Building Better: A Roadmap of Building Decarbonization Strategies to Reduce Global Greenhouse Gas Emissions

Technical Brief —Technical Innovation, *Electrification and Sustainable Energy Strategy, Advanced Buildings*

Buildings are Responsible for the Largest Share of Global Emissions

As countries, municipalities, companies, and utilities set targets for greenhouse gas (GHG) emission reductions, decarbonizing the world's existing and planned building stock can provide significant progress towards these emissions goals.

The impact of the building industry on GHG is significant. In 2019, global emissions from operating buildings reached 10 gigatons carbon dioxide (GtCO2) [1] the highest level yet recorded. Including emissions from operating and constructing buildings, the buildings industry accounted for 38% of annual global GHG emissions in 2019 (Figure 1) [2]. As the global building stock rapidly expands, decision makers should consider how quickly solutions can be implemented to address the industry's role in producing GHG. Strategies for decarbonizing buildings should consider cost-effective solutions that can be immediately deployed at scale in today's energy systems, while simultaneously preparing for a future with carbon-free power networks and innovations in low carbon fuels that could provide further deep decarbonization of the built environment.

This white paper will examine the value of building decarbonization, the challenges that must be addressed, EPRI's experience with building decarbonization, and discuss the considerations for an effective building decarbonization strategy. An effective strategy should consider how policy, technology, and market drivers influence customer choices and the adoption of the four main pillars for decarbonizing new and existing buildings: efficiency, electrification, flexibility, and low carbon fuels.

Current and Future State of the Built Environment

An estimated two-thirds of the world's current building stock area will still exist in 2050 [3]. While newer buildings may comprise a significant share of building stock in the next decades, retrofitting and decarbonizing older buildings will be necessary to achieve decarbonization goals. In 2014, half of all residential buildings in ten European Union (EU) countries were built before 1970, preceding the first thermal regulations [4]. As of 2018, only 25% of buildings in the United States (US) were constructed after 2000, with 54% built between 1960 and 1999 and 21% built before 1960 [5]. In Asia there is a lack of data on existing building energy performance, however in China it is estimated that less than 10% of existing buildings are energy efficient. [6]

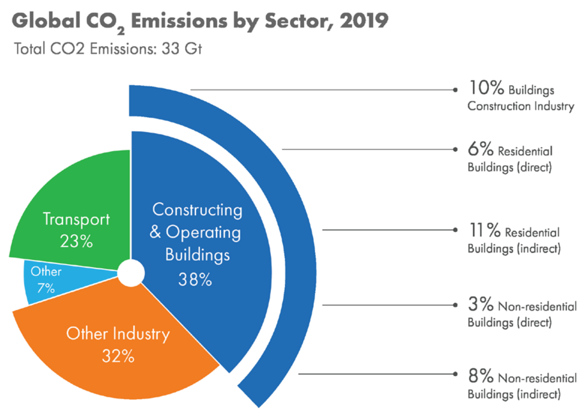

Figure 1: Global share of buildings and construction emissions, 2019 [1] [2]

Retrofitting older buildings that were not constructed with efficiency in mind poses a challenge for decarbonizing the full building stock. Decarbonizing existing buildings at least cost may require a hybrid pathways approach that combines the most technically feasible options at the least cost.

The global building stock has and will continue to grow rapidly in the coming decades. To accommodate the expected significant population growth over the next few decades, the global building stock is projected to double by 2060 from 2018 levels, translating to an additional 2.48 trillion square feet of new floor area [3]. Residential dwellings in the EU grew 3% between 2010 and 2016. The US Energy Information Administration (EIA) estimates that the total number of buildings in the US increased 6% from 2012 to 2016 [5]. Continued economic growth in ASEAN[1] , China, and India is expected to result in a growth in building stock area of two-thirds by 2040 [6].

In 2015, 196 countries joined the Paris Agreement at the Conference of Parties 21 (COP21). Countries agreed to limit global warming to well below 2˚C, preferably to 1.5 ˚C, compared to pre-industrial levels by reaching global peaking of greenhouse gas emissions as soon as possible. [7] As shown in Figure 2, numerous 2030 emissions reduction targets will

1 ASEAN, Association of Southeast Asian Nations: Thailand, Indonesia, Vietnam, Singapore, Philippines, Malaysia, Myanmar, Laos, Cambodia, Brunei Darussalam

require significantly accelerated reductions compared to what countries may have already achieved. Achieving these goals will require the transformation of global energy systems, including substantial emissions reductions in operating and constructing buildings. Of the nationally determined contributions (NDCs) submitted, 136 mention buildings [1]. Decarbonizing new and existing buildings provides the opportunity to contribute to global emission reduction goals, alleviate energy poverty and burden, and boost economic growth through job creation while allowing buildings to become assets for grid operators in the energy transition.

Multi-stakeholder Value from Building Decarbonization

Building decarbonization focuses on the reduction, substitution, and, in many cases, elimination of fossil-fuel based energy use in buildings. Decarbonization therefore offers significant value and wide-spread benefits to multiple stakeholders in the energy eco-system, including customers and homeowners, property owners and developers, utilities, and governments.

Customers and Homeowners: The direct benefit for customers and homeowners from building decarbonization is the opportunity to achieve the same (if not better) levels of comfort and convenience that they are accustomed to with fossil-fuel use but at much higher efficiencies, i.e., reduced energy use for the same end-result. For example, the use of heat-pump based space and water heating technologies are inherently several times more efficient than fossil-fuel based heating. In many cases, the improved efficiency may translate to direct cost savings for customers/homeowners. In some regions local electricity and gas rates may affect the cost savings seen by customers, while there are still non-economic benefits like indoor air quality (IAQ) and better indoor environmental quality (IEQ). The customer economics can be improved with on-site generation, and when rates and customer programs are aligned with decarbonization goals [8] [9] [10].

Property Owners: Multifamily property owners and building operators may benefit from building decarbonization through the same efficiency driven economic pathways offered to customers and homeowners. However, an important advantage for property owners who are building in urban population centers, if they choose to go the all-electric building route, is the reduction of first costs from elimination natural gas infrastructure. Not adding gas infrastructure also reduces construction time and decreases the opportunity cost of property waiting on the market while city/local permits are being sought [10]. In 2019, Berkeley became the first city in California, and the first in the US, to prohibit natural gas infrastructure in newly constructed buildings, citing the climate, cost-saving, safety, and public health benefits of requiring all-electric buildings. [11] With several other cities in California and around the US from Seattle to New York and Massachusetts following suit and implementing or considering similar bans. For property owners who own existing buildings and are looking to retrofit, the use of newer advanced space and water heating technologies may help improve energy efficiency without the need for extensive retrofit construction. A recent EPRI study found that using new Packaged Terminal Heat Pumps (PTHP) for space conditioning and CO2 heat pumps for water heating allowed for retrofits without extensive construction costs, while significantly improving quality of life for residents and energy efficiency outcomes for property owners (Figure 3) [12].

Utilities: Utilities (especially electricity distribution system operators) achieve two levels of benefits from building decarbonization:

1. Improved end-use efficiency allows for exploration of cost deferral strategies on distribution system upgrades through measures such as Non-Wires Alternatives (NWA).
2. Decarbonization implemented through customer-sited distributed energy resources (DER) provides demand-side flexibility that can be leveraged for strategies such as load-shifting towards periods of higher renewable availability and reduced use of "peaker" power plants, which are often run to support exacerbated distribution network loads such as evening peaks.

Governments: Federal, state, and local governments have been active with setting aggressive economy-wide decarbonization targets. Governments have also been active in formulating policy measures through laws and regulations supported by financial incentives to help spur-on market action on decarbonization. As noted above, cities like Berkeley have taken more decisive steps through the use of building codes and standards ("reach codes") to effect deeper decarbonization. However, all of these policy measures need concurrent market actions to make the promise of decarbonization achievable and alleviate the more drastic climate outcomes of higher than 1.5oC global warming. Building decarbonization, along with transportation electrification, can serve a key role in effecting market transformation. In Canada it is estimated that a COVID-19 recovery plan with investment in the green buildings sector at its core could contribute 1.5 million jobs and $150 billion in GDP by 2030. [13]

What are the key challenges that need to be overcome?

Today, electrification in combination with grid decarbonization is the most technically feasible pathway to attain steep reductions in carbon content of buildings. However, the upfront and operating cost of electrification, along with ensuring customer benefits and addressing building codes and grid readiness are key challenges. Some of the factors that impact the affordability of efficient electrification include:

- Cost of the equipment (i.e., high SEER Heat Pumps, high efficiency HPWH, induction cooktops)
- Cost of electrical panel upgrades to support electrified end-uses
- Cost of skilled labor for installations and retrofits
- Cost of construction upgrades to support/house electrified end-use equipment
- Cost of distribution system upgrades to support higher market penetration of electrification

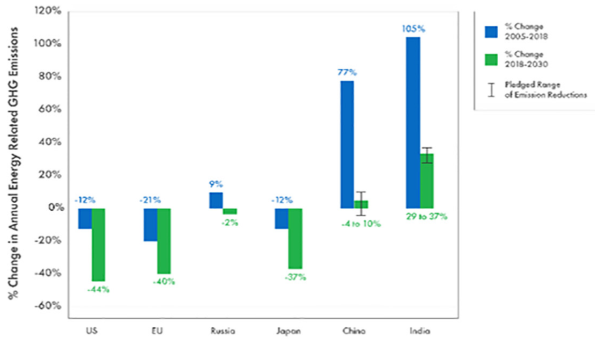

Figure 2: Percent change in select country's actual energy-related emissions between 2005 and 2018 (blue), and needed percent change in select county's energy-related emissions between 2018 and 2030 to reach announced 2030 decarbonization goals (green). Source: United Nations, Climate Action Tracker, Climate Watch

The aforementioned costs impact just the first-cost of electrification upgrade in existing buildings. They do not represent the full cost picture, which typically includes operating costs and the cost of maintenance of end-use devices. Depending upon the relative rates of electricity and natural gas, the operating costs of electrification of end-uses may or may not be higher.

Non-financial barriers to equitable building decarbonization, and in particular electrification, may include a lack of trust in new technologies. Emphasizing the importance of effective customer engagement strategies, which could include building partnerships with community organizations, as well as educational programs for both customers and the workforce.

Figure 4 identifies the objectives that should be considered for addressing the key challenges and improving affordability of building decarbonization strategies. Tackling the carbon content of existing buildings poses a significant challenge, especially considering the pace at which economy wide decarbonization is needed to avoid the worst effects of climate change [14]. The following case study illustrate how these challenges can be addressed to make retrofits more affordable and accessible for customers, creating opportunities for the rapid decarbonization of the built environment.

Case Study: EPRI's experience with decarbonization retrofits of multifamily communities

EPRI worked closely with LINC Housing to conduct decarbonization retrofits of 140 homes in two affordable multifamily communities in California. A hybrid pathways approach for least cost decarbonization was demonstrated, electrifying as much as possible, while leveraging efficiency, renewables, and flexibility. The efficiency and electrification measures deployed included:

- Upgraded wall insulation from R-13 to R-19 and added foam insulation cool roof
- Upgraded windows to low-emissivity double pane, patio doors, and frame sealing
- Indoor and outdoor lighting replaced with LED
- Single to variable-speed pool pumps
- New glass-top electric cooktops and refrigerators
- Upgraded space conditioning with 120 V ductless HPs
- Upgraded 40-gal gas storage water heaters with centralized HPWH's where feasible and replaced remaining with 98% efficient gas tankless

Evaluating an effective customer economic model was an important objective of these projects; in this case tax credit refinancing, state and utility programs, and a solar Power Purchase Agreement (PPA) were combined to cover the upfront costs and yield positive cash flows for the tenants and owners from the beginning. The projects significantly decarbonized the communities (Figure 3), improved overall efficiency of energy use, with non-economic benefits for customers that included improved comfort levels and IAQ. Some valuable learnings from these projects included:

- In one of the communities extremely high up-front costs were found when trying to electrify water heating with HPWH, this breached the 100-amp capacity limit of the in-unit panels. Which would have triggered high costs to upgrade in-unit panels and supporting electrical infrastructure like wiring and local transformers (Figure 5). These factors led to the adoption of a hybridized approach which electrified as much as was feasible to avoid these costs.
- A deeper focus on efficiency measures, low power technologies like the 120 V HPs, and centralized HPWH's with thermal storage can eliminate the need for in-unit panel upgrades. Efficient gas tankless water heaters where installed when necessary to improve efficiency and lower up-front costs.
- The efficiency measures and solar were critical to reducing the operating costs of electrification for the tenants and the owner.
- Proper coordination of customer programs and financing mechanisms was key to an effective customer economic model.

Stakeholder working groups could enhance collaboration between manufacturers, utilities, researchers, and government entities to coordinate all available financing, while also accelerating the process of identifying and testing new technologies or financial mechanisms that enable least cost

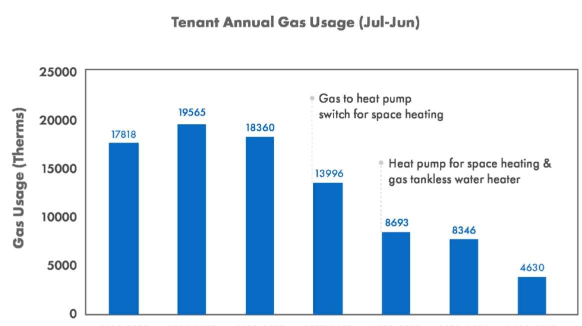

Figure 3: Reduction in gas usage from partial electrification in a multifamily community in Ontario, CA [13]

decarbonization of low-income communities [12]. Several utilities are already taking on some important roles to facilitate decarbonization of affordable communities, including, community engagement, retrofit and financing manager, workforce development, addressing the digital divide [15].

Smart panels could provide a solution to lower electrification costs while enabling demand side flexibility for a shared integrated grid. Smart Panels can prioritize and manage connected loads in a building to maintain the defined capacity limit. This could allow for full electrification and avoid the need for upgrading the capacity of a standard panel, as well as any upgrades to supporting electrical infrastructure. EPRI is working to understand the value of smart panels to both customers and utilities in new and existing buildings [42].

What are the drivers of building decarbonization?

The forcing functions for building decarbonization can be categorized in three major buckets policy, technology, and market drivers. Strategically leveraging three forcing functions can influence the building decarbonization pathway taken by customers.

Case Study: An Example of policy driving decarbonization

California Energy policy is accelerating efforts for decarbonization buildings. The California Public Utilities Commission has a vision for zero net energy buildings, meaning buildings only use as much energy as can be produced onsite with renewable resources. The current focus is on new construction [21]. As of January 1, 2020, the California Energy Commis-

Driver	Overview	Examples	Challenges to be addressed
Policy	Federal, state, and local jurisdictions are implementing decarbonization goals and associated laws, many of which speak directly to carbon reductions and energy efficiency of buildings. For example, by September 2021, over 80 countries had mandatory or voluntary building energy codes on the national or sub-national level. These codes set energy efficiency requirements and, in some cases, the reduced use of carbon-emitting fuels.[2]	European Union: The Energy Performance of Buildings Directive mandates all new buildings to be nearly zero-energy buildings (i.e., very high energy performance) [17] CA, USA: : A Berkeley City Council ordinance prohibits natural gas infrastructure in new residential and non-residential buildings after January 1, 2020, the first city in the US to do so. [18] Many cities, particularly in the US west coast but with some emerging on the east coast, have since adopted similar gas bans.	As building energy codes and standards do not exist everywhere, there may be little incentive to decarbonize in their absence. Also, standards developed in one region may not be feasible in others. For example, nineteen states prohibit bans on natural gas, allowing for more optionality in fuel sources. [19] Developing different regional codes that increase efficiency/reduce carbon emissions may pose challenges as country wide decarbonization goals are installed.
Market	Customer, or market driven, decarbonization includes adoption of technologies or participation in programs that improve building efficiency and reduce building emissions. Incentives such as utility or government rebates, as well as direct economic measures such as variable energy rates, can influence uptake.	Incentivizing demand response and energy efficiency retrofits through utility programs may increase adoptions. Similarly, customers may install solar plus storage systems to increase resilience after receiving a rebate.	While incentives and rebates can improve first costs, overall costs of technologies or energy efficiency retrofits may be prohibitive for some customers. Lack of customer/utility engagement may reduce participation in utility programs. [20].
Technology	Improvements in end-use equipment and appliances have allowed for more efficient space conditioning, water heating, and cooking. Electrified end uses, such as heat pumps for space heating and cooling, are also contributing to emission reductions.	Heat pumps Seasonal Energy Efficiency Rating (SEER) increased from 6 or less before 1980 to 15 in 2015, with efforts underway to increase the standard to 15 by 2023 [21].Emerging technologies such as 120V heat-pump and Package Terminal Heat Pumps (PTHP) are potentially game-changer in the space conditioning landscape.	The continued need to improve device efficiency to reduce energy use may require R&D investments. Limited customer education and high initial costs may inhibit adoption of new technologies. Rising customer installation and maintenance demand for new technologies may require a larger workforce, and expanded workforce training, to service this increased demand.

2. United Nations Environment Programme. 2021. [Online]. Available: https://globalabc.org/resources/publications/2021-global-status-report-buildings-and-construction. [Accessed 29-Nov-2021].

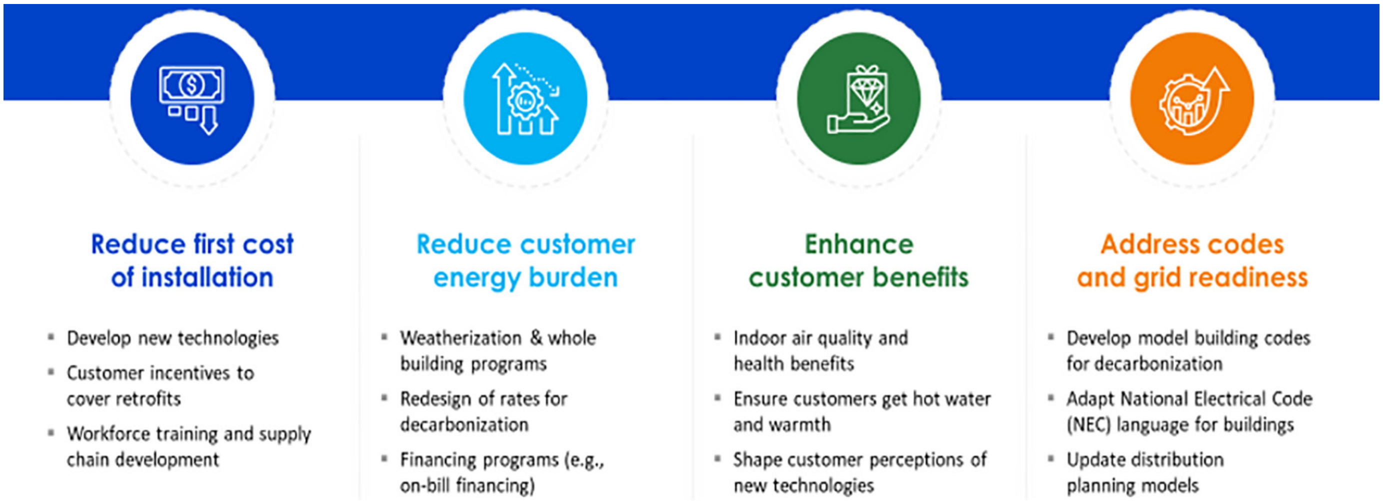

Figure 4. ActionPlans for building decarbonization may include some of the noted key objectives

sion's (CEC) Building Energy Efficiency Standards (Title 24) requires new single-family homes and multifamily residences up to three stories high to include solar photovoltaic (PV) panels [22]. On August 11, 2021, regulators voted to include a requirement of solar and battery storage installations in many new commercial buildings in the 2023 building code [23].

Adopted in 2018 and approved by the CEC in 2020, Sacramento Municipal Utility District's (SMUD) most recent Integrated Resources Plan sets a roadmap for achieving carbon neutrality by 2040. But a 2020 climate emergency declaration commits the community-owned electric service provider to work towards carbon neutrality by 2030 [24]. While SMUD's 2030 Zero Carbon Plan is focused on all aspects of their energy system, the Plan continues to prioritize electrification of buildings to reduce carbon emissions [25]. SMUD's All-Electric Smart Homes Program offers financial incentives for builders of all-electric (single fuel) or "all-electric ready" (mixed fuel) homes pre-wired for easy conversion to electric equipment [26]. These incentives include a $4,000 standard incentive per single family home, and a $1,000 induction cooking appliance bonus. Similar incentives are in place for multifamily homes. There are also rebates for homeowners who switch their residence from gas to all-electric [27]. SMUD's SolarShares program provides solar power from a utility-scale solar farm in California, allowing for an alternative way to meet the Title 24 requirement of solar installations in new builds [28]. In 2019, EPRI conducted an analysis of possible costs and savings with all-electric home construction in SMUD's service territory, with results showing the benefits associated with residential electrification, such as operating cost savings and 40% fewer GHG emissions. [29].

SMUD's efforts to electrify homes and reduce carbon emissions provide an example of utility decision making aligning with state energy policies and building codes. Rebates and incentives from the utility or governing body can assist in making these efforts economically feasible and preferable for both builders and homeowners.

Case Study: The Energiesprong Initiative

The Energiesprong approach aims to realize self-sustaining markets for the rapid deployment of net-zero energy home renovations at scale. This approach is defined by some key innovations:

- **Energy performance guarantee:** A 30-year performance guarantee of retrofit packages is backed by an insurer. This package is critical for enabling financing of upfront costs.
- **Integrated and industrialized supply chain:** The initiative is coordinating all aspects of the renovation from pre-fabrication and procurement to the team of trusted contractors working in unison. This coordination can reduce costs, ensure the quality of the retrofit (vital for the energy performance guarantee), and allow a one-week install time with minimal interference for residents [30].

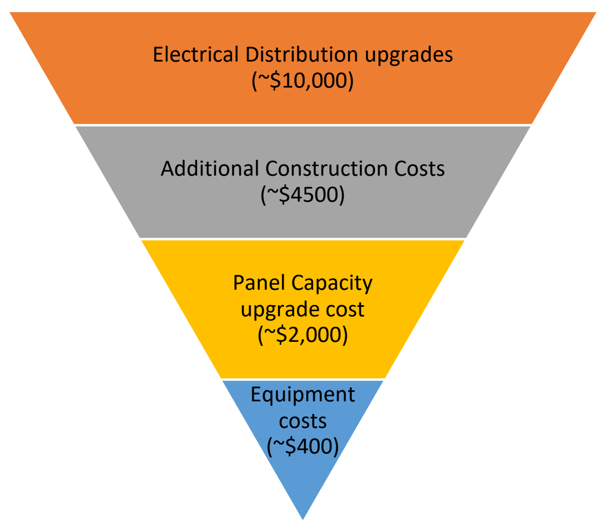

Figure 5: First cost impact per-apartment for HPWH upgrades that breach in-unit panel capacity limits in a multifamily community in Southern CA. Equipment costs are low compared to the cost to upgrade infrastructure to accommodate electrification [13].

Figure 6: Net-zero energy retrofit completed using the Energiesprong approach

- **Financial model:** The net present value of the lifetime energy cost savings covers the upfront costs. Residents transition from their energy bill to an "energy plan", maintaining their cost of living while benefiting from a more comfortable, attractive, and valuable home [31].

Local market development teams take the role of the intermediary by coordinating a multi-disciplinary team of partners, including architects, contractors, efficiency experts, market and financial experts, regulators, policy makers, and technology providers [32]. The team works closely with social housing associations to get a large demand volume of houses to retrofit, with the goal of setting up Retrofit Solution Providers (RSP) that can leverage the industrialized supply chain and the innovative financial models to reduce the costs of retrofits to enable a self-sustaining net-zero retrofit market.

Energiesprong have secured a deal to retrofit 110,000 homes in the Netherlands, of which 5,700 retrofits have been achieved to date [33]. Market development teams in France and the United Kingdom are in early stages of implementing the net-zero retrofit markets there. In the US, spin off programs inspired by the Energiesprong approach are underway in New York (RetrofitNY) [34] and California (REALIZE) [35].

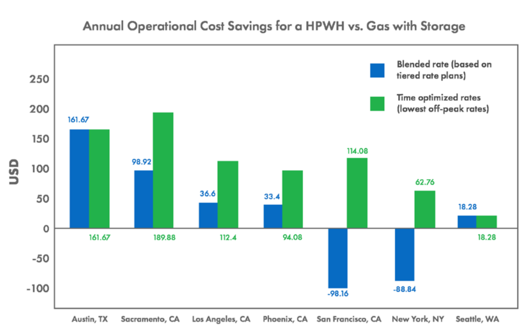

Figure 7: Comparison of operating cost of heat pump water heater vs. gas storage water heater for various cities in the US shows that rates should be aligned with electrification goals and managing for time-of-use rates is imperative. [10]

Approach to Building Decarbonization Strategy

The discussion on the three categories of forcing functions is pertinent because the overall approach to strategy uses a framework where the policy goals drive market and technology evolution, which gets contextualized in a multi-pronged strategy that depends upon local conditions. Decarbonization goals in colder climates may drive different strategy compared to warmer or moderate climates. As examples, colder climates could require a strengthened focus on envelope efficiency and air tightness, or technologies that can improve efficiency with the recovery of waste heat from ventilation or water piping as these may have greater value when temperatures are low. Whereas in warmer and sunnier climates solar PV and fuel-switching for efficient heat pumps may be the best approach. Policy should be adapted on a regional basis to incentivize adoption of the most valuable measures for carbon and cost reductions.

It is important to consider customer decision making in any pathway to decarbonized buildings as this will ultimately shape the path taken, as customers may be influenced by corporate targets, social considerations, or a desire to reduce their environmental impact. However, decisions more often than not are based primarily on economic factors. EPRI found the local and regional rates can heavily influence the economics of various decarbonization measures. Figure 7 illustrates the difference in operating costs for a HPWH compared to a gas-based system in several regions, note that while cost savings for the customer are greater on time-of-use (ToU) rates, this assumes that the HPWH is managed effectively with no usage on peak rate periods.

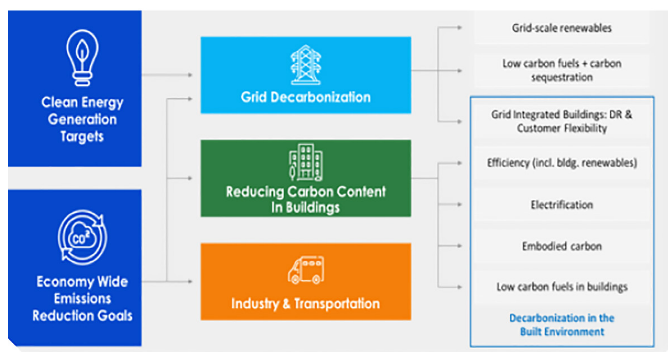

Figure 8: Framework for building decarbonization strategy

There are multiple pathways to decarbonize buildings that vary both on technical readiness and long-term cost potential [36]. As seen in Figure 8 the decarbonization strategies for buildings can be categorized into four main pillars: efficiency, electrification, flexibility, and low-carbon fuels (LCFs). The fifth and important consideration is that of embodied carbon, or the carbon footprint of the materials and processes used in construction. This final consideration needs to be part of the overall strategy especially as the grid decarbonizes and the bulk of the building's carbon footprint shifts from emissions related to embodied carbon. A hybrid approach to decarbonization that combines all these pillars can lead to the most technologically feasible and cost-effective strategy.

Efficiency: Improved efficiency plays a pivotal role as it supports the success of other strategies by reducing the size of heating and cooling equipment needed, therefore reducing energy consumption, carbon emissions, and the electrification impacts on the grid, while improving the building occupant comfort level and operating costs. Deep efficiency addresses all aspects of the building envelope, including wall and roof materials, insulation, windows, and foundation. In addition to significant energy improvements and renewables provisions in residential and commercial buildings in the 2021 IECC Energy Code, energy efficiency is also prominent in the local laws enacted in many cities [37].

Electrification: Fuel switching end-uses with electric appliances is a significant strategy towards building decarbonization. The three major categories of end-uses are space conditioning (heating and cooling), water heating, and cooking. Electrification strategies may differ based on the ambient local climate, with the local and regional rate conditions effecting the customer economics.

Flexibility: Smart grid-integrated buildings with a combination of renewables, storage, and controllable loads have value for utilities by enhancing system visibility and flexibility to balance supply and demand locally, and for managing impacts on grid infrastructure. Participating in energy flexibility markets can provide new revenue streams for customers to reduce their energy costs. [38]

Low-carbon fuels (LCFs): While LCFs like hydrogen, ammonia, or renewable biogas have not reached commercialization yet, they offer significant potential to replace fossil fuel fired systems in buildings where electrification is not feasible. It is important that any long-term building decarbonization strategy considers LCFs becoming a more cost-effective solution in the coming decades.

Embodied Carbon: The embodied carbon content of building materials is a significant contributor to the overall carbon emission associated with buildings. Decarbonizing materials like concrete and steel, as well as the emissions associated with the construction processes (i.e. fossil fuel fired machinery) will be a significant challenge. However, some progress has already been made using supplementary cementitious materials (SCMs) to reduce the embodied carbon of concrete. Fly ash from coal combustion is the most common SCM and has been shown to significantly reduce GHG emissions from producing concrete. [63] Innovation in decarbonizing heavy industry and transport will compliment building decarbonization in the coming decades. Systems could be implemented that incentivise or mandate carbon tracking for construction of new buildings and renovations to influence change towards a more sustainable construction industry that enables the circular economy. Similarly, policies that require a certain share of embodied carbon reduction from cement can be used to reduce embodied carbon while spurring on innovations in low-carbon concrete (e.g., Bay Area Low Carbon Concrete Code [65], Berkeley Green Code). [64]

Hybrid Decarbonization Pathways Approach

EPRI sees three broad pathways that end users and building owners may consider, separately or in some combination, for building decarbonization: early electrification, options capitalization, and deferred decision (Figure 9). Some highly motivated corporations, like Google, are already setting a stake in the sand for 24/7 carbon free energy supply by 2030 [39], which today will require renewables and electrification [40]. Others who are more cost constrained could choose to undertake what makes economic sense today, such as deep energy efficiency measures and electrification where feasible.

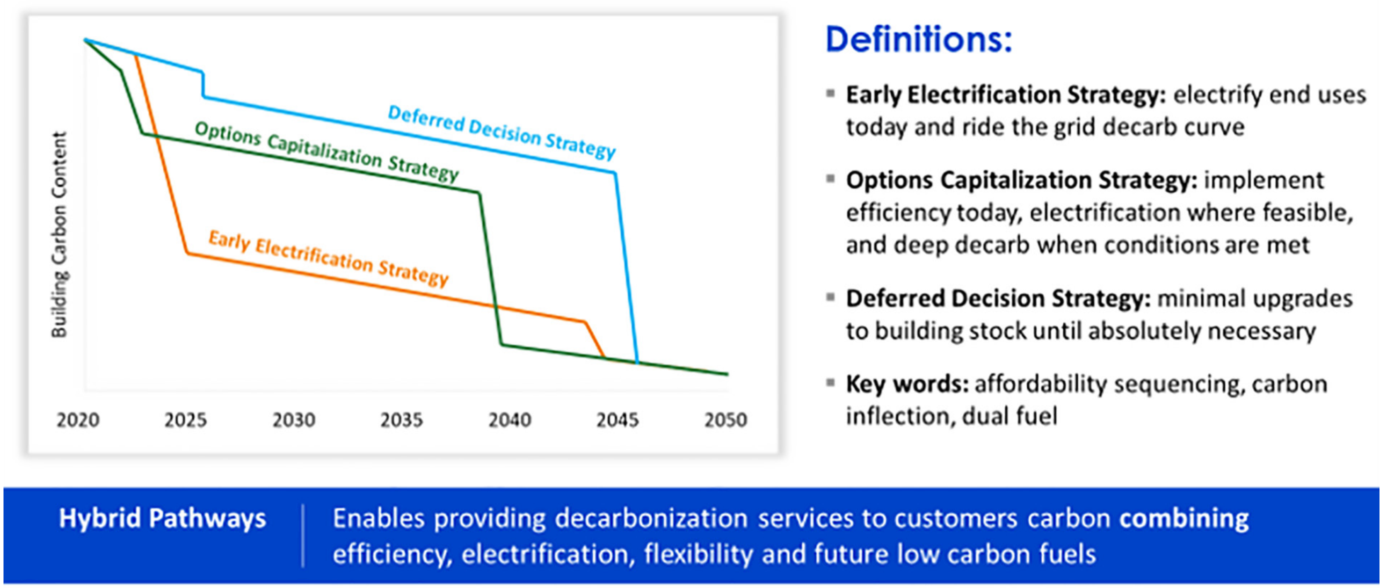

Figure 9: Hybrid Pathways to building decarbonization

The hybrid pathways approach to building decarbonization attempts to find the sweet spot between the three broad pathways highlighted above, to result in the most technically feasible and cost-effective pathway for customers and society. In some cases, this may mean partially replacing fossil fuel fired systems with a hybrid system that electrifies 50 – 80% of energy use, while reducing peak grid impacts. This leaves the door open for future LCFs to displace the rest of the energy use, or for advances in electrification technologies to do the same. Many customers will take a wait and see approach, motivated by policy-driven mandates, and not by incentives, that may take different forms based on regional differences and technological readiness in subsequent years.

Understanding how customer choices, which may be driven by economic considerations, has an impact on achieving decarbonization objectives is necessary to develop appropriate roadmaps that are aligned with customer economics. In particular, understanding these impacts can help utilities exercise levers such as rate design and customer programs to help customers make choices that are both economically better for them and help drive decarbonization.

What technologies and approaches can enable building decarbonization?

There are numerous available and emerging technologies that could accelerate the decarbonization of energy use in residential and commercial buildings [41]. Examples of these technologies which focus primarily on electrification and efficiency can be seen in Figure 10.

Heat pumps will be a key technology to efficiently electrify water and space conditioning and eliminate carbon emissions from the primary sources of operational energy consumption in buildings. In Ireland, the recently published National Development Plan identifies the retrofit of 500,000 homes and the installation of 600,000 heat pumps by 2030 as a strategic investment priority to transition to a climate-neutral and resilient society [42].

Flexibility is a key consideration to insure the seamless integration of electrified buildings within the power system. Speakers at EPRI's recent Building to Zero forum [43] highlighted findings from the US Department of Energy (DOE) that buildings with two-way communication, sensors, the ability to optimize efficiency of energy use, and the flexibility to become a grid resource could save upwards of $200 Billion, while reducing power sector carbon emissions by 6% [44]. EPRI has been working to understand the value of smart buildings [45], as well as connected communities of smart buildings in several demonstration sites [46] [47].

Innovative approaches to deploying energy communities at scale could help to engage customers while affordably increasing clean generation capacity, power system flexibility, reducing grid impacts of electrification, and reducing carbon emissions from buildings. EPRI demonstrated the integration of one of the world's first zero-net energy communities in California [48]. In Europe, E.DSO have emphasized the important role that utilities and electricity distributors have as facilitators of energy communities to enable the transition towards more customer centric energy markets where customers are actively engaged in the energy transition [49].

Community ownership business models can help to engage customers, enhance trust in new technologies, and provide individuals a voice in shaping the energy transition in their local area. As well as the ability to reduce the first cost of technologies through economies of scale, while reducing their energy costs and democratizing access to affordable clean energy [50]. Creating a business case for third parties to invest in the development of energy communities and subsequently manage energy generation and flexibility from DER, could lead to a more affordable transition to a decentralized and digitized energy system with decarbonized buildings [51]. In Europe there is a growing network of over 1.2 million citizens actively participating in the energy transition in around 1,900 energy communities [52].

Careful consideration is needed to shape strategies for building decarbonization to reduce the upfront and operating costs of electrification technologies and efficiency retrofits, while engaging customers so that they understand the opportunities and benefits that building decarbonization offers. In commercial settings, making a solid case for investments in technologies that can reduce operating costs and enhance quality of life with non-economic benefits like improved indoor air quality will be an important factor to influence decarbonization.

Case Study: Decarbonizing Healthcare Facilities

EPRI is currently working with the University of San Diego (UCSD) Health and Conservant Systems to understand how healthcare facilities can maintain good indoor air quality (IAQ) and decarbonize energy use required for space heating, cooling, and dehumidification which accounts for as much as 50% of energy use in hospitals. The project aims to demonstrate that recycling energy removed from air while cooling, to reheat the air after moisture removal can be a cost-effective solution to improve energy efficiency and reduce carbon emissions. To this affect, two aging air handling unit (AHU) systems will be replaced with high-efficiency dehumidification system (HEDS) integrated within AHUs in Thornton Hospital, part of the UCSD Jacobs Medical Center. HEDS AHU balances the energy requirement for reheating cooled and dehumidified air with energy needed to precool hot humid air before it is dehumidified through condensation. Some of the expected outcomes and value of this project are:

- Improved IAQ [53]
- Reduced or eliminated natural gas use for HVAC
- ~50-70% energy savings from chiller and boiler for relative humidity control
- Lower energy costs with energy savings
- Less fan and pump requirements can reduce maintenance costs and enhance reliability

This project will demonstrate and validate the energy and cost savings of HEDS AHU, to illustrate to the market and HVAC design community its potential to enhance energy efficiency, lower operating costs, and reduce carbon emissions in hospitals and large commercial facilities.

Affordability Sequencing

Affordability Sequencing is an intentional ordering of electrification steps that provide cost-optimal decarbonization pathways. Specific choices of electrification technologies can and should be incentivized because they help with decarbonization and with customer affordability. The affordability and decarbonization potential of these choices differ by location, utility rate structures, and average carbon intensity based on generation mix. Regional approaches should formulate appropriate market measures to incentivize customers to adopt electrification. Taking customer affordability into account helps to determine the sequence of electrification options that provides optimal long-term value in terms of operating cost and carbon savings.

Figure 11 highlights the cost saving implications of electrification technologies in existing homes in Fresno and Phoenix, the utility rate structure plays a key role in the cost savings for the customer. Time based rates can positively impact the cost savings of electrification technologies provided the consumption of the technologies are managed, ToU rates can also benefit utilities by spreading out energy use throughout the day and avoiding high peak demand. As illustrated previously in Figure 5 the cost savings of technologies like HPWH's can heavily depend on managing for ToU rates.

Considerations for Equitable Electrification

Affordability Sequencing helps with understanding and utilizing customer economics as a factor in their energy conservation choices. This is critical when considering a segment of customers who are significantly impacted by energy costs, particularly low-income customers. The nexus of poverty, high energy costs, and lack of access to affordable clean energy leads to a stratified impact on disadvantaged communities including energy access, energy poverty, energy insecurity, and energy burden [65]. The notion of the energy burden becomes a principal consideration for stakeholders in the energy market transformation. A recent report projects that approximately 14% of the US population lives in poverty. Sixty seven percent of households with median incomes less than 200% of the Federal Poverty Level experience energy burden and 36% experience severe energy burden [54]. For customers facing an energy burden, measures beyond simple first-cost incentives and rebates have to be constructed, along with approaches that engage a full spectrum of stakeholders, including community-based organizations that support these customers as necessary. A survey of residents in low-income communities whose living units were retrofit with deep efficiency upgrades and partial electrification indicated that, based on their assessment of performance, simple measures such as improved windowpanes and doors rated higher than high efficiency HVAC, while refrigerators and cooking appliances ranked among customers favorite measures deployed.

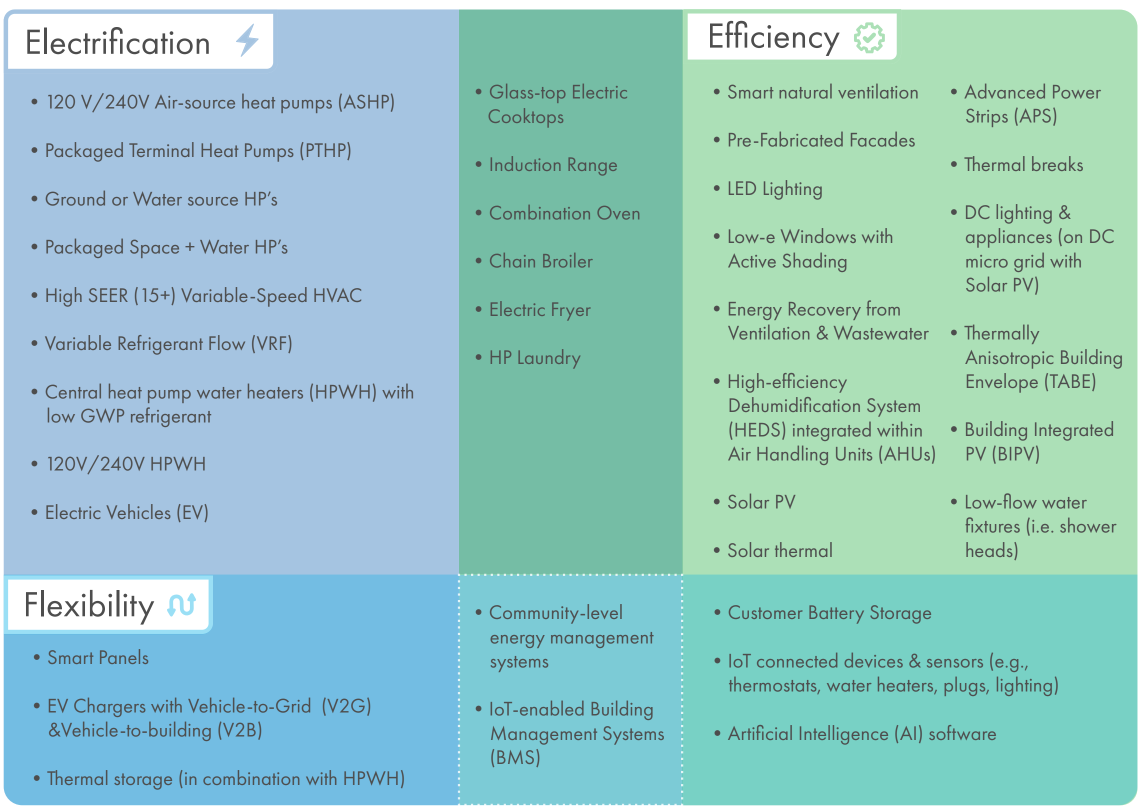

Figure 10: Examples of technologies that are enabling building and power system decarbonization through electrification, efficiency, and flexibility.

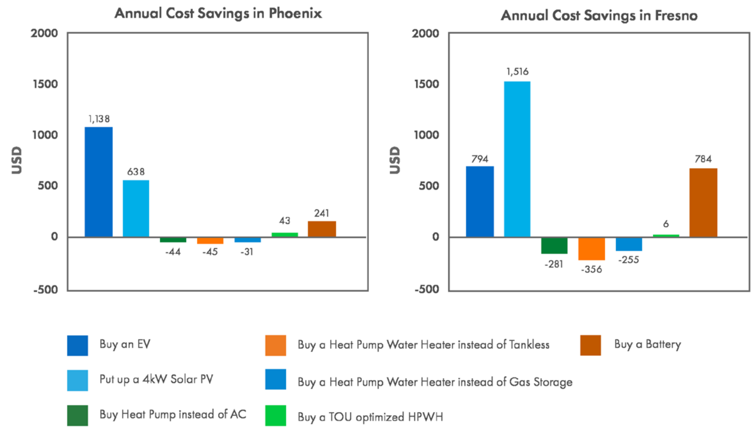

Figure 11: EPRI research found that if customers choose electrification technologies based on cost savings, the local and regional rates can influence the choice made. [9]

Call to Action on Building Decarbonization

To summarize the above discussion, demand, supply, and regulation in the buildings decarbonization space must take actions to support each other in helping to transform buildings and turn the overall energy market towards decarbonization (Figure 12).

Demand Side: Comprised principally of homeowners, building residents, home builders, and property owners, the demand side represents the market for both energy and buildings. The demand side should develop a keen understanding of the energy and climate impact of the choices that they make, especially as it relates to buildings and the built environment. Considerations include being more energy-aware and orienting actions towards energy conservation and efficient use. Customers can also take advantage of the significant potential for social media-outlets that empower them to guide their circles of influence towards the importance of decarbonization actions. Finally, when it comes to product adoption, specifically products that have significant impact on their energy use like space conditioning and water heating, customers should consider making choices that are oriented towards efficiency and decarbonization.

Supply Side: The supply side is principally comprised of end-use technology and product developers, e.g., space conditioning vendors, electricity and gas generation and distribution utilities, and solar power purchase agreement operators. These entities can start developing products and technologies that address customer needs in the most efficient and "decarbonized" way possible. It will be crucial for technology manufacturers to bolster the supply chain of decarbonizing technologies to prepare for their increasing demand. It will be equally as important to support their products with customer and trade education programs that can help the market understand the value proposition and how to install/use these to achieve optimal results. For utilities, a major call to action would be to consider a set of strategic actions that can help spur customer adoption of high efficiency and low-carbon end-uses including: new programs focused on decarbonization of end-uses, efficient electrification, competitive rates for electrification to help alleviate customer's operating cost concerns, and incentives and rebates to help lower the first cost of replacing inefficient fuel-fired end-uses with higher efficiency electrified and low-carbon end-uses. Figure 14 summarizes the broad framework of actions that can be taken to implement a particular set of strategies to equitably decarbonize buildings in response to regional specificities and drivers. EPRI is working with a number or utilities to apply this framework to develop regionally specific roadmaps to accelerate the benefits of building decarbonization.

Regulation: The regulatory side, typically comprised of governments (federal, state, and local) and associated policy makers, fundamentally needs to take decisive action on decarbonization. While several local governments in the US have taken steps like natural gas bans on new residential construction, there have been other state and local governments that have instituted policies that block incentives for fuel switching from fossil fuels to electricity even though there is significant decarbonization potential [55]. Policymakers have the power to affect market transformation through appropriate policies that address the drastic effects of climate change and the challenge(s) of implementing and using decarbonization measures. Measures such as setting decarbonization goals help spur-on and drive supply and demand side actions, as illustrated in Figure 16. In addition to establishing goals, policy makers should consider providing roadmaps that can help guide market strategies, measure progress achieved, and assess the need for additional and accelerated actions. An important caveat is considering and keeping electrification equity concerns front and center. Economically vulnerable populations tend to be the most challenging segment of the market to transform, but with equitable policy measures the challenges with severe energy burden may be overcome.

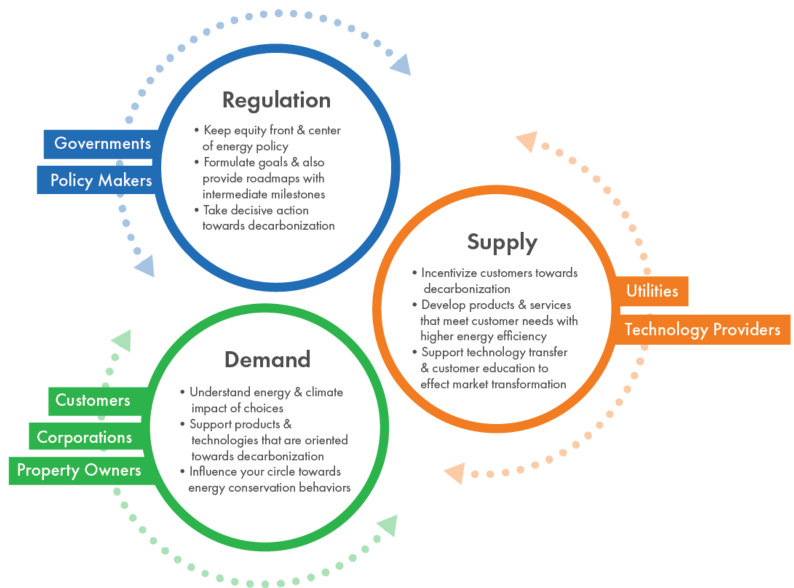

Figure 12: A call to action for players in the building decarbonization market

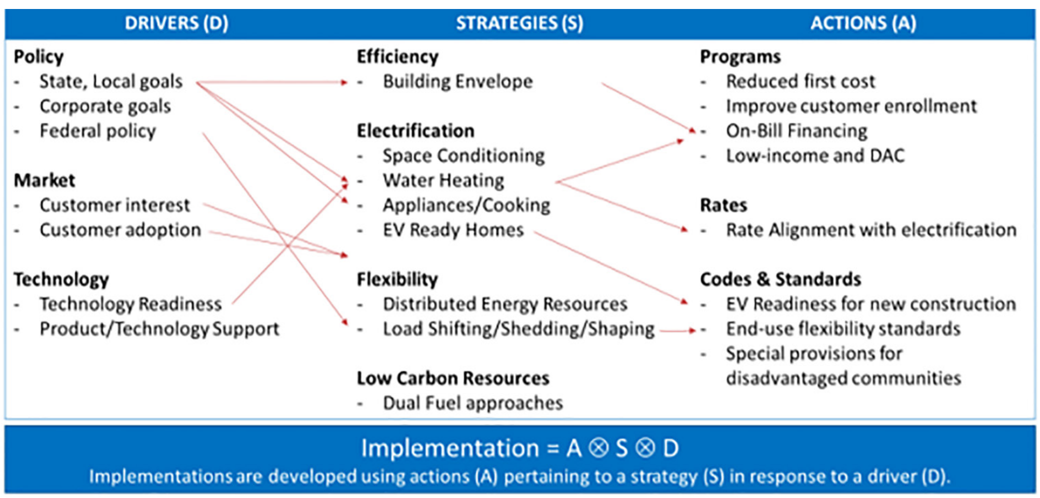

Figure 13: Framework for developing equitable building decarbonization roadmaps in response to Drivers. Actions can be taken by utilities to influence the combinations of strategies that will be most cost-effective for a particular region.

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