is most cost-effective. For the greatest impact, compliance should be outcome-based, using actual, measured energy data.

Tool 3 - Green Zoning Requirements: In some cases, building codes may not be within a jurisdiction's authority, necessitating workarounds such as zoning requirements. Cities may require new construction to meet design thresholds before issuing development permits. Creative, less direct mechanisms like carbon linkage fees could force developers to pay for the impact of their buildings' emissions. A density bonus could be used to incentivize net-zero construction. Zoning regulations have another benefit – developments usually undergo a comprehensive approval process, which provides policymakers an opportunity to discuss with developers the options to lower their emissions even more than required with energy-saving measures like district energy, microgrids, renewables, electrification, or energy storage.

Tool 4 - Benchmarking and Disclosure: Benchmarking policies are a logical first step for jurisdictions aiming for net-zero since they provide extensive data that can be used to inform future policy design. They can also be used to monitor policy outcomes and manage enforcement.

Tool 5 - District Energy Systems: District energy systems offer numerous benefits. They reduce emissions by being extremely efficient (especially CHP) and they increase resilience, since district systems can often continue providing services even if energy distribution networks fail. Cities should pursue the installation (or expansion) of district energy to reduce citywide emissions. A caveat is that many district heating facilities run on fossil fuels, locking in future emissions. Long-term planning is crucial so that district energy can eventually be fully decarbonized using renewable energy, carbon-neutral fuels, or carbon capture and storage.

Policy Strategies

Simply instituting these policy tools hardly guarantees they will effectively spur the development of net-zero buildings. The process of developing, implementing, and enforcing them requires significant effort, and it may not be immediately obvious how this should be handled. The following strategies should be used as a framework for net-zero building policies. Some guide policy design, whereas others inform policy implementation efforts. These undergirding strategies can help maximize the effectiveness of the five policy tools listed above.

Strategy 1 - Lead by Example: Public buildings should be the first to go net-zero, in part because public buildings are often the only buildings that a jurisdiction can directly regulate. This might be the case if another level of government has the authority to set building codes. Net-zero standards for public buildings also demonstrate the benefits and feasibility of net-zero buildings to private developers. They help transform the market by building demand for technologies and materials used in net-zero buildings and develop a clean energy workforce. Demonstration projects and pilot programs can spur additional "first movers." These programs might provide incentives to net-zero developers or feature a net-zero design competition with a cash prize. Such programs should heavily publicize the buildings that result to give developers more incentive to participate.

Strategy 2 - Net-Zero as a Messaging Tool: Net-zero is an intuitive, easy-to-communicate concept, making it quite useful as a messaging tool. A policy goal of a net-zero building code is specific and tangible. It takes a broad issue with many important stakeholders and effectively focuses all their efforts in a single direction. This prevents the necessity of separate stakeholder engagement processes to develop policies about building electrification, renewables, and energy efficiency. Instead, engagement and policy targets can be centered around net-zero buildings, aligning all relevant stakeholders toward the same goal – reducing emissions. When announced years in advance, a centralized net-zero goal can also spark innovation in building design, materials, and construction, as this provides a long-term market signal to encourage research and development in these fields.

Strategy 3 - Flexible Approach: Flexibility should be built into net-zero definitions. Different buildings have different energy demands, so it may not make sense to hold them all to the same standard. This might mean defining multiple tiers of net-zero performance or phasing in a policy over time, beginning with the easiest buildings to decarbonize. Flexibility may mean defining net-zero at different scales, such as portfolio- or campus-wide, which is often more cost-effective. Flexibility makes policies more achievable and improves buy-in from otherwise skeptical stakeholders.

Strategy 4 - Stakeholder Engagement: Engagement should be comprehensive and prioritize outreach to marginalized communities. Listening to all relevant perspectives ensures policy is effective and does not disproportionately impact marginalized groups. This process should begin early on and occur continuously throughout development, implementation, and enforcement of policies. By viewing engagement as a constant responsibility rather than a step to complete, strong stakeholder relationships can be fostered, which can maximize compliance with policy.

Strategy 5 - Prioritize Compliance: Policies are only effective when they are enforced. Constant stakeholder engagement, compliance training and education, and rigorous inspection and commissioning procedures can maximize the impact of decarbonization policy.

Strategy 6 - Integrated, Data-Driven Policy Design: Building policy should not be thought of as distinct from broader decarbonization efforts. The power sector, transportation, and buildings are all interconnected parts of one goal – reducing GHG emissions. Buildings can install electric vehicle charging stations, home energy storage can provide grid stability, and housing density around transit access can reduce communitywide emissions. Data-driven analysis can help determine the most cost-effective pathways to collectively transform all these interrelated systems.

Strategy 7 - Policy Alignment: Whenever possible, aligning policy at all levels of government (i.e. city, state, regional, national, etc.) is beneficial. Without policy alignment, conflicting incentive structures can limit the effectiveness of new policies. Building and maintaining relationships with other governments that share authority enables the pursuit of consensus approaches to decarbonization. Policies that hamper progress toward decarbonization goals should be modified or replaced with supportive, synergistic policies that amplify policy effectiveness. Understanding the incentive structures faced by building sector stakeholders is critical to removing barriers to decarbonization created (often unintentionally) by poorly designed policies.

Strategy 8 - Mandatory Programs: Mandates are preferable to voluntary programs because the latter are often underutilized. For example, some building owners may undervalue the benefits of an energy-saving retrofit and will not undertake one unless required, even if the retrofit will save them money. However, understanding the current state of the market and the capacity of stakeholders to meet mandates is important. A mandate may require enabling policies (e.g. workforce development, market transformation, education/outreach, and financial assistance) to ensure compliance is feasible.

Strategy 9 - Just Transition: Decarbonizing buildings can provide communities with significant benefits, and these benefits should be experienced by all. This includes, among many other considerations, keeping housing affordable, minimizing energy burdens, and providing employment with a robust clean energy workforce. Morality aside, failing to plan for a just transition also increases the risk of failing to meet climate goals. Decarbonizing the building sector is a large, complex task, which means near-universal buy-in is essential. Without the support of marginalized and underrepresented communities, policies will not be successful. For example, retrofit incentives that are inaccessible to low-income households are not just unfair – they also fail to capture significant emissions reduction potential from those households.

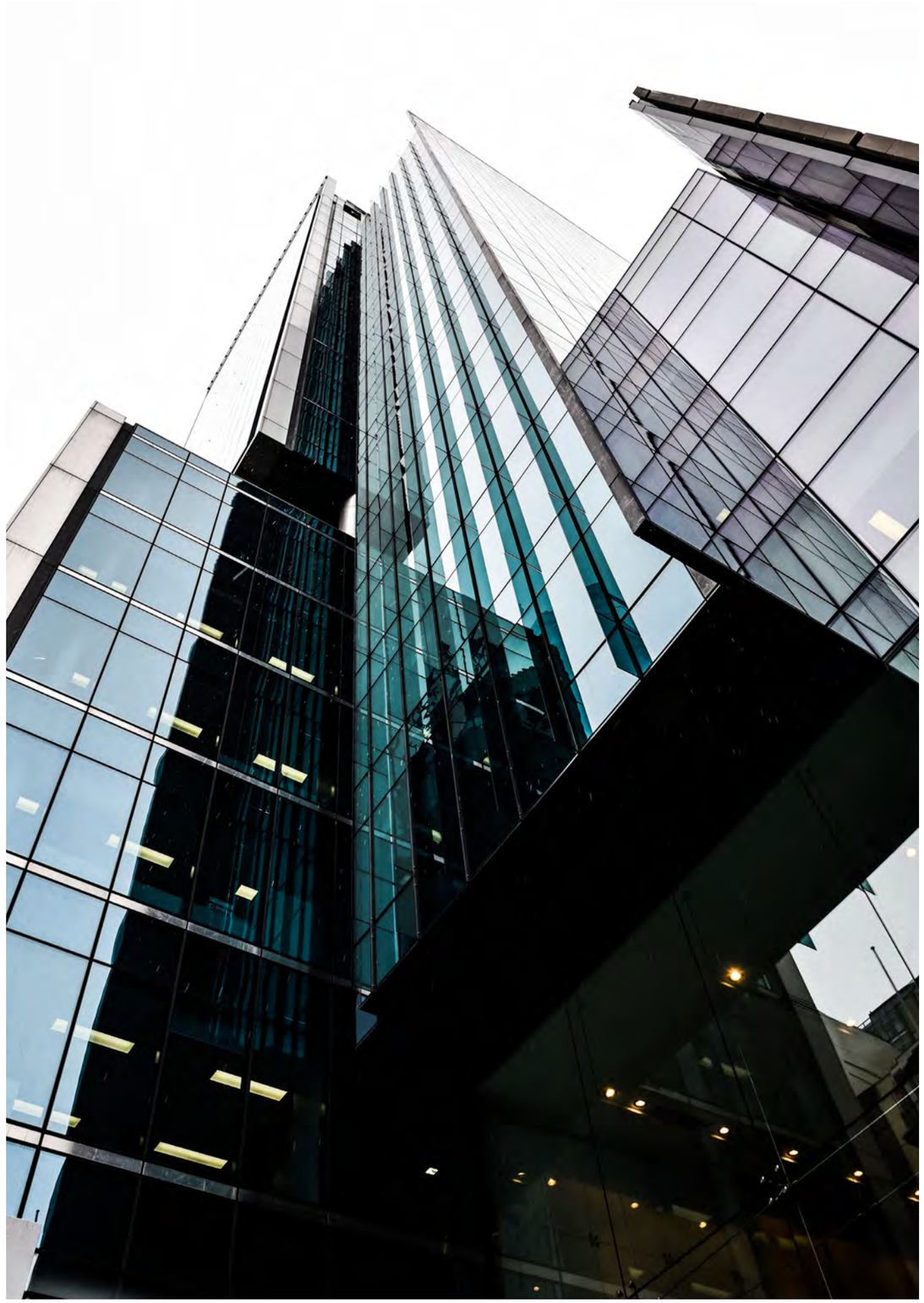
Strategy 10 - Financing: This remains one of the greatest challenges to decarbonization in buildings. One problem is magnitude – transforming the building stock will require the mobilization of capital on a large scale. Existing financing resources (e.g. utility-based incentives) should be maximized and/or repurposed to focus on specific financing gaps. Furthermore, split incentives and energy poverty are common problems that make financing energy improvements in the building sector difficult to finance. Financing instruments should be specifically designed to address these barriers to be as effective as possible with often limited resources. Limited public investment should be used to leverage

greater private investment, using techniques such as publicly guaranteed private sector loans or green loan warehousing services.

The policies and strategies recommended above are demonstrated and effective and serve as a foundation for jurisdictions hoping to encourage the proliferation of net-zero buildings. While this list is not comprehensive, research conducted for this report indicated that these strategies are some of the most impactful options based on their proven results in leading jurisdictions such as Boston and California.

Decarbonizing the building sector represents a daunting challenge, yet an exciting opportunity. Already a significant contributor to global GHG emissions, the global stock of buildings is expected to grow rapidly by mid-century, the de facto deadline for reducing global GHG emissions to net-zero. Due to the long lifetime of most buildings, ambitious policy action is necessary immediately in the building sector if we are to meet this deadline. Although the technology needed to eliminate GHG emissions from buildings exists today, the building sector is characterized by challenging barriers such as split incentives and slow turnover that hamper the dissemination of these technologies. Innovative policy approaches are urgently necessary.

Net-zero buildings are especially important to solving this puzzle. Such buildings integrate exceptional energy efficiency with renewable energy generation to achieve the pinnacle of building energy performance. Conceptually, net-zero buildings are inspiring and intuitive, so framing building sector policy around net-zero building goals is a useful framework to align stakeholders behind a common goal. Based on extensive review of policies in the US and Europe and two in-depth case studies, we find that a relatively short list of policy tools and strategies can help jurisdictions achieve their net-zero building goals. Although building sector decarbonization is challenging, it is necessary, and by following the policy framework outlined here, jurisdictions worldwide can help lead the global effort to decarbonize the building stock.



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