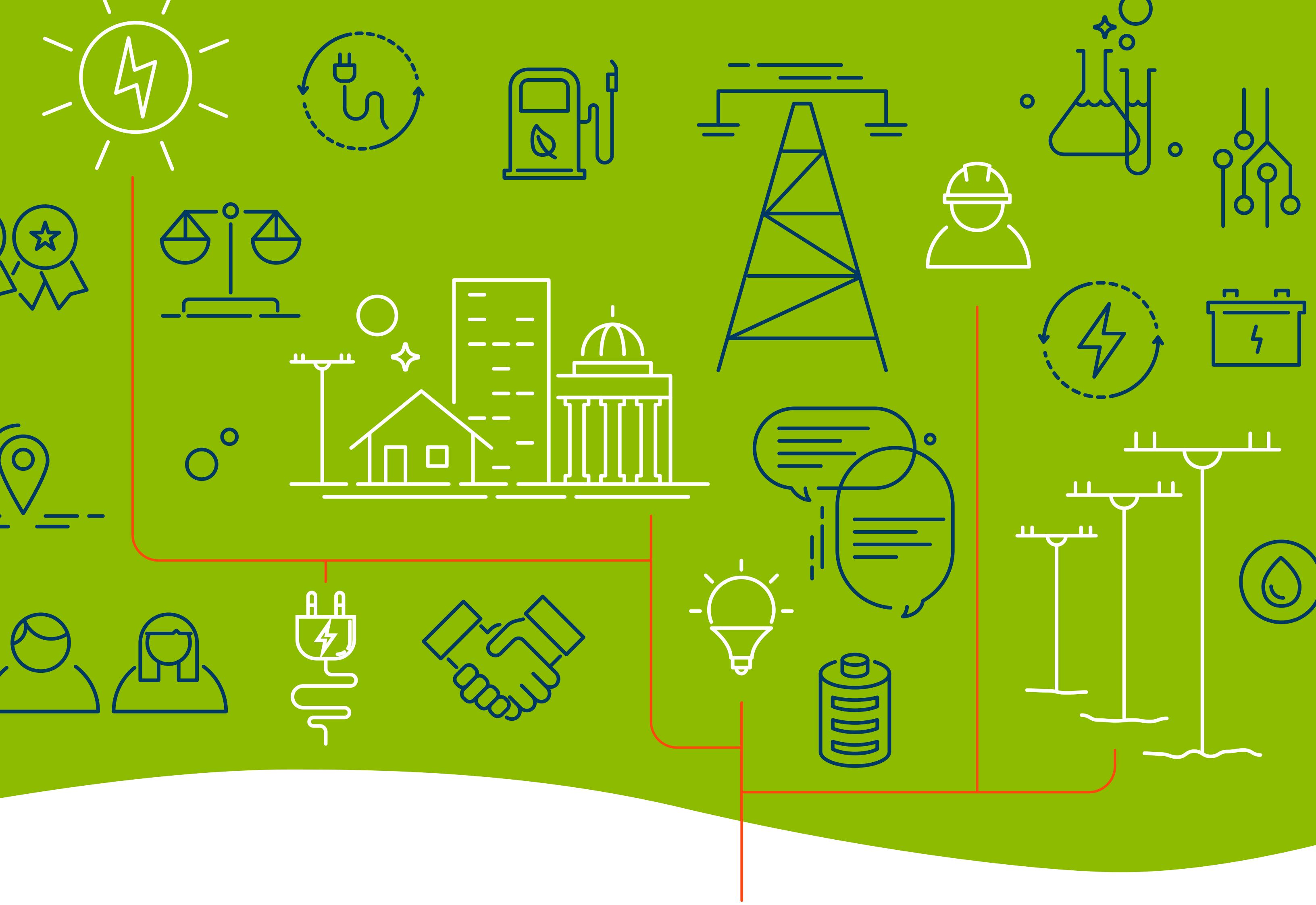

A Road Map to Decarbonization in the Midcontinent

BUILDINGS

MIDCONTINENT POWER
SECTOR COLLABORATIVE

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Midcontinent Power Sector Collaborative Participants

The following participating entities took part in the development of this road map. Nothing in this road map binds any signatories to any specific position. Nothing in the road map authorizes any signatory to speak on behalf of other signatories, though signatories are welcome to use the existence of co-signatories as evidence of the appropriateness of the recommendations in this road map.

Alliant Energy

Center for Energy and Environment

Clean Wisconsin

Dairyland Power Cooperative

DTE Energy

Ecology Center

Entergy

Madison Gas and Electric

Michigan Energy Innovation Business Council

Midwest Energy Efficiency Alliance

The Nature Conservancy

Union of Concerned Scientists

WEC Energy Group

Wolverine Power Cooperative

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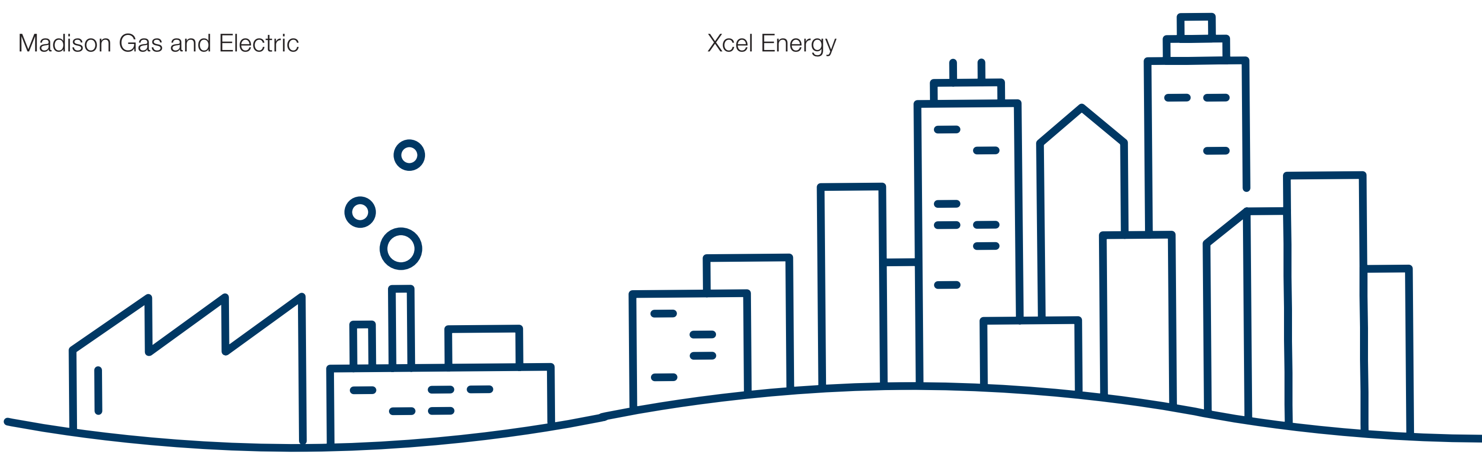
Xcel Energy



A Road Map to Decarbonization in the Midcontinent

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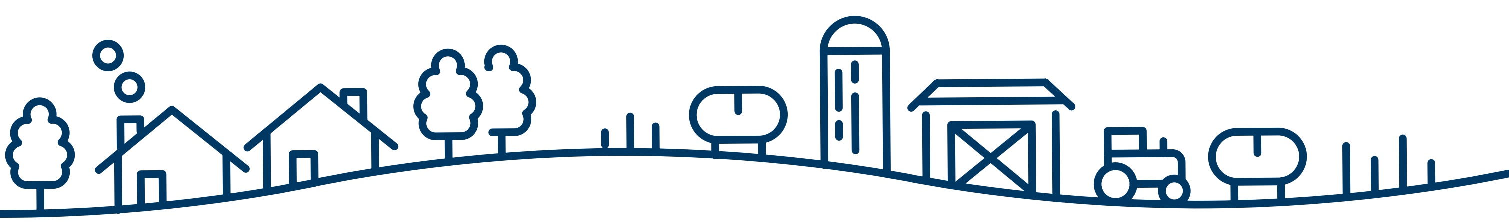

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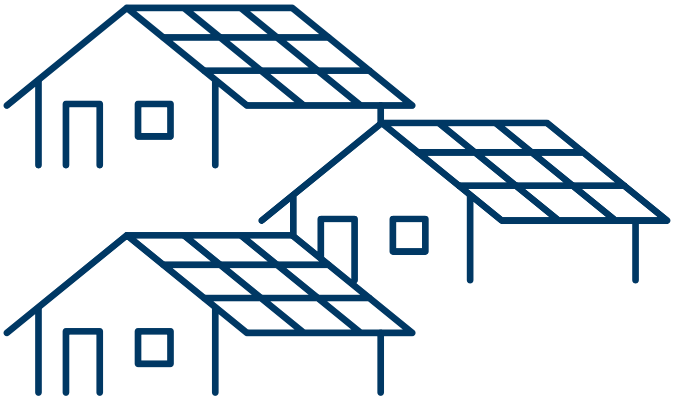
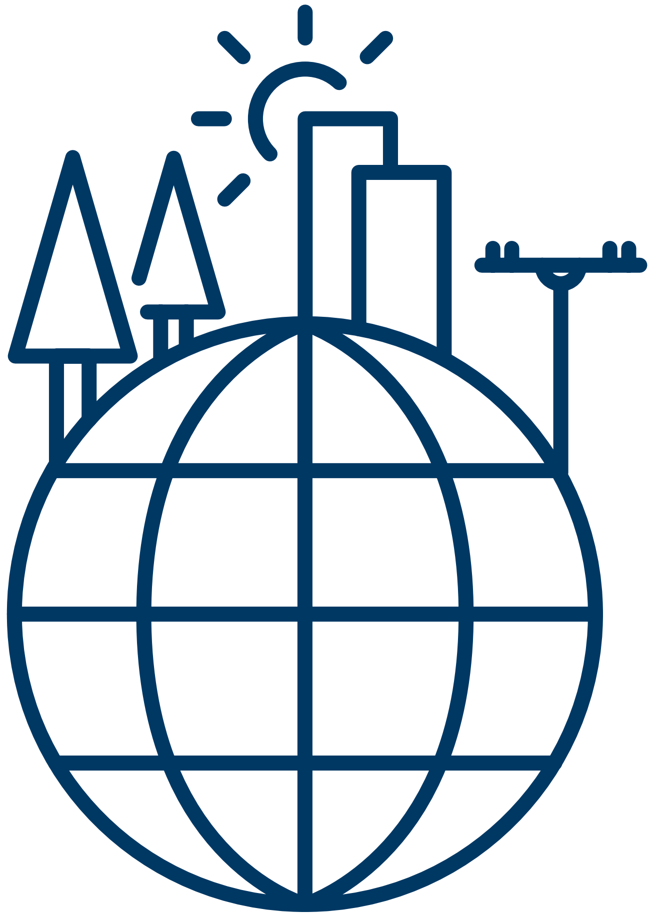


Contents



ACKNOWLEDGMENTS

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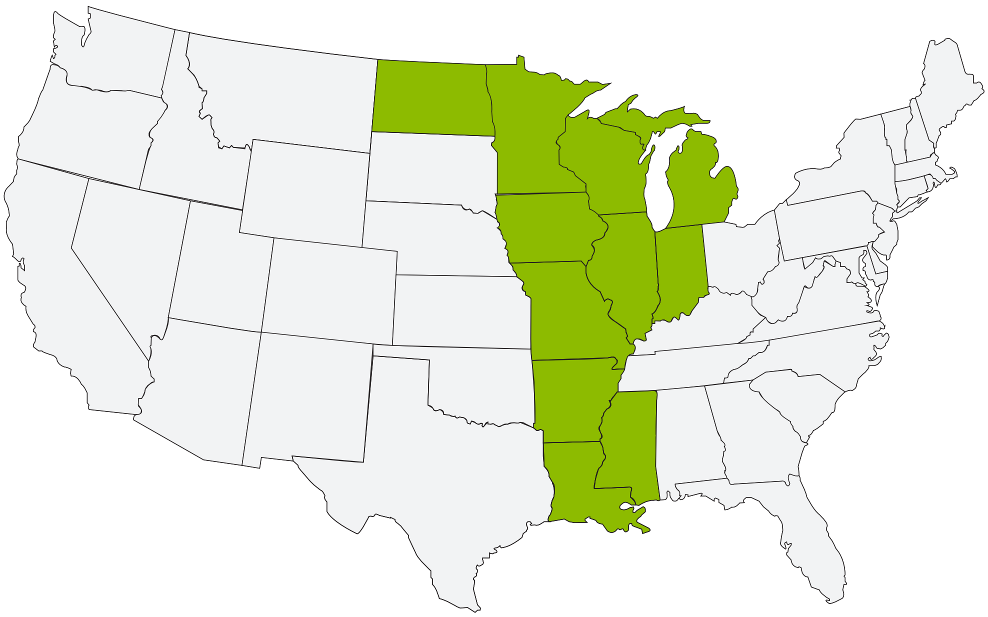
Introduction

REDUCING CARBON EMISSIONS FROM BUILDINGS is a key part of any plan to achieve net-zero greenhouse gas emissions economywide by midcentury, as the Intergovernmental Panel on Climate Change has suggested is necessary to limit global temperature increase to 1.5ºC. Decarbonization of buildings will require making buildings more energy efficient, and replacing fossil fuels currently used for space and water heating with very low- and zero-carbon electricity, as well as pursuing very-low and zero-carbon alternative fuels such as renewable natural gas and hydrogen. This road map explores the roles of end-use energy efficiency, electrification, renewable natural gas, and other very low- or zero-carbon fuels in the decarbonization of buildings, and makes recommendations to accelerate progress toward buildings decarbonization.



The Midcontinent Power Sector Collaborative began studying potential pathways to decarbonizing the electricity sector in January 2017 and issued *A Road Map to Decarbonization in the Midcontinent: Electricity Sector* in July 2018. The Collaborative then turned its focus toward electrification of transportation in the latter half of 2018, putting out *A Road Map to Decarbonization in the Midcontinent: Transportation Electrification* in January 2019. As with these two prior road maps, this buildings road map does not arrive at a single prescription for decarbonizing buildings. Rather, as discussed below, the Collaborative finds that electrification can play a very significant role in the decarbonization of buildings but policy makers, building owners, and key stakeholders should be prepared to bring a mix of solutions to the decarbonization challenge. This is particularly the case because of the wide variation in climate zones across the Midcontinent region being evaluated (see map above): the best way to provide decarbonized heating and cooling may not be the same in northern Minnesota and southern Louisiana.

This road map begins with a brief description of the context for buildings decarbonization, including a review of carbon emissions trends, energy efficiency as a resource, the current state of alternatives to fossil fuel for space and water heating in buildings, and the importance of heat pump technologies. The current policy and regulatory context for buildings is discussed next, followed by the details of the Collaborative's modeling analysis of buildings. The road map concludes with the Collaborative's recommendations for accelerating the decarbonization of buildings in the region.

Understanding the Context

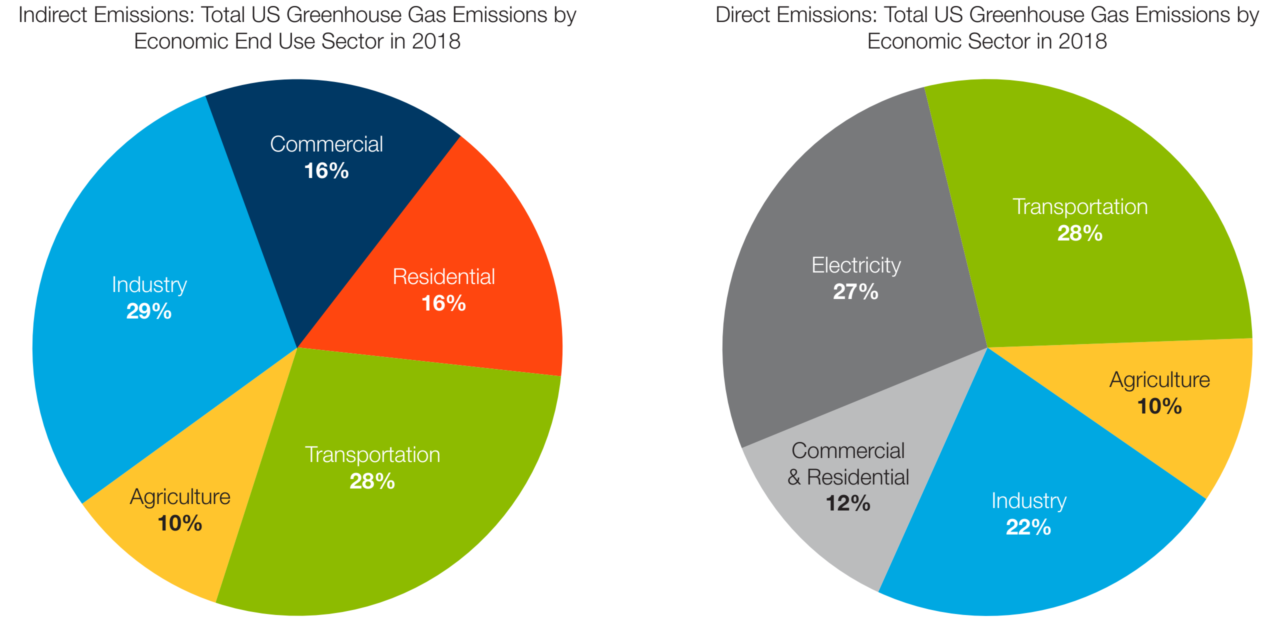
Carbon Emissions from Buildings

DECARBONIZATION OF BUILDINGS WILL require reducing both direct and indirect emissions. Direct carbon emissions from fossil fuel use in buildings are attributable primarily to space and water heating. Direct emissions from the commercial and residential buildings sector, as shown in Figure 1, are about 12 percent of all direct emissions by sector. When indirect emissions from electricity generation are included, emissions from the commercial and residential sectors made up nearly one-third of US greenhouse gas emissions in 2018.[1] Emissions from buildings have been relatively flat since 2010.[2] Though this road map is focused on direct emissions, it is important to note that electricity use in buildings is also indirectly responsible for carbon emissions at power plants and will continue

1 US Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018,* (April 11, 2019): table ES-7, accessed April 2020, http://www.epa.gov. The figure includes both direct emissions, as well indirect emissions such as electricity generation and any natural gas fuel leakage. EPA accounts for indirect electricity emissions with emissions factors in the inventory. For natural gas, EPA includes natural gas system emissions as indirect industry emissions, which also captures any methane leakage. Of the natural gas industrial emissions in the 2018 inventory, 3.9 percent of emissions from natural gas systems could be attributed to methane leakage from the transmission and distribution segment.

2 "Greenhouse Gas Inventory Data Explorer," US Environmental Protection Agency, https://cfpub.epa.gov/ghgdata/inventoryexplorer/index.html#commercial/allgas/source/all.

FIGURE 1: **Proportion of Indirect and Direct Greenhouse Gas Emissions across Sectors in the United States**



to be as long as electricity has carbon emissions.[3] This underscores the importance of decarbonizing the electricity sector by midcentury or sooner.

Energy Efficiency Potential

Energy efficiency is expected to play a significant role in the decarbonization of the buildings sector by reducing the energy necessary to provide the same or better water heating, space heating and cooling, and other building services. More efficient buildings and appliances are thus an important enabler of other strategies, regardless of whether the heating fuel remains conventional natural gas or switches to electricity or renewable natural gas. In this context, it is important to distinguish between new and existing buildings as their respective opportunities and challenges are different. Seizing cost-effective energy efficiency opportunities requires that policy makers and energy efficiency providers overcome barriers to action.

1. New Buildings. New buildings present significant opportunities for the cost-effective implementation of energy efficiency strategies because the incremental cost of building an efficient building envelope, installing efficient lighting and appliances, and efficient heating and cooling is small relative to the energy saved.

2. Existing Buildings. Most buildings expected to be in use in 2050 already exist. Energy efficiency retrofits are therefore an important part of maximizing energy efficiency in the sector. Building envelope improvements reduce energy consumption by reducing space heating and cooling requirements. Retrofitting space and water heating appliances with more efficient appliances, especially through fuel switching from fossil fuel-fired equipment to electricity, can also save energy and money under the right circumstances and in certain parts of the Midcontinent region.[4] As described below, heat pump penetration is greater in the warmer parts of the region across all scenarios.

3 The Collaborative's *A Road Map to Decarbonization: Electricity Sector* detailed ways the region could substantially decarbonize the electricity sector. Since release of the electricity road map, a number of utilities in the region have announced goals to fully decarbonize their systems by midcentury. As a result, this road map assumes that electricity will decarbonize over time, making electricity a very low- or zero-carbon buildings fuel by 2050.

4 See Trieu Mai, Paige Jadun, Jeffrey Logan, Colin McMillan, Matteo Muratori, Daniel Steinberg, Laura Vimmerstedt, Ryan Jones, Benjamin Haley, and Brent Nelson, *Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States* (Golden, CO: National Renewable Energy Laboratory, 2018), NREL/TP-6A20-71500, https://www.nrel.gov/docs/fy18osti/71500.pdf.

About This Buildings Road Map

A Road Map to Decarbonization in the Midcontinent: Buildings, and the modeling analysis that informs it, are the work products of the Midcontinent Power Sector Collaborative, convened and staffed by the Great Plains Institute. The Collaborative brings together a diverse set of stakeholders from across the Midcontinent region, including investor-owned utilities, cooperatives, merchant power, public power, environmental groups and observing state officials. This road map does not recommend a specific policy or set of policies, nor a specific technology or mix of technologies. Nothing in this road map authorizes any participant to speak on behalf of other participants, though participants are welcome to use the existence of other signatories as evidence of the appropriateness of the recommendations in this road map.

About This Road Map Series

Since January 2017, the power companies, environmental advocates, and state officials that make up the Midcontinent Power Sector Collaborative have come together to gain a better understanding of how the region might meet the challenge of climate change through substantial decarbonization. This road map focused on the buildings sector is the third installment in a series that began with the electricity sector, and then turned to transportation electrification.

3. Barriers to Adoption. With both new and existing buildings, hurdles exist that may prevent building owners from making even energy-efficient choices that will save the building owner money. In some cases, building owners and their contractors are not well-informed about the choices. Sometimes higher upfront costs act as a barrier, even when those higher upfront costs will be recouped through energy and cost savings over time. In the case of existing buildings with existing appliances, building owners are unlikely to even consider replacing inefficient appliances without incentives until and unless those appliances no longer work. In rental buildings, incentives may be split between landlords and tenants. These and other hurdles to building efficiency have been the target of energy efficiency programs for many years with significant success and many lessons learned.

Alternatives to Fossil Fuel

Decarbonization of buildings depends on switching from fossil fuel to alternatives that result in very low or no carbon emissions. In general, that means electrification of building end-uses that currently are powered by fossil fuel, or replacing fossil fuels with a very low-carbon or zero-carbon alternative, like renewable natural gas in its many forms or hydrogen.

1. Electricity and Electrification. Electricity is an abundant, “home-grown” fuel that is expected to get cleaner and cleaner as time goes on. Indeed, many cities, states, and utilities in the region have adopted carbon goals consistent with the substantial decarbonization of the electricity sector. Switching from fossil fuel for heat and hot water also often entails a substantial improvement in efficiency, as in the case of electric heat pumps replacing a natural gas furnace—though challenges remain for the coldest days, as discussed below.

2. Renewable Natural Gas. Renewable natural gas (RNG) derived from organic wastes and other renewable sources represents an alternative to natural gas.[5] Estimates on future RNG supply are uncertain, with some researchers estimating that RNG could replace only 3 percent of current natural gas consumption while others estimate that RNG could replace as much as 30 percent of current natural gas consumption. The amount of RNG which will be ultimately available for widespread building consumption will depend heavily

5 The term “renewable natural gas” as used here includes pipeline quality gas derived from: landfill gas, animal manure, water resource recovery facilities, food waste, agricultural residues, forest residues, energy crops, municipal solid waste and methanation through power to gas. American Gas Foundation, *Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment* (December 2019), study prepared by ICF. Zero-carbon methanation through power to gas depends on available electricity generation from non-emitting sources.

on technological advancements and the competing demand for RNG across various sectors of the US economy, especially sectors with end-uses that are particularly hard to electrify like heavy industries and cold climate residential space heating. Given the likely competition for available RNG supplies from other sectors, there is a risk that smaller amounts of the total RNG supply will be available for use in buildings across all areas of the country. Considering some of these supply limitations, RNG may be a smaller part of the decarbonization toolbox in the more temperate (south and central) parts of the study region due to the ability of heat pumps to meet most heating demand there. In the northern part of the study region, RNG may play a greater role—especially if it proves more cost-effective than electrification, and/or as an option for decarbonizing the backup fuel likely to be needed for air-source heat pumps.

3. Hydrogen. Hydrogen is another alternative fuel that could play a significant role in the decarbonization of buildings, though it was not included in this modeling exercise. "Green hydrogen" is created through electrolysis of water using non-emitting electricity generation, such as wind, solar, or nuclear. Natural gas can also be converted to hydrogen by stripping and capturing the carbon atoms and sequestering that carbon to create a low-carbon version that is sometimes called "blue hydrogen." Once produced, hydrogen can be burned without emitting carbon. It can also be blended with natural gas in the near-term to improve the carbon profile of the natural gas distributed to buildings as a near-term carbon reduction solution.[6] The extent to which hydrogen can be mixed with natural gas without modifications to infrastructure will vary by utility system, but it has been estimated to be somewhere between 5 and 30 percent by volume.[7] In the long term, fully substituting fossil gas with green hydrogen would require either significant modifications to existing gas infrastructure or new hydrogen-compatible infrastructure,[8] as well as new hydrogen-compatible appliances.

Heat Pump Technology: Opportunities and Challenges

Heat pumps are able to heat air and water much more efficiently than combustion furnaces or electric resistance heating. Heat pumps use just enough electricity to power two fans, a compressor, and refrigerant pump. Because of this, heat pumps are capable of providing more than three units of indoor heat for every unit of electricity used, for an average efficiency rate of more than 300 percent in moderate climates and over 200 percent in colder climates. This compares to an efficiency rating below 100 percent for even the most efficient natural gas furnaces.

Electric heat pumps move heat from one place to another. In cold weather, when indoor heating is needed, heat pumps move heat from outside a building to the indoors, even when the temperature is lower outside. In warmer weather, heat pumps can be operated in reverse to move heat from inside a building to the outdoors. Heat pumps that extract or discharge heat into the outdoor air are called air-source heat pumps, while ground-source heat pumps extract or discharge heat underground. The schematic in Figure 2 illustrates how a heat pump functions in heating mode.

Outside super cold low-pressure refrigerant is warmed by outside air as it flows through the coil, before it is compressed and sent inside. Inside, room temperature air is heated when air flows past a coil with hot refrigerant. After heat is extracted from the refrigerant in this way, it is sent through an expansion valve, where the cycle continues.

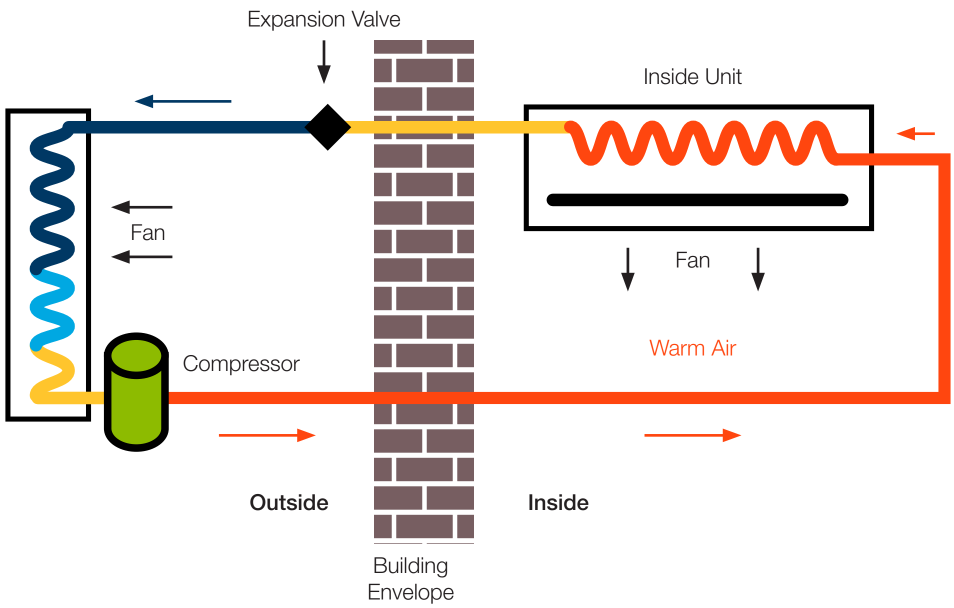
In general, heat pumps are less efficient as temperatures get very cold. Recent advances, however, have produced cold climate heat pumps that are 100 percent efficient even when outside temperatures fall below zero degrees Fahrenheit. Current heat pump technology can provide heat in most parts of the Midcontinent without needed backup; however, in the northernmost parts of the region and coldest weeks of the year, heat pumps will require a backup source of heat. This backup requirement presents a challenge for decarbonizing buildings in colder parts of the region, because backup heating adds costs, both for the heating appliances as well as to operate. In full-

6 See M.W. Melaina, O. Antonia, and M. Penev, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues* (Golden, CO: National Renewable Energy Laboratory, 2013), NREL/TP-5600-51995, https://www.nrel.gov/docs/fy13osti/51995.pdf.

7 See Fuel Cell and Hydrogen Energy Association, *Road Map to a US Hydrogen Economy: Reducing emissions and driving growth across the nation* (October 2020), https://www.ushydrogenstudy.org. Hydrogen as a fuel for residential and commercial buildings is discussed on pages 29-32. "Various studies show blending levels limited at 5 to 30 percent by volume without appliance upgrades." Ibid, 29.

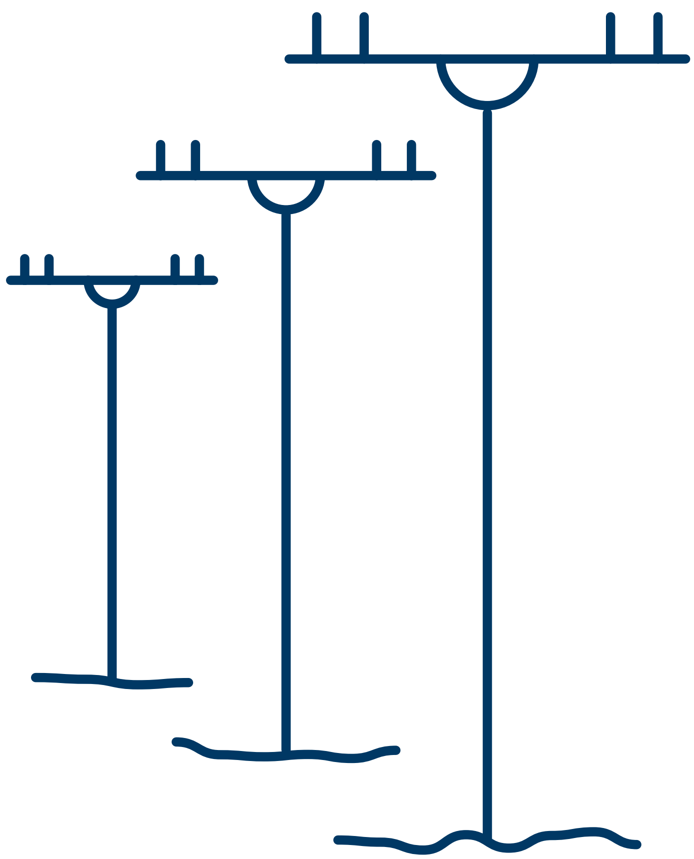
8 See Melaina, Antonia, and Penev, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues*.

FIGURE 2: Overview of the Heating Cycle of an Air-Source Heat Pump



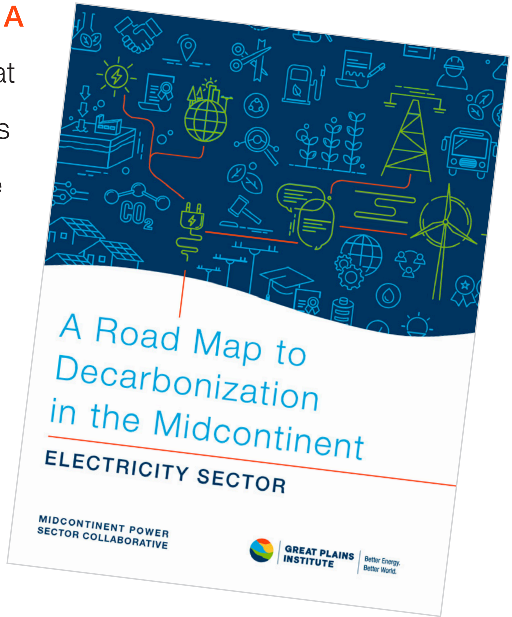
electrification scenarios where the backup heat source is also electric (e.g., electric resistance), converting all building heating to electric can more than double the peak demand of the electric system needed to provide heat on the coldest days. In colder parts of the region, therefore, the most cost-effective near-term applications for heat pumps will be those that replace the more expensive and emissions-intensive forms of heating, such as propane, heating oil, and solid fuels (i.e., wood).

Because heat pumps can be run in reverse to cool the inside air in the summertime, they provide a building service that combustion furnaces do not. For building applications where air conditioning is being added or replaced, heat pumps become more attractive because they can do double duty, providing heating and cooling. As climate change drives summertime temperatures hotter and introduces new demands for cooling, this dual opportunity will become increasingly important.



Current Policy and Regulatory Context for Buildings

Electricity Supply and Decarbonization of Electricity



IF ELECTRIC HEAT PUMPS ARE TO PLAY A big role in decarbonizing buildings by midcentury, what happens to the electricity sector in the coming decades is very important. The Collaborative conducted extensive modeling analysis of the electricity sector in connection with *A Road Map to Decarbonization in the Midcontinent: Electricity*.[9] That analysis was updated for this buildings road map.

9 The electricity road map can be found on the Great Plains Institute website, http://roadmap.betterenergy.org/wp-content/uploads/2018/08/GPI_Roadmap_Web.pdf.

Figure 3 shows generation looking forward under a business-as-usual scenario, where no new policies or actions are taken to reduce carbon emissions from the power sector.[10] Both natural gas and wind generation are expected to increase through 2050, while coal generation decreases to about half of its 2020 level. Solar increases, while nuclear and hydro generation remain the same. These graphics do not depict end-use energy efficiency as a measure—only supply side actions. Figure 4 shows the projected change in fleet makeup over the same time period.

FIGURE 3: What to Expect from the Electricity Sector Business as Usual: Less Coal; More Wind, Solar, and Natural Gas

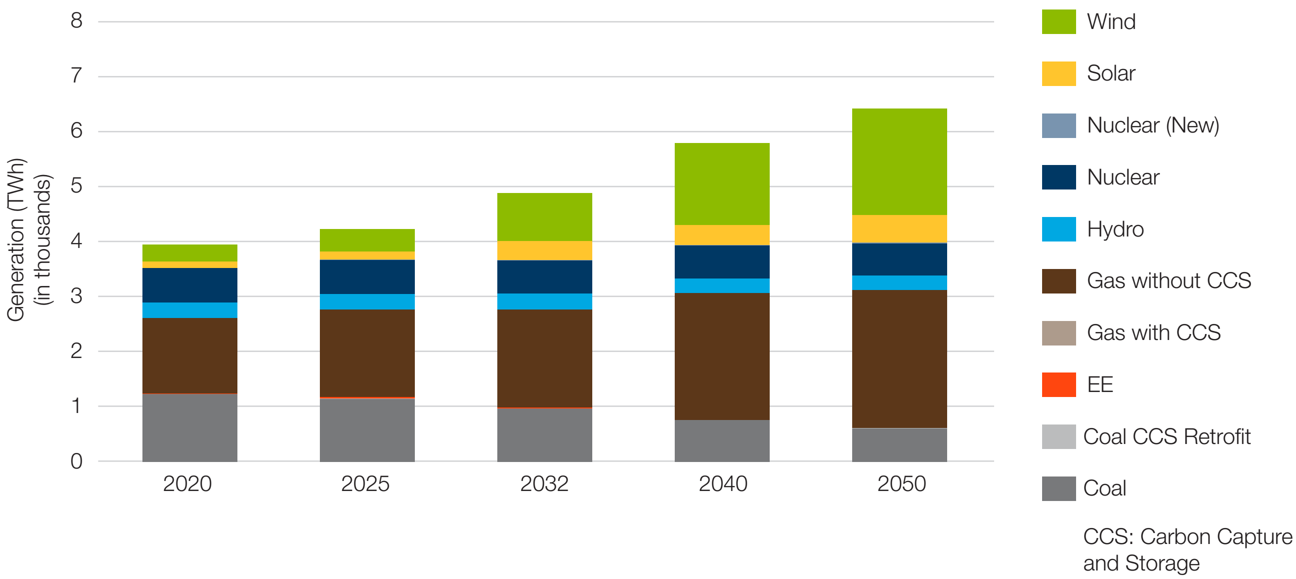
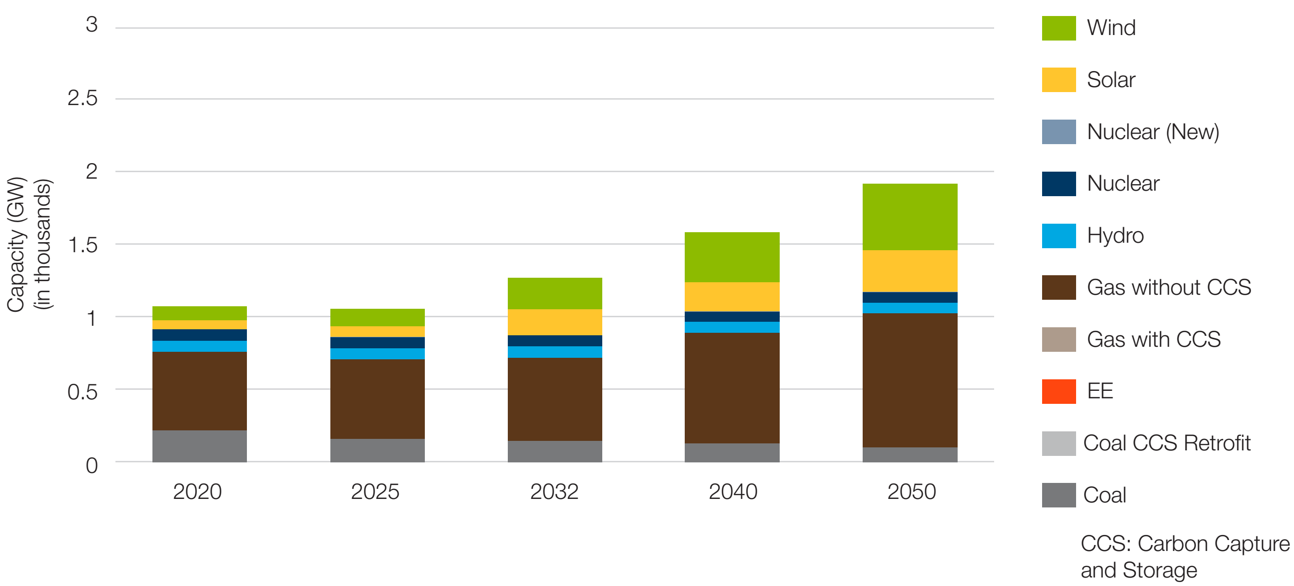


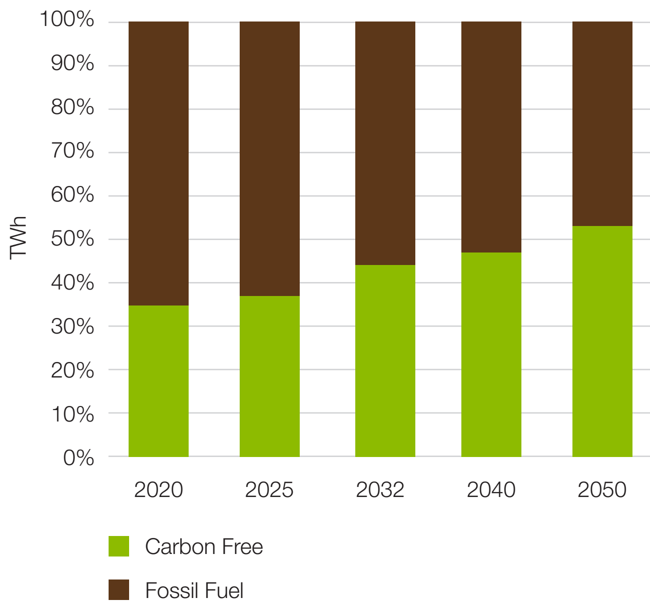
FIGURE 4: Changes in the Electric Generating Fleet through 2050 under Business as Usual: More Wind and Solar; More Natural Gas; Some Coal Retirements



10 The results included here were based on updated assumptions in 2020, including current demand forecasts, fuel price projections and technology costs. The business-as-usual scenarios assume no new actions are taken by utilities or state regulators after 2020, including utility carbon targets because state commissions have so far not approved all of the investments necessary to achieve those targets. These business-as-usual demand forecasts also do not account for potentially significant load growth through electrification of transportation, buildings and other end uses.

Figure 5 shows the business-as-usual scenario in terms of the share of carbon-free electricity through 2050. While carbon-free generation increases, it only reaches 50 percent of total generation in 2050.

FIGURE 5: **Share of Carbon Free Generation under Business as Usual through 2050**



About the Modeling Analysis

This road map analysis relies on sophisticated energy-economic modeling performed by Sustainable Energy Economics and KanORS-EMR using the FACETS modeling platform to project what the region's electricity sector might look like under various future conditions. Modeling projections are not predictions of the future, but rather provide a sense of what may happen in the future given a set of assumptions. The assumptions we make today do not take into account technology step changes or other unforeseeable conditions that may occur in the future that will change what the future holds for the region's electricity or buildings sector. In this report we note the assumptions that are most important to the outcome of the modeling analysis. More information about the model can be found at: www.facets-model.com.

When the model is required to achieve a 95 percent reduction from the power sector, we see that near-total decarbonization of electricity is indeed possible. As shown in Figures 6 and 7, the model projects a much greater increase in wind generation than in the business-as-usual scenario and a total phaseout of coal in the region. Uncontrolled natural gas generation is replaced with natural gas with carbon capture.[11] New nuclear is also added between 2040 and 2050. While this precise mixture of generating technologies represents the model's projection as to the lowest-cost mix through 2050, the mix could be different if the future plays out differently than the assumptions suggest. In addition, the analysis was conducted on a regional basis, but analyses of specific utility systems might yield a different lowest-cost mix of resources for decarbonization based on a utility's unique circumstances.

Even though a substantial amount of natural gas capacity remains in 2050, and a very small amount of coal capacity, these plants contribute very little to the total generation. Indeed, nearly all generation in 2050 is from carbon-free sources. This helps illustrate the point that a small amount of firm capacity—even if it operates very few hours in a year and thus emits very little carbon dioxide—can be helpful to enable a deeply decarbonized electric sector affordably and reliably.

Energy Efficiency Policy in the Region

Energy efficiency policies and programs are important in the buildings decarbonization context, both because increased energy efficiency reduces energy consumption and because decades of experience in delivering energy efficiency programs will inform how utilities and others implement electrification programs. Indeed, many of the same barriers that stand in the way of implementing cost-effective energy efficiency stand in the way of retrofitting buildings with efficient appliances and decreasing reliance on fossil fuels and increased electrification.

States and utilities in the Midcontinent region have a long history of implementing energy efficiency policies and programs. Figure 9 shows the states in the region that have energy efficiency resource standards or energy savings goals.

11 Although our analysis did not include this option, hydrogen created without carbon emissions—either green or blue hydrogen—could also fire turbines in place of natural gas.

FIGURE 6: What Electricity Looks like Under 95% Decarbonization by 2050: No Coal; More Wind, Solar, Nuclear and Gas with Carbon Capture

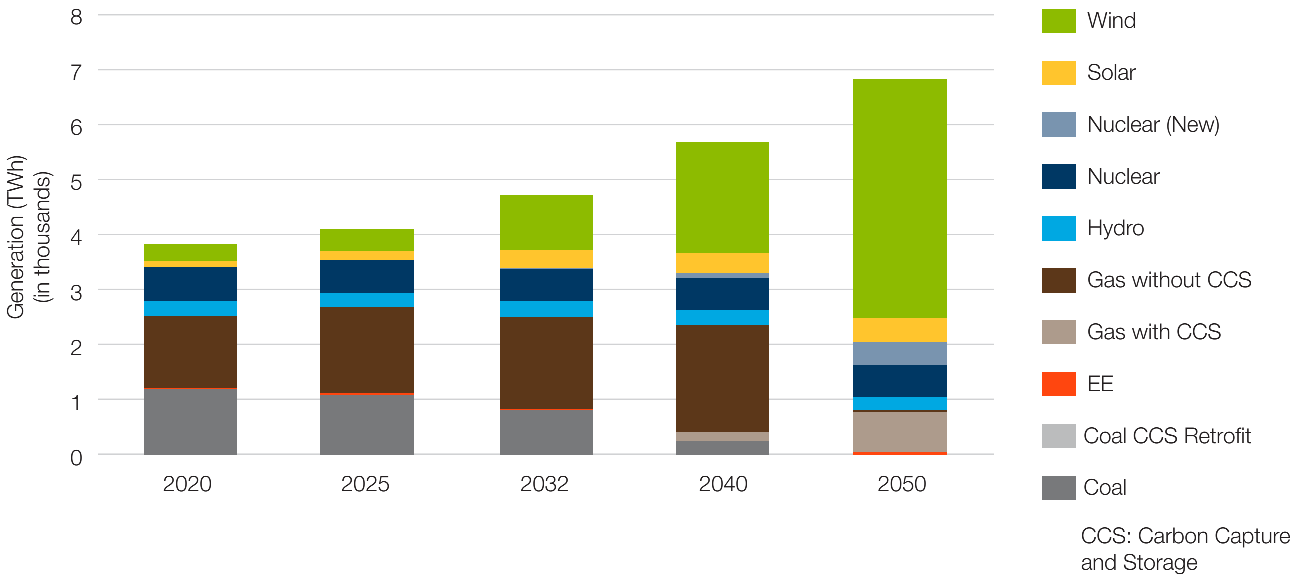


FIGURE 7: Changes in the Electric Generating Fleet under 95% Decarbonization: Almost all Coal Retires; Much more Wind and Solar; Some New Gas with Carbon Capture

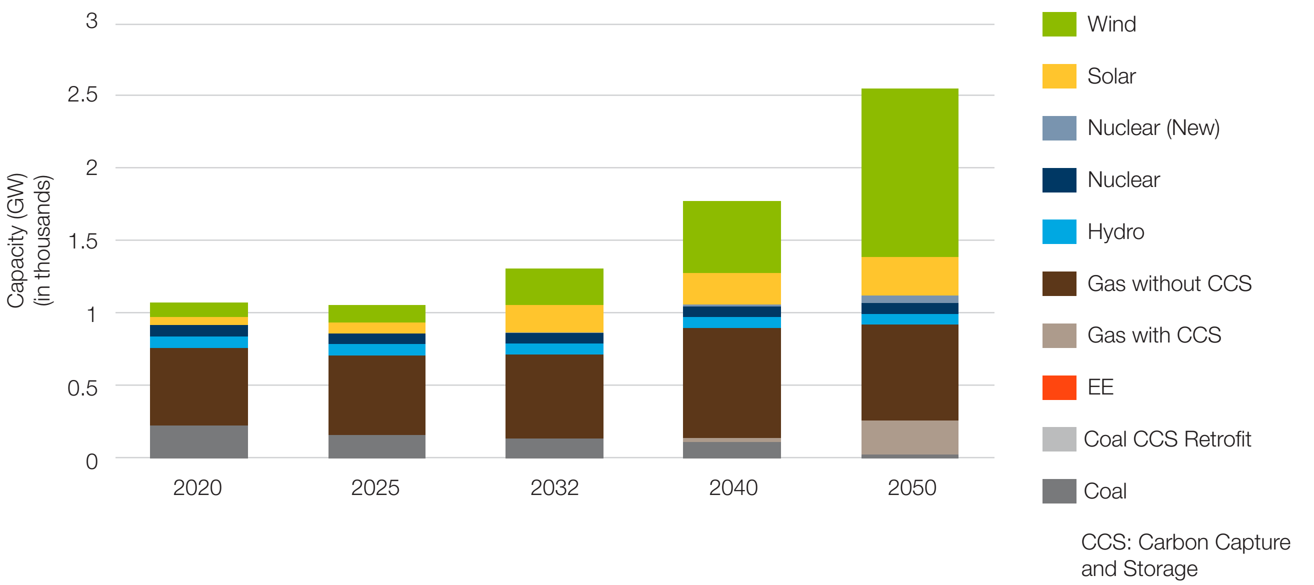


FIGURE 8: States in Region with Energy Codes for Residential and Commercial Buildings

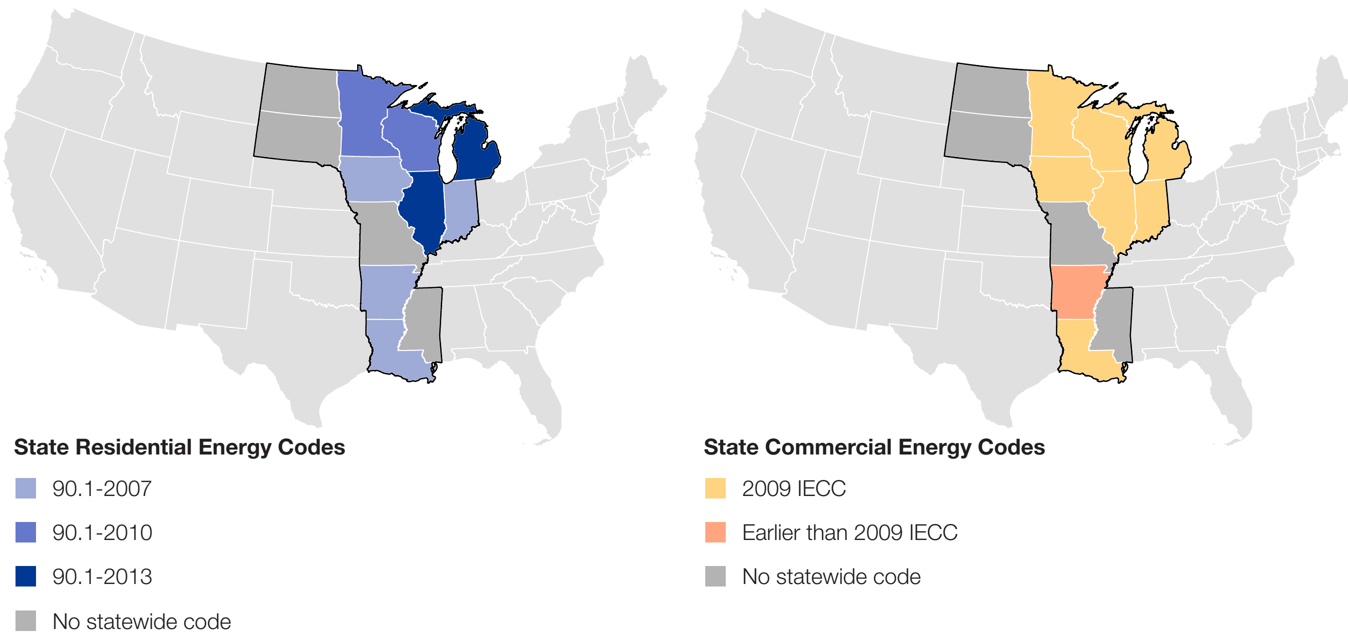
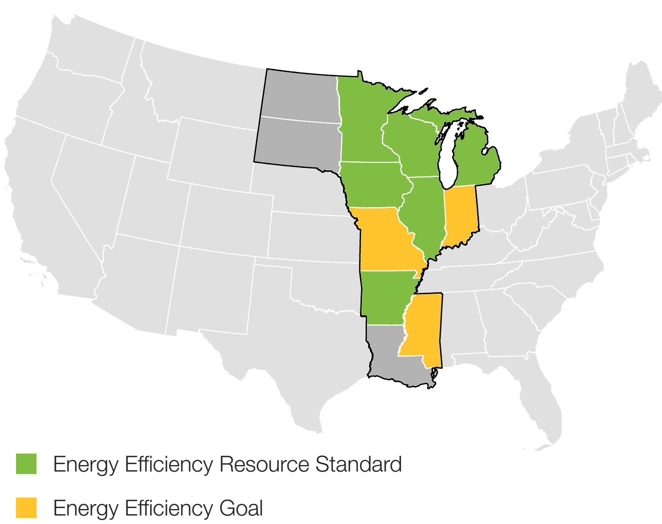


FIGURE 9: States in Region with Energy Efficiency Standards or Goals



The American Council for an Energy-Efficient Economy (ACEEE) issues an annual report card on states' performance in the area of energy efficiency.[12] Table 1 shows where the Midcontinent states rank among states in the scorecard, as well as each state's score by category. While the ACEEE scorecard is just one assessment, it does provide one standardized overview of states in the region and how their energy efficiency actions compare to other states.

The state scoring the highest on the scorecard, Massachusetts, scored a 44.5 out of 50 points for 2019. As shown in Table 1, states are scored based on utility programs (up to 20 points), transportation programs (up to 10 points), building codes adoption and compliance (up to 8 points), encouragement of combined heat and power (up to 3 points), state government actions (up to 6 points), and adoption of appliance standards (up to 3 points). It bears noting that the current regulatory construct for energy efficiency bases cost-effectiveness on a utility's avoided costs compared to the utility's other options for meeting electricity demand. If energy efficiency were valued in comparison to the other options available for decarbonization, it is likely that much more energy efficiency would be deemed cost-effective.

12 The State Energy Efficiency Scorecard," American Council for an Energy-Efficient Economy, https://www.aceee.org/state-policy/scorecard.

TABLE 1: American Council for an Energy-Efficient Economy (ACEEE) Rankings for States in the Region in 2019

State	Ranking Among 50 States & DC	Utility & public benefits programs & policies (20 points)	Transport Policies (10 pts)	Building Energy Efficiency policies (8 pts)	Comb. heat & power (3 pts)	State govt. Init. (6 pts)	Appliance stds. (3 pts)	Total Score Out of 50 points
Arkansas	33	7	1	3	-0.5	3.5	0	14
Illinois	11	11.5	5	6	2.5	4	0	29
Indiana	40	3.5	2.5	2.5	0	2	0	10.5
Iowa	23	9	2.5	5	0.5	1.5	0	18.5
Louisiana	48	0.5	1.5	2	0	2.5	0	6.5
Michigan	13	14	3.5	6	1	4	0	28.5
Minnesota	8	14.5	5.5	6	1.5	5	0	32.5
Mississippi	45	2	2	1.5	-0.5	3	0	8
Missouri	30	2.5	2.5	4	1	4.5	0	14.5
Wisconsin	25	7.5	1	3.5	0.5	3.5	0	16
Average State Score		**7**	**4**	**5**	**1**	**4**	**0**	

Analysis of Key Strategies for Buildings Decarbonization

TO BETTER UNDERSTAND TO WHAT EXTENT and how the region's building sector could be decarbonized, the Midcontinent Power Sector Collaborative undertook a modeling analysis of the sector using the FACETS model. In projecting the future, the model matches building energy demand with available heating, cooling and other building technologies, seeking the lowest-cost mix of technologies given the assumptions. By varying assumptions about the future, participants are able to isolate the most important factors contributing to the electrification and decarbonization of buildings. The electricity sector is also modeled into the future as described above and in the electricity road map.

It bears noting that this type of modeling is useful for understanding broad, directional trends and the effect of changes in assumptions about the future on those trends. Because the model seeks the lowest-cost outcomes, measures that are not cost-effective based on current and expected costs will not be chosen. For example, ground-source heat pumps are generally not the technology of choice in the model because of the higher upfront costs involved in installing ground-source heat pumps as compared to alternatives like air-source heat pumps. Similarly, as noted above, hydrogen may end up playing a role in the decarbonization of buildings but its current state of development makes it difficult to include in a modeling analysis and compete against already developed fuels and technologies. Unexpected advances in technology that lead to decreases in costs currently unanticipated will bring new options in the future and are not captured in this analysis.

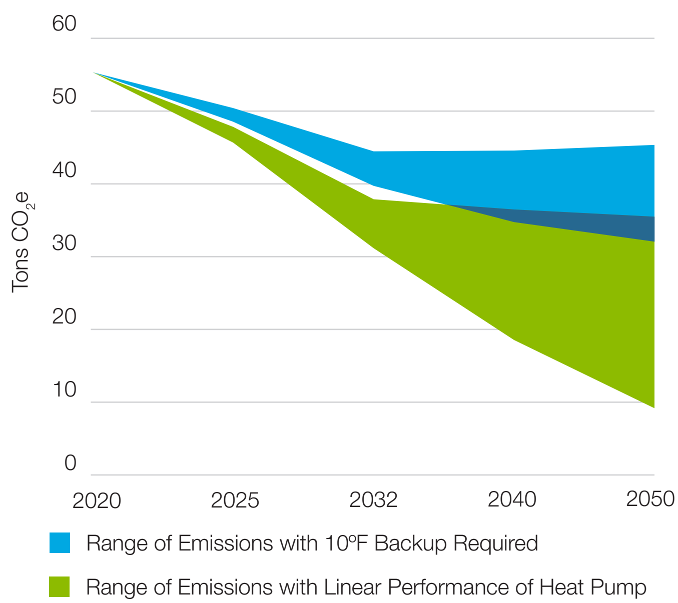
It is also difficult in this type of modeling to anticipate penetration of measures that are highly site-specific and difficult to generalize over large geographic areas, such as combined heat and power (CHP) and geothermal district loop systems. CHP applications require site-specific alignment of heating and electricity demand and often require significant on-the-ground coordination of multiple uses. As a result, this analysis uses publicly available data sources for CHP potential that some might consider conservative.

The modeling analysis resulted in a broad range of potential emissions outcomes across scenarios, suggesting great strides can be made toward decarbonization of buildings in the region under the right conditions. After testing many different variables identified through research as well as stakeholder input, the modeling revealed the key variables for electrification and decarbonization. Considerations like heat pump performance in various temperature conditions, technology type, rate of heat pump deployment, and what one assumes about the extent building owners face barriers to investment were identified as the most influential policy levers to impact building emissions. Barriers to investment were analyzed by assuming specific hurdle rates to investment that operated like a percentage cost imposed on the investment amount. The modeling results are detailed in the following sections.

Overall Emissions Reduction Potential

Across scenarios modeled, the region's buildings sector achieved a wide range of carbon emissions results. Figure 10 shows two shaded emissions ranges, expressed as carbon dioxide equivalent (CO_2e). The upper shaded area represents the emissions results assuming that heat pump technology operates only above 10 degrees Fahrenheit. The lower shaded area represents the deeper range of reductions achievable when the heat pump technology is assumed to perform, but with decreasing effectiveness as the temperature decreases below 10 degrees Fahrenheit.

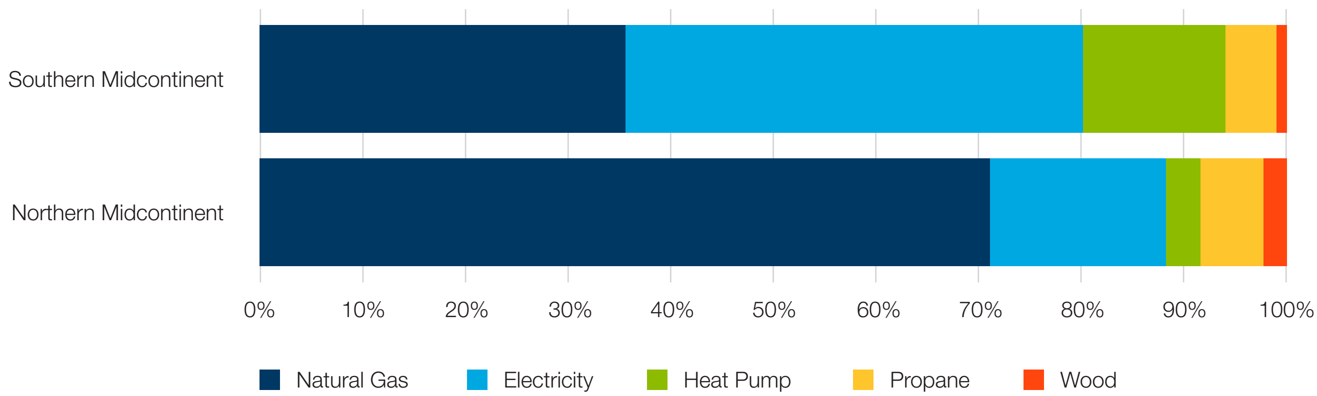
FIGURE 10: The Range of Building Sector Emissions Reductions Across Scenarios is Broad; *Reducing Barriers to Adoption and Improving Technology are Key Factors*



Within each range, the factors most determinative of the emissions result include whether one assumes (a) slow or rapid development of heat pump technology in the future; (b) backup heat is required below 10 degrees Fahrenheit or can be supplied to augment a heat pump that functions on a linearly decreasing basis to 20 degrees below zero; and (c) whether the assumed "hurdle rate" to adoption of heat pumps more closely resembles a 20 percent cost adder or a 7.5 percent cost adder in the analysis.

The 20 percent cost hurdle is meant as a proxy for current conditions for the penetration of heat pumps in the region, while 7.5 percent represents the implementation of

FIGURE 11: Heat Pump Penetration in Northern and Southern Parts of Midcontinent According to 2018 American Housing Survey



policies to reduce the barriers to adoption—education of consumers, training for workers, financial incentives, and other similar measures.

The modeling scenario achieving the deepest reduction in 2050 assumes a combination of these critical factors—rapid advancement of heat pump technology, linear backup requirements **and** measures are implemented to reduce the effective hurdles to heat pump adoption. Specific results from the individual scenarios are detailed below.

The Heat Pump Scenarios

Figure 11 shows the current penetration of heat pumps in the northern part of the central United States compared to the southern part,[13] relative to other primary heating sources. Because heat pumps are already cost-effective for numerous applications in warmer regions, we already see a significant penetration in the southern part of the Midcontinent. In the north, however, heat pump penetration has been quite modest.

To explore how fast we might expect heat pumps to be adopted in the region, numerous scenarios were modeled, as depicted to the right. Results were separated by northern, central, and southern parts of the Midcontinent region to reflect the different heating demands of the two parts of the Midcontinent region. These regions are depicted on the map in Figure 12.

Five Key Scenarios Modeled

Five key scenarios were modeled. The first scenario assumed a business as usual.

1 Relatively modest advancement of heat pump technology, full backup required at 10° Fahrenheit, and a 20 percent hurdle rate

Three additional scenarios were modeled which explored individual levers for impacting building decarbonization.

2 Rapid advancement in heat pump technology

3 Linear heat pump performance to negative 20° Fahrenheit

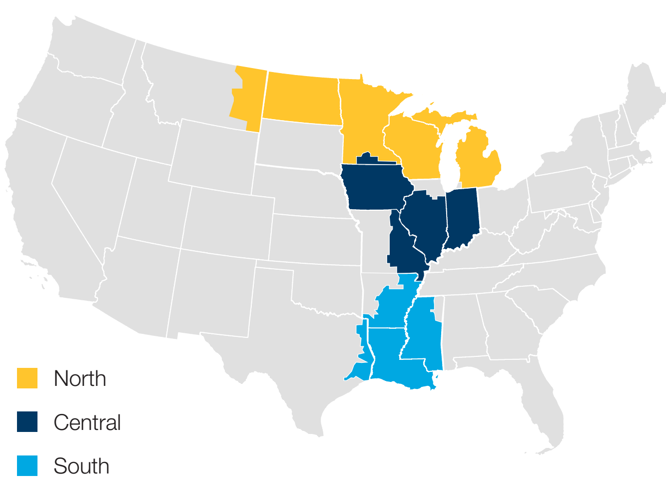
4 Reduced hurdle rate, which was modeled as a proxy for active efforts to reduce hurdles associated with decarbonization initiatives and technology adoption from 20 percent to 7.5 percent “adder” on cost

A final scenario looked at what could happen if all three individual levers for impacting building decarbonization occurred simultaneously.

5 Referred to as “All three,” this scenario modeled rapid heat pump technology, linear heat pump performance, and a reduced hurdle rate from 20 percent to 7.5 percent

13 For Figure 11, South Central includes Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas. North Central includes Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota and Wisconsin.

FIGURE 12: Regions in Analysis: North, Central, and South

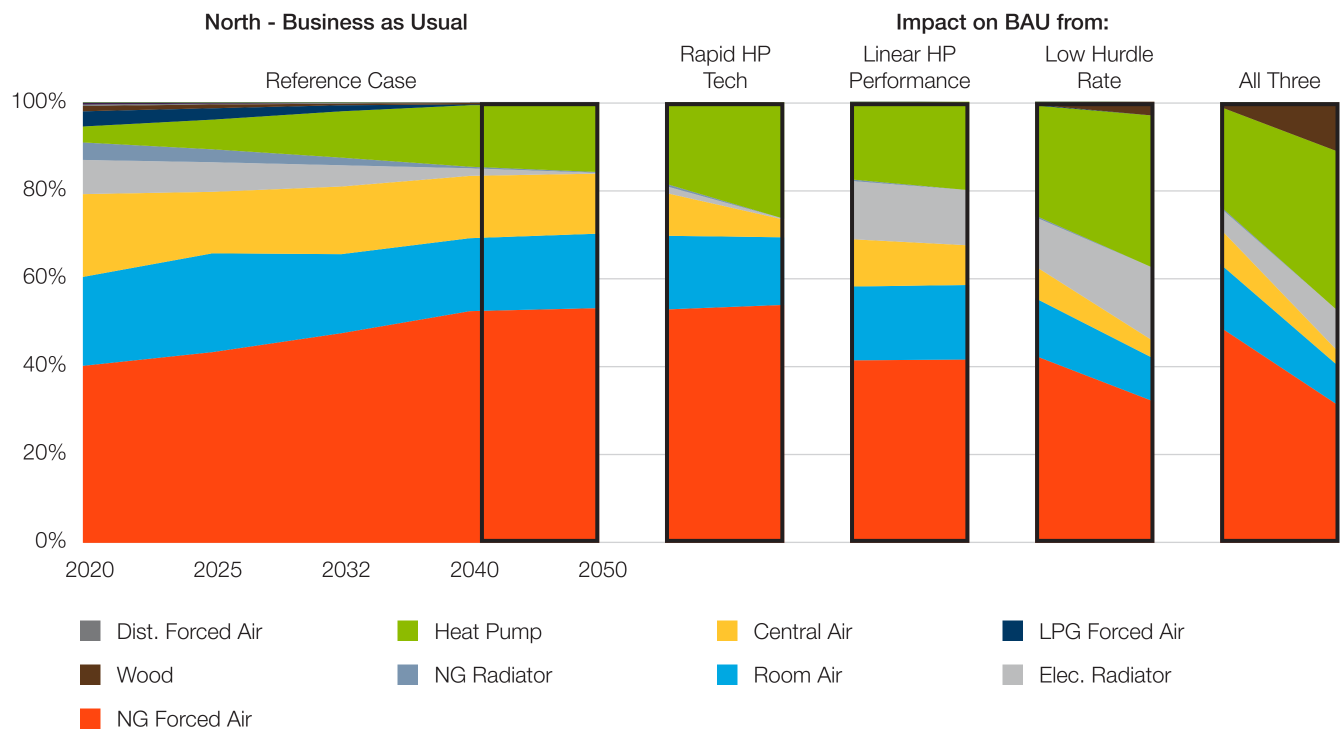


Heat Pumps in North of Region

Figure 13 depicts projected heat pump penetration as a share of heating devices across various scenarios in the northern part of the Midcontinent region. On the left in Figure 13, business-as-usual projections suggest some uptake in air-source heat pumps even with modest technology improvements. The analysis suggests that heat pumps are already cost-effective for applications that replace existing propane or home heating oil furnaces.

On the right side of Figure 13, heat pump penetration between 2040 and 2050 is depicted relative to other heating devices when rapid improvements in heat pump technology is assumed, or linear heat pump performance is assumed, or it is assumed that barriers to adoption look more like a 7.5 percent cost adder than a 20 percent cost adder. Lastly, we see heat pump penetration is greatest when all three factors are assumed to speed heat pump adoption. In the northern region, we see wood becomes a backup fuel in more heat pump situations, presumably to cover the coldest days when the heat pump is less effective.

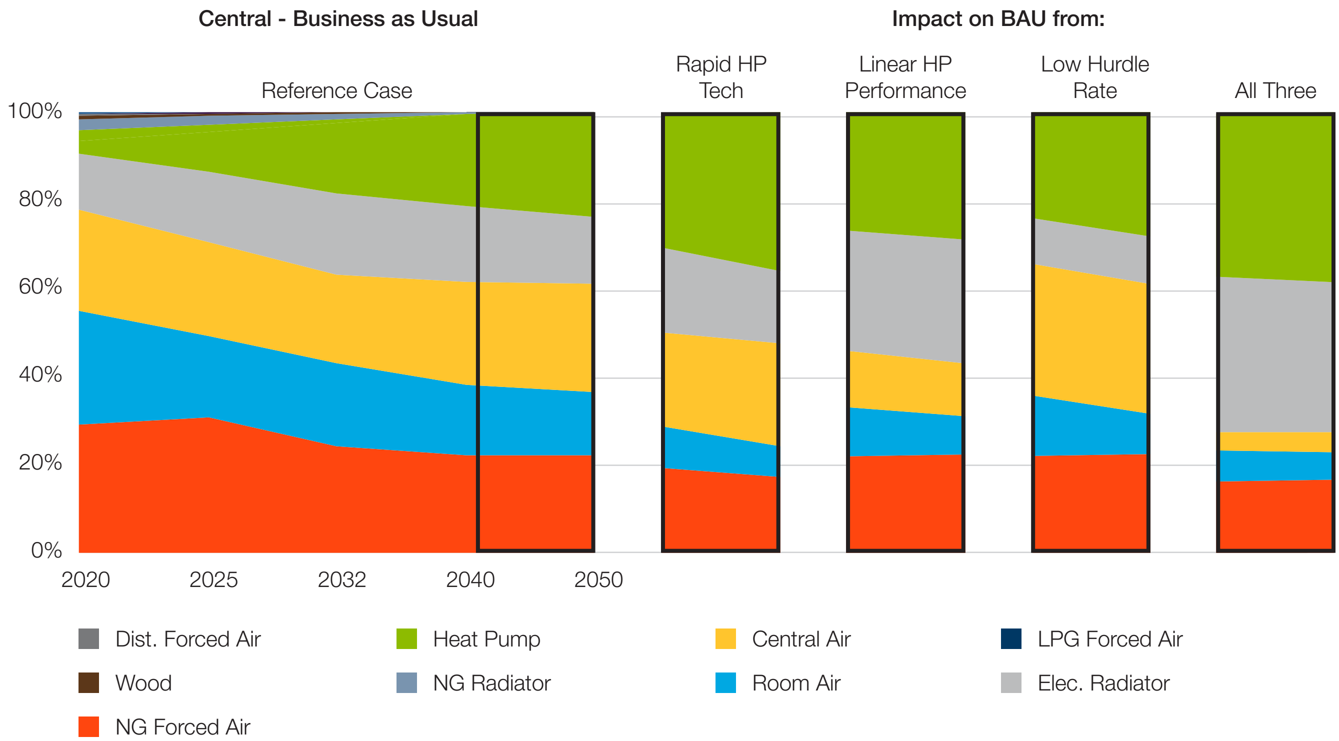
FIGURE 13: Heat Pump Penetration as a Share of Devices Across Scenarios in the North of Region

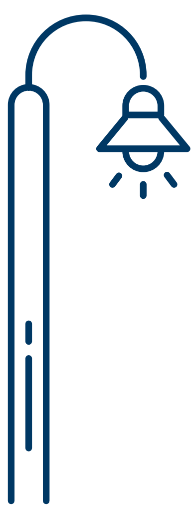


Heat Pumps in Central Part of Region

Figure 14 below shows the projected heat pump adoption in the central part of the region. On the left in the figure, the business as-usual-projection shows greater uptake of heat pumps in the milder climate of the central region, with a corresponding decrease in natural gas appliances. The model also projects that advances in heat pump technology and linear heat-pump performance in colder temperatures will substantially increase heat pump adoption in the central region

FIGURE 14: Heat Pump Devices as a Share of Devices Across Scenarios in Central Part of Region

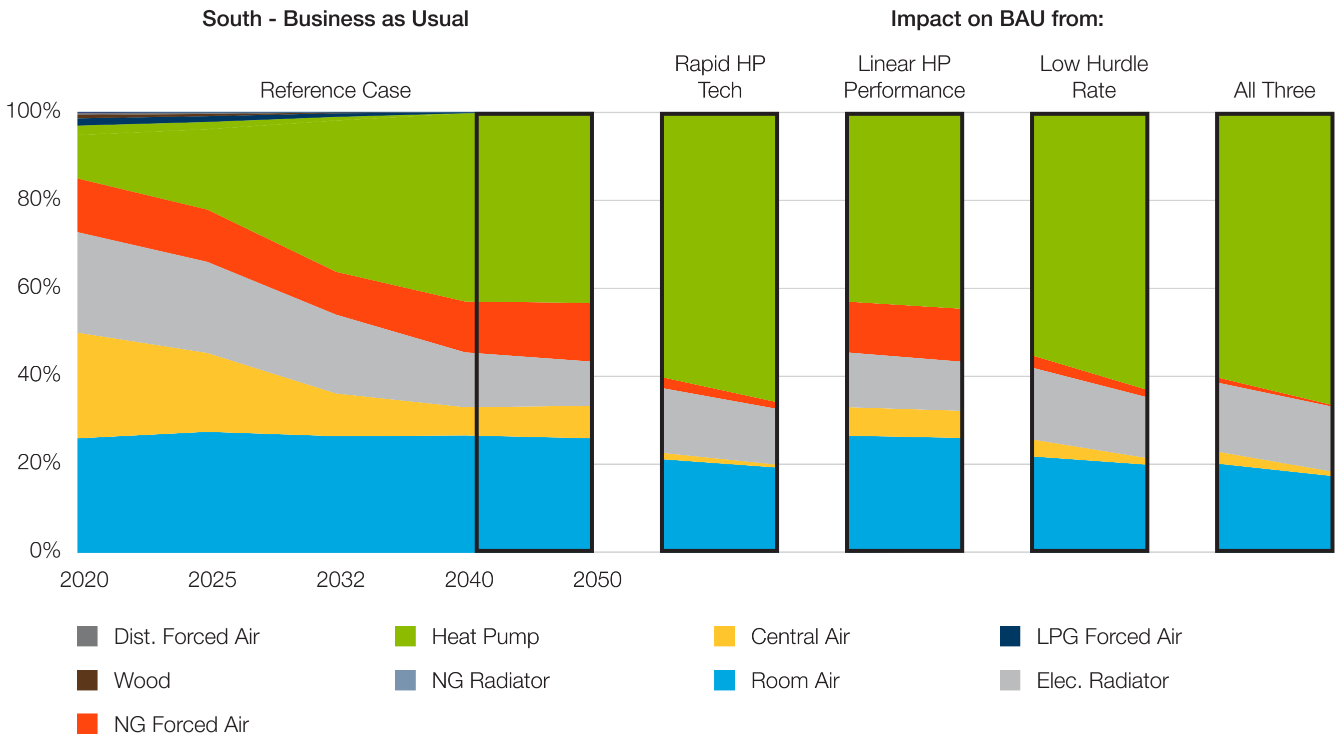




Heat Pumps in South of Region

Heat pump adoption in the south of the region is also considerably greater across all scenarios, as shown in Figure 15, when compared to the northern region, and somewhat greater than the central region. When heat pump technology is assumed to improve rapidly, heat pump adoption improves, nearly driving out natural gas heating. The same is true for reducing barriers to adoption to the equivalent of a 7.5 percent hurdle rate. Linear performance of heat pumps is not a relevant feature for the mild climate of the southern region, because there are so few days below 10 degrees Fahrenheit.

FIGURE 15: Heat Pump Penetration as a Share of Devices Across Scenarios in the South of Region



Modeled Impacts on Energy Consumption

While Figures 13, 14 and 15 show penetration of devices, it is important to also see what that penetration means from an energy consumption perspective. Indeed, heat pumps are far more efficient than furnaces that create heat from natural gas, propane, or heating oil. Figures 16, 17 and 18 show energy consumption by device across the same scenarios for each of the northern, central, and southern parts of the Midcontinent region. On the left-hand side of Figure 16, under business-as-usual conditions in the north of the region, we see a no decrease in energy consumption in 2050, even with the adoption of heat pumps and other higher efficiency appliances. On the right in Figure 16, however, substantially reduced energy consumption is possible through faster improvements in heat pump technology, by reducing the hurdles to heat pump penetration and through deployment of heat pumps with linear performance. When pursued in combination, energy consumption is reduced to just over half of what it would be without those measures.

The results in the more temperate parts of the Midcontinent region are more positive for heat pump adoption and therefore reductions in energy consumption and corresponding emissions. Figure 17 shows energy consumption in the central part of the Midcontinent and Figure 18 in the south of the Midcontinent. The greater potential for heat pump adoption in these warmer parts of the region translates to dramatic energy savings and corresponding emissions reductions.

FIGURE 16: Energy Consumption by End Use and Device Efficiency in The North of Region

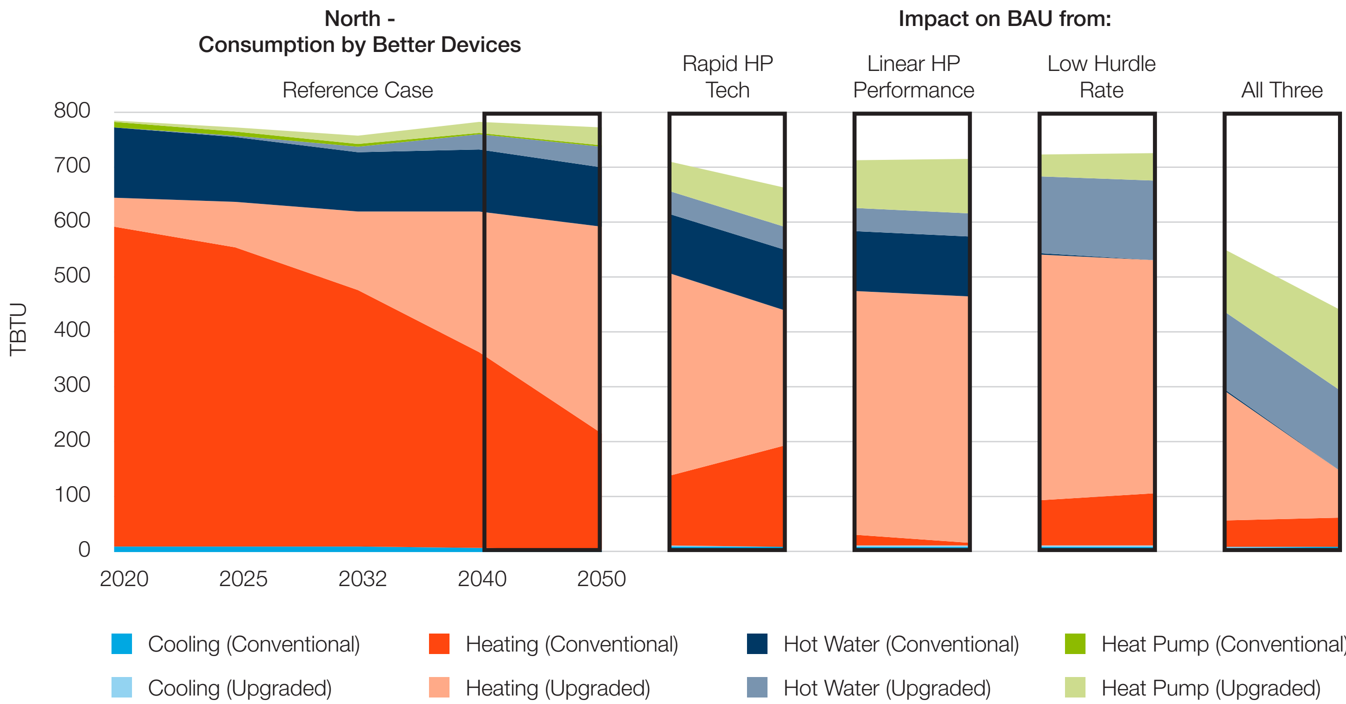


FIGURE 17: Energy Consumption by End Use and Device Efficiency in Central Part of Region

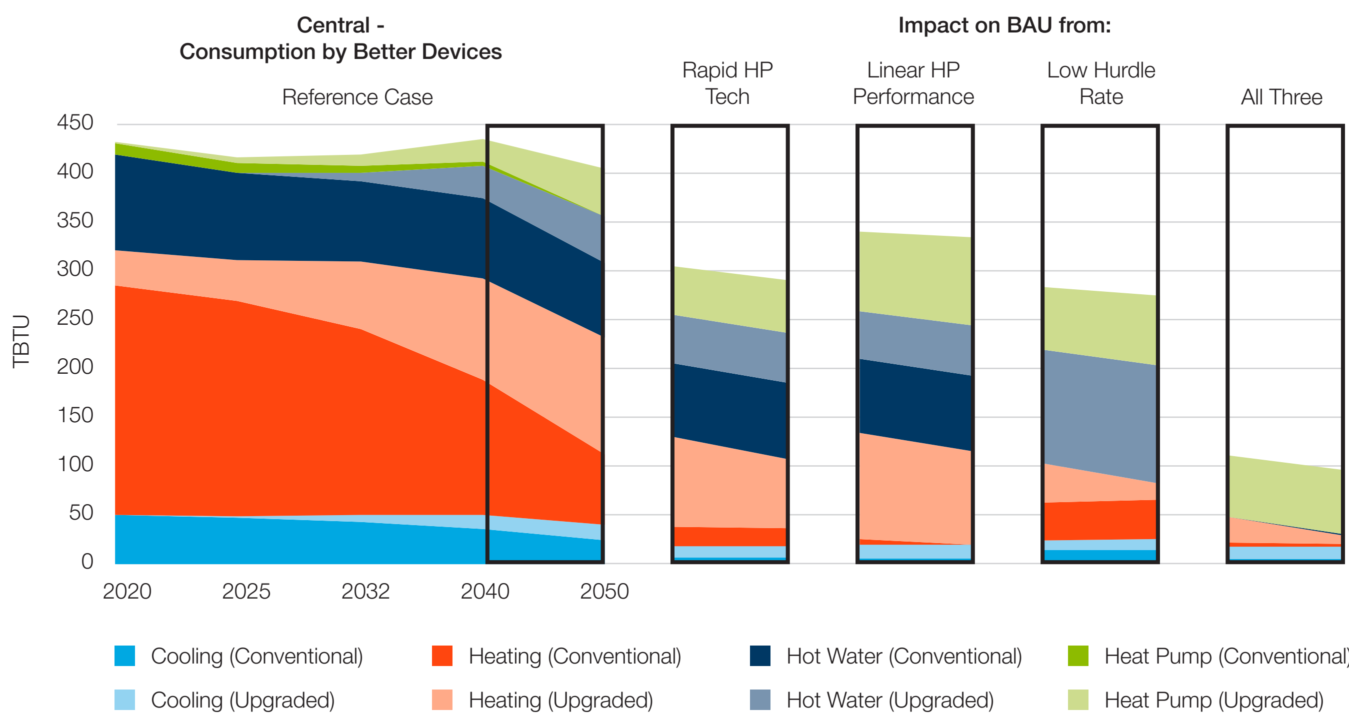
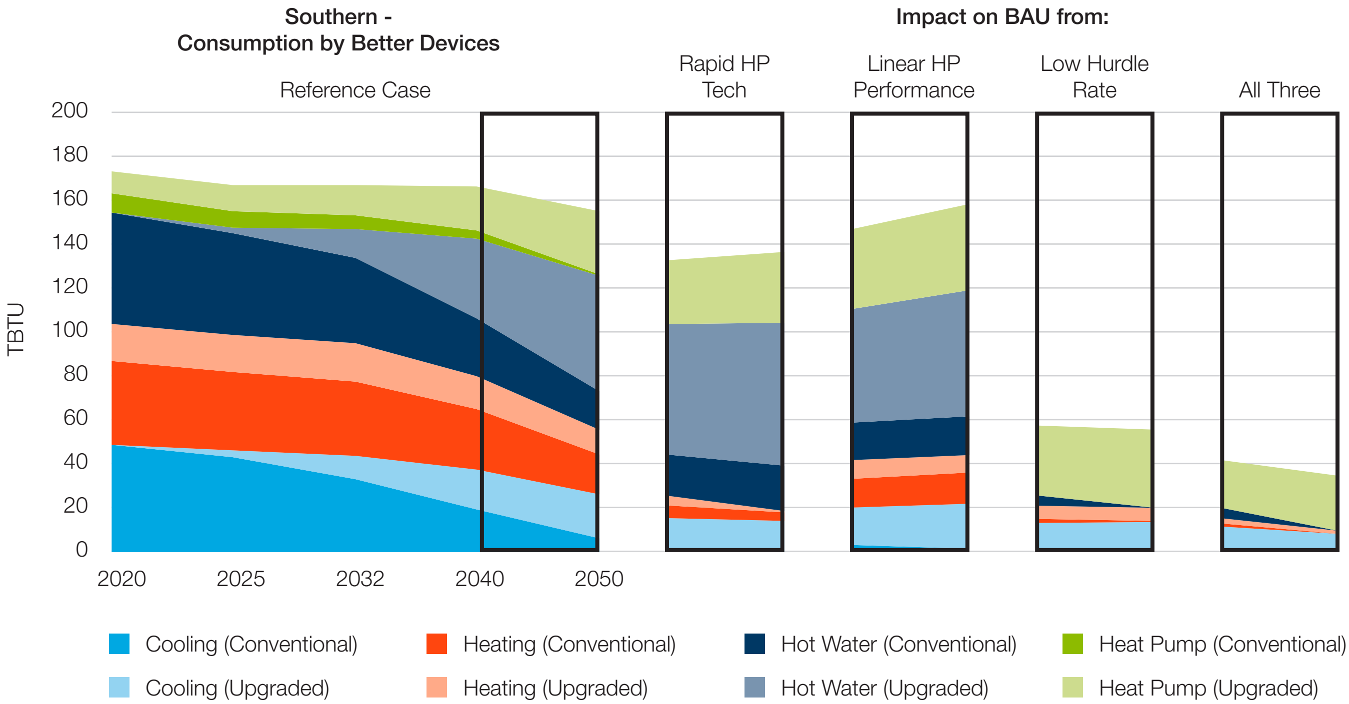


FIGURE 18: Energy Consumption by End Use and Device Efficiency in South of Region



Energy Efficiency Improvements to Building Envelopes

Just as buildings were modeled to assess adoption of energy efficient heating appliances, especially heat pumps, the analysis also explored whether and to what extent building envelope improvements were likely to occur. As Figure 19 depicts, building envelope improvements took place in 14 to 18 percent of the buildings in the northern parts of the region. In these runs, the barriers to building envelope improvements were assumed to be equivalent to a 7.5 percent hurdle rate. Building envelope improvements are less likely in the southern region, presumably because those measures do not yield as big a return on investment in milder climates. The central region sees the most building envelope improvements as a share of the baseline—perhaps because those areas start with a less efficient building stock than the northern region.

FIGURE 19: **Additional Share of Regional Households Adopting Building Shell Improvements by Region with 7.5% Hurdle Rate** (Adjusted from Baseline)

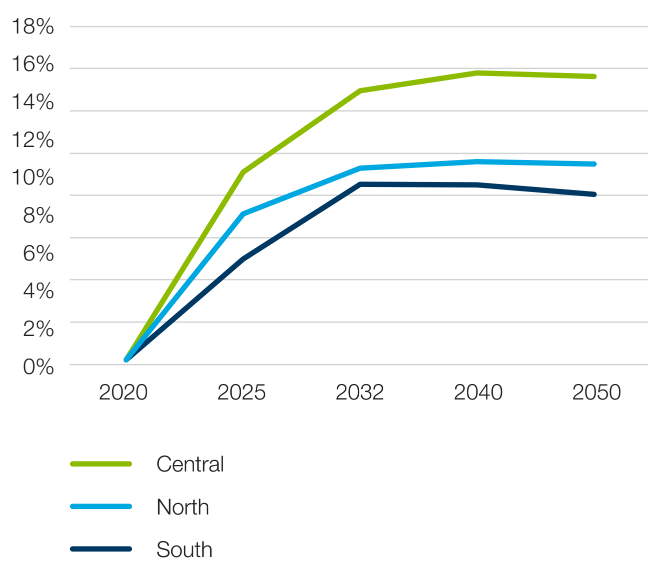
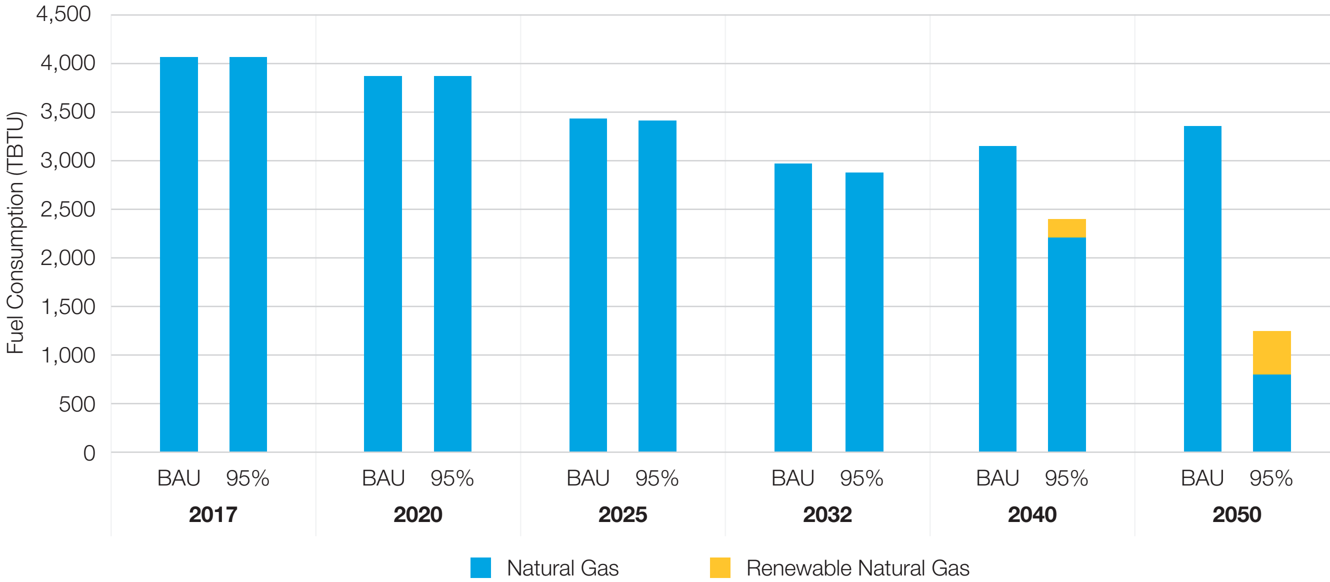


FIGURE 20: **Consumption of Natural Gas and Renewable Natural Gas in the Region Business as Usual versus a 95% Carbon Policy**



The Potential Role of Renewable Natural Gas

While the primary focus of the analysis was on heat pump penetration in the Midcontinent region, the analysis did allow renewable natural gas (RNG) to compete with other available fuels.[14] The model made RNG available to buildings using a publicly available cost curve that suggests RNG is more expensive than other available fuels, including natural gas and electricity.[15] Only when the analysis assumed a carbon constraint requiring emissions decrease by 95 percent by 2050 did we see some uptake of RNG in the buildings sector. See Figure 20 above.

While the uptake of RNG is limited in this analysis, projecting RNG supply and costs in coming decades is a highly uncertain exercise. In the event a cost-effective approach to converting excess renewable electricity to renewable gas becomes available, for example, RNG may be competitive with very low- or zero-carbon electricity in some applications or RNG and other low-carbon fuels could play a role in decarbonizing back-up heating in cold climates, even while the majority of heating demand is served by heat pumps.

14 RNG supply was taken from a supply curve published by ICF in 2017, taking the midpoint between ICF's low and high-supply curves, and limiting the RNG available to buildings to only one-third of total supply. See Philip Sheehy and Jeff Rosenfeld, *Design Principles for a Renewable Natural Gas Standard* (ICF, 2017), https://www.icf.com/insights/energy/design-principles-for-renewable-gas.

15 The model was allowed to choose up to one-third of the available supply, as calculated by ICF in its publicly available cost curve. See Philip Sheehy and Jeff Rosenfeld, *Design Principles for a Renewable Gas Standard* (ICF, 2017). The supply curve illustrated in Exhibit 6 of the ICF report was used for this analysis.

Summary of Findings and Collaborative Recommendations

IN LIGHT OF THE BACKGROUND AND ANALYSIS set out above, the Midcontinent Power Sector Collaborative participants offer the following findings and recommendations. Transitioning to more energy efficient buildings with heat pumps will be a key part of decarbonizing the building sector. It will be important to pursue these objectives while simultaneously preserving customer affordability and system reliability.

Summary of Findings

- Electric heat pumps are a promising buildings decarbonization strategy that can contribute to dramatic increases in energy efficiency and reductions in carbon emissions, as long as progress toward electricity system decarbonization continues.

- Heat pumps are already cost-effective in the southern part of the Midcontinent region where heat pump adoption is likely to increase even without new measures or technological advances. However, the modeling analysis further suggests that heat pump adoption would increase significantly in the south if measures are taken to reduce barriers to adoption, and/or if heat pump technology advances more rapidly.

- In colder parts of the region where natural gas is heavily used for heating, heat pumps face bigger obstacles related to the backup requirements of heat pumps in colder temperatures. In the north, increasing heat pump adoption will depend on advances in heat pump technology that lower cost, increase cold-weather efficiency, viable options for decarbonizing backup heating requirements that are likely to remain on the coldest days, and reducing informational and financial barriers to adoption.

- Given the challenges to deeper heat pump adoption in the northern part of the region, alternatives such as RNG and hydrogen may prove important to achieving decarbonization goals in the north. At current price projections, however, RNG and hydrogen are not expected to play a big role in residential buildings, even in the presence of a 95 percent decarbonization goal. This could change if renewable gas and/or hydrogen supplies increase and/or become less costly relative to natural gas.

- Building shell improvements can also play a role in helping curb energy demands, reducing building emissions and improving building resilience. These will be helpful regardless of whether the decarbonization technology is electrification or lower-carbon fuels.

Collaborative Recommendations

1. New buildings should be built to maximize energy efficiency and enable electrification. One way to help accomplish this goal is to adopt building energy codes that maximize efficiency and enable electrification, as well as provide training for contractors, architects, and engineers on efficiency and electrification. Another way is to tie financing to green building standards. States can and often do this with state bonding funds. Local governments can do the same with funding or incentives that they provide to developers.

2. For existing buildings, improvements in building shell efficiency should be encouraged wherever cost-effective. To accomplish this goal, states can draw upon decades of experience and best practices learned in energy efficiency policy and programs. For example, states and local governments can develop supportive policies such as those that encourage disclosure of building energy use at point of sale or on a regular basis; building energy audits; or building energy retrofits.

3. For existing buildings, update energy efficiency programs or develop policies that encourage heat pump retrofits. Ways to encourage customer adoption of heat pump retrofits in existing buildings include:

   A. Energy efficiency programs could approach building energy efficiency to achieve efficiency gains and optimize energy use across all building energy demands and all fuels.

   B. Implement programs to encourage fuel switching from fossil fuels to electricity, including lifting restrictions on fuel switching when criteria are met to demonstrate this is beneficial. These criteria generally include reduced emissions, reduced costs to customers/society, and improved efficiency of grid utilization.

   C. Reduce financing burden for building owners seeking to retrofit, such as through low-cost financing, tax credits, or point-of-sale rebates.

   D. Programs to educate contractors and consumers.

4. Improvements in the cost and effectiveness of heat pump technology depend on increased use of the technologies to create economies of scale. To increase the size of the heat pump market, states could support utility programs that target already cost-effective applications first, such as homes using propane or heating oil for heat, and homes with natural gas heat that add air conditioning. States could also support heat pump adoption directly by providing low-cost financing and making them eligible technologies in state-run efficiency programs.

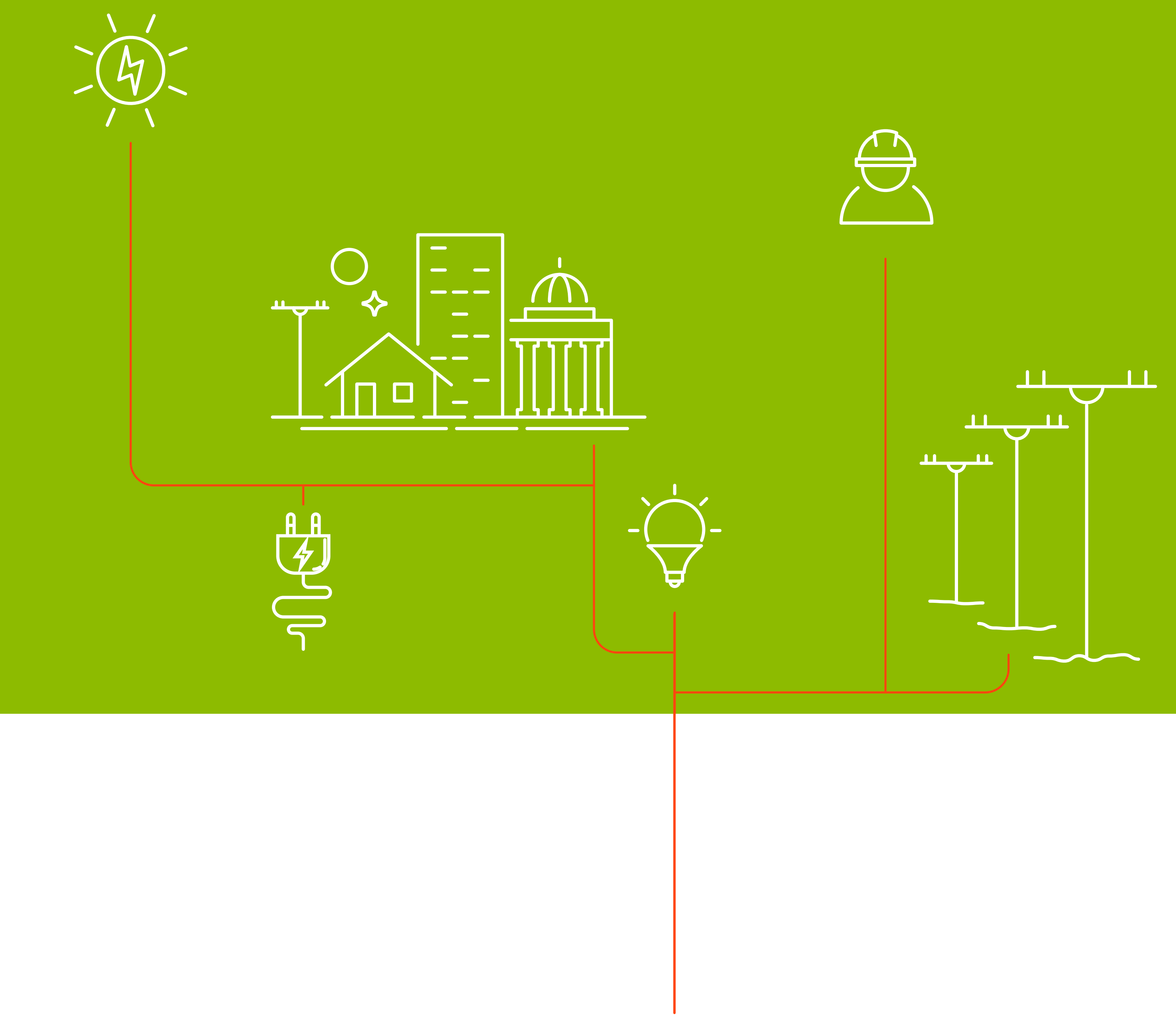
5. As a decarbonization strategy, electrification hinges on continued decarbonization of the electricity sector as well as the necessary upgrades to the electricity system to handle the increases in electricity demand that electrification of buildings entails. To achieve electric sector decarbonization, states should refer to the recommendations of the Collaborative in *A Road Map to Decarbonization in the Midcontinent: Electricity Sector*.[16] States should also recognize the need to account for the additional burden that is placed on the electric sector to decarbonize as it is asked to supply more carbon-free electricity to both the buildings and transportation sectors.[17]

6. Increased electricity demand from increased heat pump penetration should be smartly managed through programs that make the new demand flexible, such as smart thermostat programs and demand response aggregation—while recognizing that the ability to shift and curtail space heating demand in a cold climate is far more limited than with other types of electrification, and some source of backup heat is likely to be required.

7. Because electrification may not be able to achieve the full decarbonization of buildings by midcentury, states should assess the potential for renewable natural gas, hydrogen, and other alternative fuels, and, if promising and cost-effective for customers compared to electrification, identify and work to remove barriers to increase their production and use.

16 See *A Road Map to Decarbonization in the Midcontinent: Electricity Sector*, https://roadmap.betterenergy.org/wp-content/uploads/2018/08/GPI_Roadmap_Web.pdf.

17 See *A Road Map to Decarbonization in the Midcontinent: Transportation Electrification*, https://roadmap.betterenergy.org/wp-content/uploads/2019/02/GPI_Roadmap_Electrification_Online2.pdf.



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