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Equity through climate action

Characterization of Cold Climate ASHPs in Dane County's Residential Housing Stock

Prepared for Dane County Office of Energy and Climate Change

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Executive Summary

The purpose of this study is to examine the potential for upgrading to cold-climate air-source heat pumps (ccASHPs) across certain housing stocks in Dane County. The scope of this analysis included residential units (single-family and multi-family) in buildings that do not use natural gas for heating (approximately 80,000 residential units). Opportunities within specific housing stocks were identified based on the carbon emission reduction potential, utility reduction, and implementation cost. Both the heating and cooling impacts of transitioning to ccASHPs were analyzed. The carbon savings were conducted across two electricity grid scenarios: (1) business as usual, and (2) substantially more renewable energy. Carbon savings were also evaluated separately for residential units already with either central or window unit air-conditioning (approximately two-thirds of units) and units without air-conditioning (one-third of units). In addition, 15 interviews were conducted with stakeholders to contextualize the quantitative findings and identify additional barriers to ccASHP implementation experienced by those recently pursuing ccASHPs in Dane County. Key recommendations are presented below.

1. Expand ccASHP electrification efforts to residences with electric resistance heat. Both single-family and multi-family electric resistance housing stocks can be converted to ccASHPs in most scenarios at a lower cost as compared to propane and fuel-oil heated homes, while also resulting in higher carbon savings and targeting more lower income households.

    a. To achieve the highest carbon and utility savings on a per unit basis, offer ccASHP programs aimed at replacing electric resistance heating in the single-family housing sector. This sector has the highest per unit carbon savings (3.1-5.2 tons carbon saved per unit), highest utility savings ($1,100-$1,350 saved annually per unit), and lowest average simple payback (10 years) of the housing stocks analyzed.

    b. To achieve the largest scale of impact, offer ccASHP programs aimed at replacing electric resistance heating in the multi-family housing sector. This sector has the largest opportunity for carbon and utility savings based on the number of units (nearly 34,000), with moderate per unit carbon savings (1.0-1.8 tons carbon saved annually per unit) and utility savings ($330-$470). This housing stock also has the lowest expected upgrade cost ($8,500 per unit).

    c. Assist lower income households by prioritizing upgrades in the electric resistance heating building stock. Lower household incomes are associated with higher prevalence of electric heated homes in Dane County.

    d. Target urban census tracts for ccASHP programs aimed at replacing electric resistance heating. Electric heating is concentrated in urban areas across Dane County.

2. Consider the following key programmatic recommendations across all heating types.

    a. Target ccASHP programs to homes without air-conditioning, as approximately one-third of residential units do not currently have access to air-conditioning and adding cooling represents a significant opportunity to improve resident health and safety during increasingly occurring extreme temperature events. The portion of households without

air-conditioning is relatively consistent across Dane County geographies and heating types.

b. Create a core program dedicated to electrifying residential buildings to scale electrification of homes in Dane County. Because of ccASHP technology skepticism, lack of contractors, and relatively small incentives, a one-stop-shop approach that aligns existing programs and resources available in Dane County is recommended.
c. Complete a similar study for homes heated by natural gas.

3. For ccASHP programs aimed at conversion of fuel-oil and propane heated residences, focus initially on single-family housing stocks located in rural census tracts where this heating type is concentrated. While fuel-oil and propane residences have higher simple paybacks and generally lower carbon savings as compared to electric resistance homes, this housing stock is a key segment outlined in the Dane County Climate Action Plan and important to not leave behind in electrification efforts.

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Introduction

Decarbonization is a becoming a key strategy for many governments in combatting today's climate crisis. ASHPs (ASHPs) provide an efficient, all-electric way to both heat and cool homes using one system. ASHPs are becoming a common recommended approach for many decarbonization strategies. Previously ASHP technology had been limited to moderate climates[1]; however, improvements in heat pump technology over recent years have enabled the development of ccASHPs (cold-climate ASHPs), which can produce adequate heat even in extreme sub-zero temperatures. The purpose of this report is to quantify the potential for upgrading certain housing stocks in Dane County to ccASHPs and develop strategies for accelerating ccASHP adoption in Dane County in existing homes that do not use natural gas for heating.

Dane County has a broader 2020 Climate Action Plan (CAP), of which decarbonization is a key strategy to meet the countywide goals of reducing greenhouse gas (GHG) emissions by 50% by 2030 in order to carve a path toward carbon neutrality by 2050. The CAP is a living document with six guiding principles that inform the recommendations to meet Dane County's GHG emission goals, including: (1) equity/justice, (2) local economic benefit, (3) health benefits, (4) resiliency/security, (5) bridging the urban and rural divide, and (6) ecosystem benefits.

For Dane County to meet the 50% GHG reduction benchmark and eventual carbon neutrality laid out in their CAP, significant changes must be made in energy consumption county-wide. Across Wisconsin, the residential sector accounts for 24% of the state's total energy consumption (EIA, 2019) and therefore represents a significant opportunity for GHG reduction. This report focuses on the carbon savings opportunity in electrifying the residential housing stock with ccASHPs.

In charting a path for 50% GHG reductions, Dane County identified about a dozen outcomes that, when combined, reduce emissions in half. Several of those outcomes are about ASHPs; one outcome identified in Dane County's CAP is to transition half of the fuel-oil and propane heated homes to heat pumps by 2030, and all of homes with these heating fuels to heat pumps by 2045. Converting fuel-oil and propane heated homes to ccASHPs can lower primary fuel use and is especially beneficial when combined with on-site renewable energy sources such a solar. Furthermore, electrification can reinforce the vision of equity, economic savings, wellness, and climate resiliency underscored in the CAP by improving home comfort through cooling and removing potentially harmful toxics from the indoor air by eliminating the use of fossil fuel within the home. Despite ccASHPs' ability to provide adequate heat in cold climates, reduce carbon emissions, and increase access to cooling, uptake of ccASHPs in Wisconsin has been low.

This report quantifies existing heating sources, evaluates the potential of ccASHP technology, gathers stakeholder perspectives toward ccASHPs, and recommends best practices to accelerate installation of ccASHPs across Dane County. Our quantitative analysis examines ccASHP economic viability and how to

[1] ASHPs are air conditioners that can run in reverse. In cooling mode, the ASHP cools the inside of the home and moves the heat to the outside, just as a standard air conditioner does. In heating mode, the inside heat exchanger and outside heat exchanger effectively change roles; the ASHP cools the outside and moves the heat to the inside of the home. ccASHPs are specially designed to operate at colder outside temperatures than standard ASHPs.

prioritize varying housing stocks. The qualitative analysis identifies obstacles and motivators in implementation, as well as gathered perceptions to inform messaging.

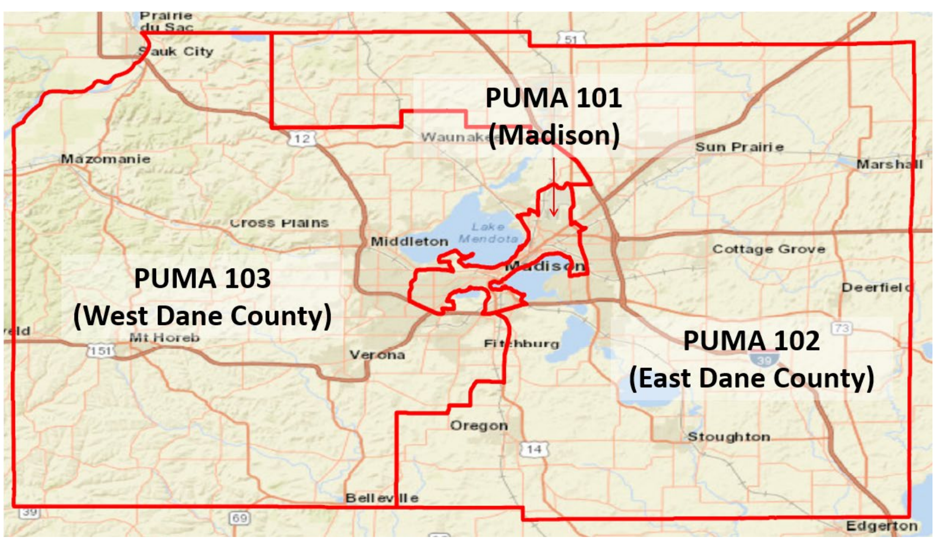
Approach and Methodology

The scope of this analysis includes space heating in residences that do not use natural gas across Dane County. The building stock across Dane County is diverse and requires varied approaches for ccASHP retrofits; our goal is to identify niches within the scope in order to target ccASHP implementation programs that can best help Dane County reach its carbon savings goals. Our approach is two-fold: (1) quantify the Dane County building stock to identify target segments and quantify the carbon, utility, and cost impact of ccASHPs used for space heating in such segments, and (2) collect qualitative data on the experiences of homeowners and building owners with or considering ccASHP technologies. This section includes a description of our methodology, assumptions, and limitations for each approach is described. A more detailed description of the methodologies used in this report is included in Appendix A.

Quantitative Analysis Methodology

The primary data source for the analysis is the National Renewable Energy Laboratory's (NREL) ResStock™ data tool. ResStock™ has representative residential building stock information throughout the United States and uses the American Community Survey (ACS) and American Housing Survey (AHS) data at the Public Use Microdata Area (PUMA) level, along with other datasets, to create a database of representative buildings. PUMA geographies represent statistical geography areas defined by the U.S. Census, which are non-overlapping areas with a population of at least 100,000 people. Dane County consists of three PUMA boundary areas (Figure 1): City of Madison (PUMA 101), East Dane County (PUMA 102), and West Dane County (PUMA 103). From a housing development perspective, PUMAs 102 and 103 are more rural compared to the PUMA 101, which is located within the city limits of Madison.

Figure 1. Dane County PUMA Boundaries



The ResStock™ database used for this analysis contains approximately 20,000 residential units statistically sampled to be representative of the Dane County building stock. Data points include detailed building characteristics for each residential unit (e.g., square footage, heating system type, heating system efficiency) and annual baseline energy use by end-use and fuel (e.g., heating fan electricity consumption, heating propane energy consumption). These data points are used in our analysis to characterize the Dane County housing stock and estimate energy savings from implementation of ccASHPs. Additional information on the ResStock™ database and assumptions about the database used for this analysis can be found in Appendix A.

Energy savings estimates are calculated by applying engineering calculations to the baseline energy use obtained through the ResStock™ database. The lifetime of the ccASHP was assumed to be 20 years. Utility bill savings are calculated using average fuel rates (Table 1). Each rate is multiplied by the estimated energy use by fuel type before and after the ccASHP retrofit. Details on the methodology for these calculations can be referred to in Appendix A.

Table 1. Fuel Price Assumptions

Fuel	Price	Source
Electricity	$0.12 per kWh	Madison Gas & Electric, Wisconsin Power & Light[2]
Propane	$1.55 per gallon	EIA – Wisconsin 5-year average
Fuel-oil	$2.33 per gallon	EIA – Wisconsin 5-year average

For our upgrade cost estimates, if a unit's existing heating system already has ducts (e.g., a central furnace), a ducted heat pump air handler with electric resistance supplemental heat is proposed. The existing duct system is assumed to be adequate. If a unit's existing heating system does not have ductwork (e.g., electric baseboard heat), a ductless mini-split heat pump system is proposed with multiple heads. The primary source for cost information is RSMeans with a location of Madison, WI. However, we did compare costs obtained through RSMeans with other data sources such as contractor quotes obtained by Elevate for similar install work ongoing in Wisconsin and a recently published Wisconsin-specific report on ccASHP costs (Center for Energy and Environment, 2021). Details of the proposed ccASHP system based on the existing heating system and items included in the cost estimates can be found in Appendix A.

Energy savings are converted to carbon savings under two different future grid scenarios using NREL's Cambium tool. The two scenarios are as follows:

- **Business-As-Usual:** Also referred to as Mid-Case by NREL, this scenario uses current policies and default or mid-level assumptions to generate a reference case. This scenario reflects changes in the grid over time, but only changes that flow from the current business-as-usual factors and policies.
- **Low Renewable Cost**: This scenario is modeled using low costs for renewable energy, therefore increasing the share of renewables on the grid compared to other sources. Unlike business-as-usual, this scenario reflects shifts in the factors that influence the fuel mix of the grid. Both Madison Gas & Electric and Alliant Energy have clean electricity goals to substantially reduce

[2] The average electric rate was calculated for the major electric utilities in Dane County

carbon emissions in the coming decades.[3] Given the likely policy and subsidy changes on the horizon, we feel this low-renewables cost scenario is a very likely and reasonable future model to use.

A detailed description of the rationale behind these two scenarios can be found in Appendix A.

Interview Methodology

Interviews were conducted with various stakeholders who have considered or already installed ASHPs in Dane County to gather feedback on their experience with this in Wisconsin and help contextualize our quantitative findings as part of the data analysis. Municipalities were also engaged in interviews to understand their perspectives and outlook on ASHP programs.

Sustain Dane led recruitment of interviewees. Sustain Dane has a wide breadth and depth of individuals and organizations that they work with on sustainability issues across Dane County. Emails were sent individually to 40 people, asking if they or someone in an organization that they are a part of would be interested in being interviewed. The recipients of outreach emails included local business leaders, non-profit and religious organizations, municipal staff and leaders, vendors of ASHPs, energy sector representatives, and building owners in the multi-family sector working with the Sustain Dane and Elevate Efficiency Navigator program. Many of the contacts further expanded our outreach through their networks as well. For example, we asked a Green Team church representative to share interview information with their entire congregation. An example of the recruitment outreach flyer can be found in Appendix D.

Sustain Dane also promoted the project and request for interviewees in their June 2021 electronic newsletter and on social media platforms. The notification about interviewer recruitment highlighted that we were seeking candidates that aligned with a research focus of either: (1) single-family (detached) housing with propane fuel, electric baseboard, or electric furnace heat; or (2) multi-family (5+ units) housing with electric baseboards, electric shared heating, or electric furnace heat. Interviews were estimated to take 30 minutes and all participants were entered to win a $200 visa gift certificate. Interviewees reached out from all three approaches (i.e., emails, the newsletter, and social media). Ultimately, we conducted 14 interviews.

We acknowledge that there are limitations with the use of the interview information. The feedback collected is a small sample and cannot be considered representative across an entire sector. Interviewees were self-nominated/self-selected, and already had an interest in or connection with ASHPs prior to the interview. The interviewees also represented a wide variety of sectors, including homeowners, building managers, ASHP representatives, and municipalities. Interviews were conducted for 30 minutes via Zoom, which is a short amount of time to gather the full extent of the interviewee's perspective on ASHPs. That being said, the interviews were highly informative as case studies. They brought to the forefront lived experiences, perceptions of opportunities and challenges, and considerations for future education and/or incentive program implementation.

[3] https://www.mge.com/net-zero-carbon-electricity; https://www.alliantenergy.com/cleanenergy/ourenergyvision/responsibilityreport/cleanenergyvisiongoals?utm_source=WS&utm_campaign=Legacy&utm_medium=AboutAlliantEnergy/ResponsibilityReport/CleanEnergyVisionGoals

Data Analysis Results

Dane County Housing Stock and Heating Fuels

According to the ResStock™ database, Dane County has 239,800 residential units as of 2018.[4] As mentioned, the focus of this report is housing in Dane County not heated with natural gas. Roughly two-thirds of those units are heated with natural gas (Table 2). Non-natural gas units are predominantly heated with electricity (25% of units) or propane (5% of units).

Table 2. Space Heating Fuels Across Dane County

Space Heating Fuel	Total Residential Units	Percent of Housing Stock
Natural Gas	158,844	66%
Electricity	59,758	25%
Propane	12,769	5%
Other Fuel[5]	4,868	2%
Fuel-oil	2,074	1%
None	1,487	1%
Dane County Total	**239,800**	**100%**

In Figures 2-4, the percentage of electric, propane, and natural gas heat for each census tract is mapped across Dane County. Census tracts with darker colors indicate a higher portion of the residences in that census tract use the specified type of heat. For context, municipalities in Dane County are outlined in black and labeled. As expected, census tracts in more rural areas tend to have propane space heating (Figure 3). Census tracts in more urban areas tended to have electric space heating (Figure 2). Of note, the data used in these maps is from the ACS[6] and is not used in the energy or carbon savings analysis. This is because while ACS offers high spatial granularity, ResStock™ offers higher granularity with regards to the housing characteristics, systems, and energy use.

[4] Residential unit refers to a single-family home, a multi-family unit, or a mobile home.
[5] Other Fuel includes the following heating types: wood, coal, solar, and other.
[6] ACS 2019 5-year estimates

Figure 2. Percentage Residences With Electric Heat by Census Tract

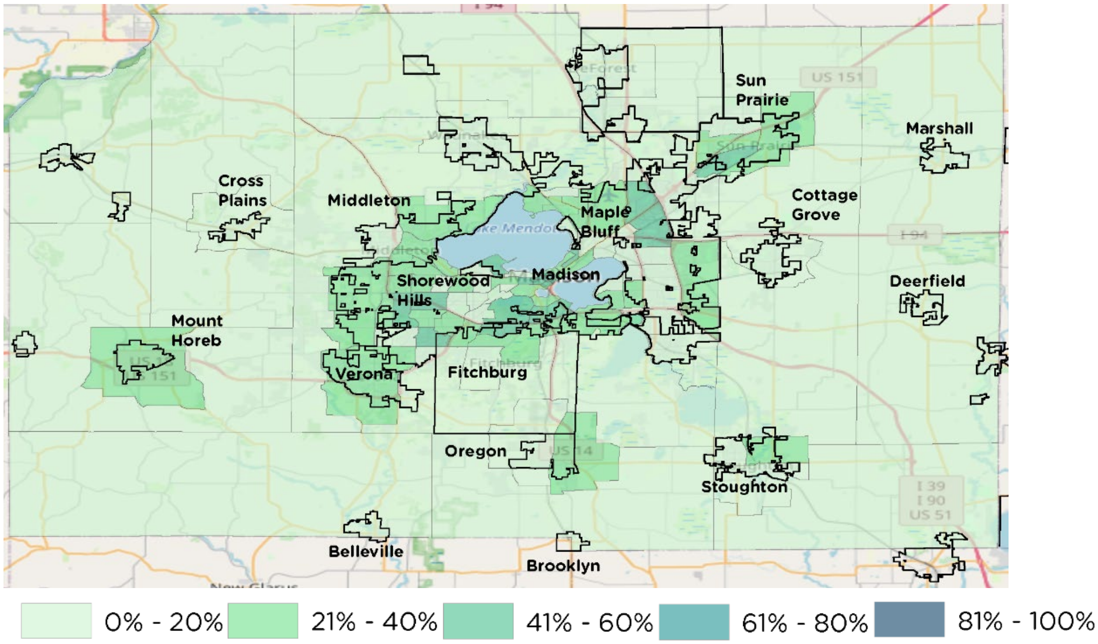


Figure 3. Percentage Residences With Propane Heat by Census Tract

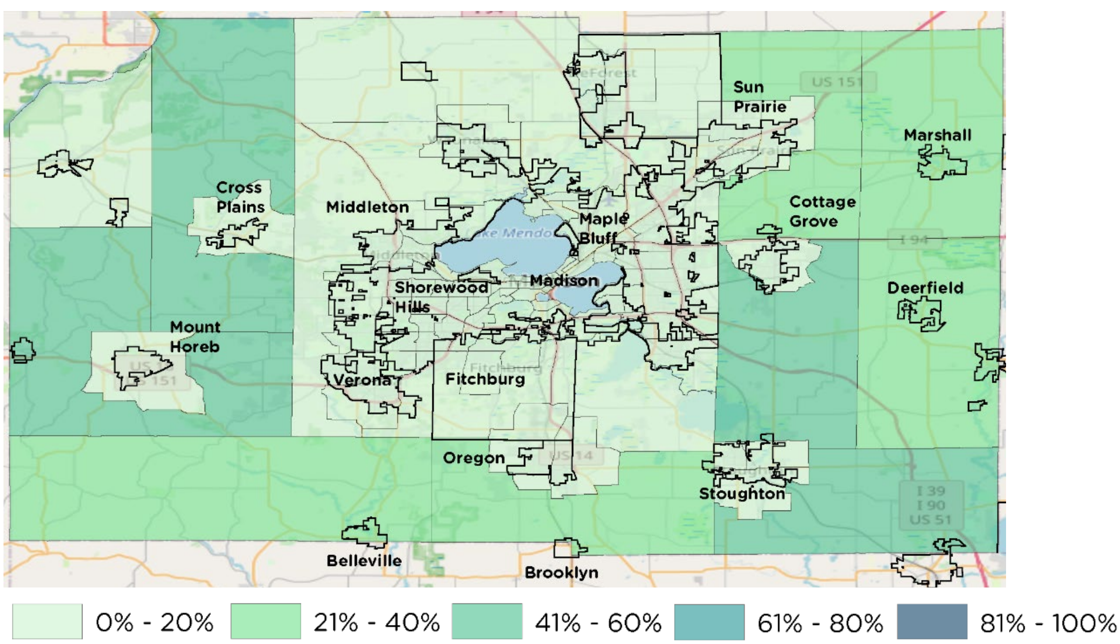
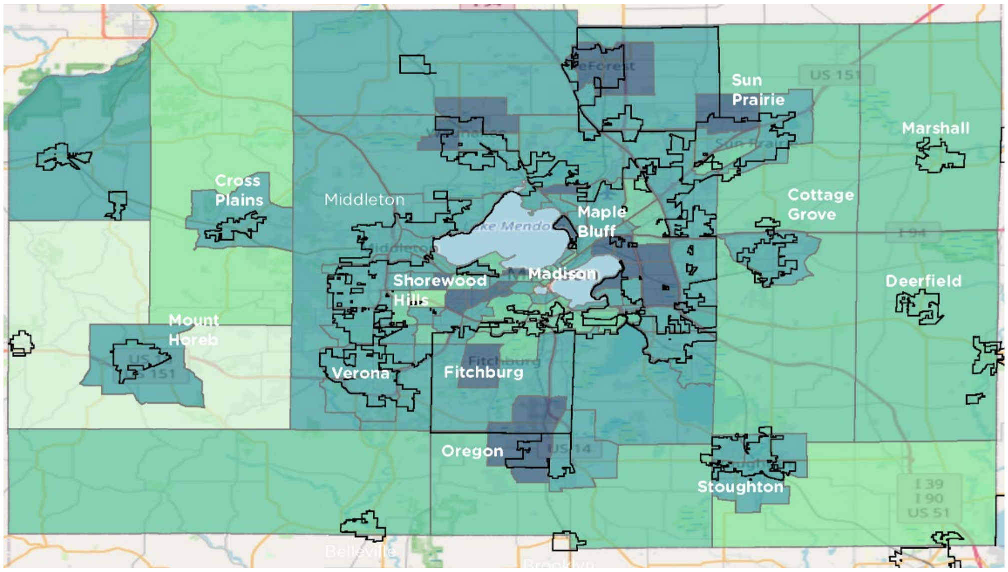


Figure 4. Percentage Residences With Natural Gas Heat by Census Tract



0% - 20% | 21% - 40% | 41% - 60% | 61% - 80% | 81% - 100%

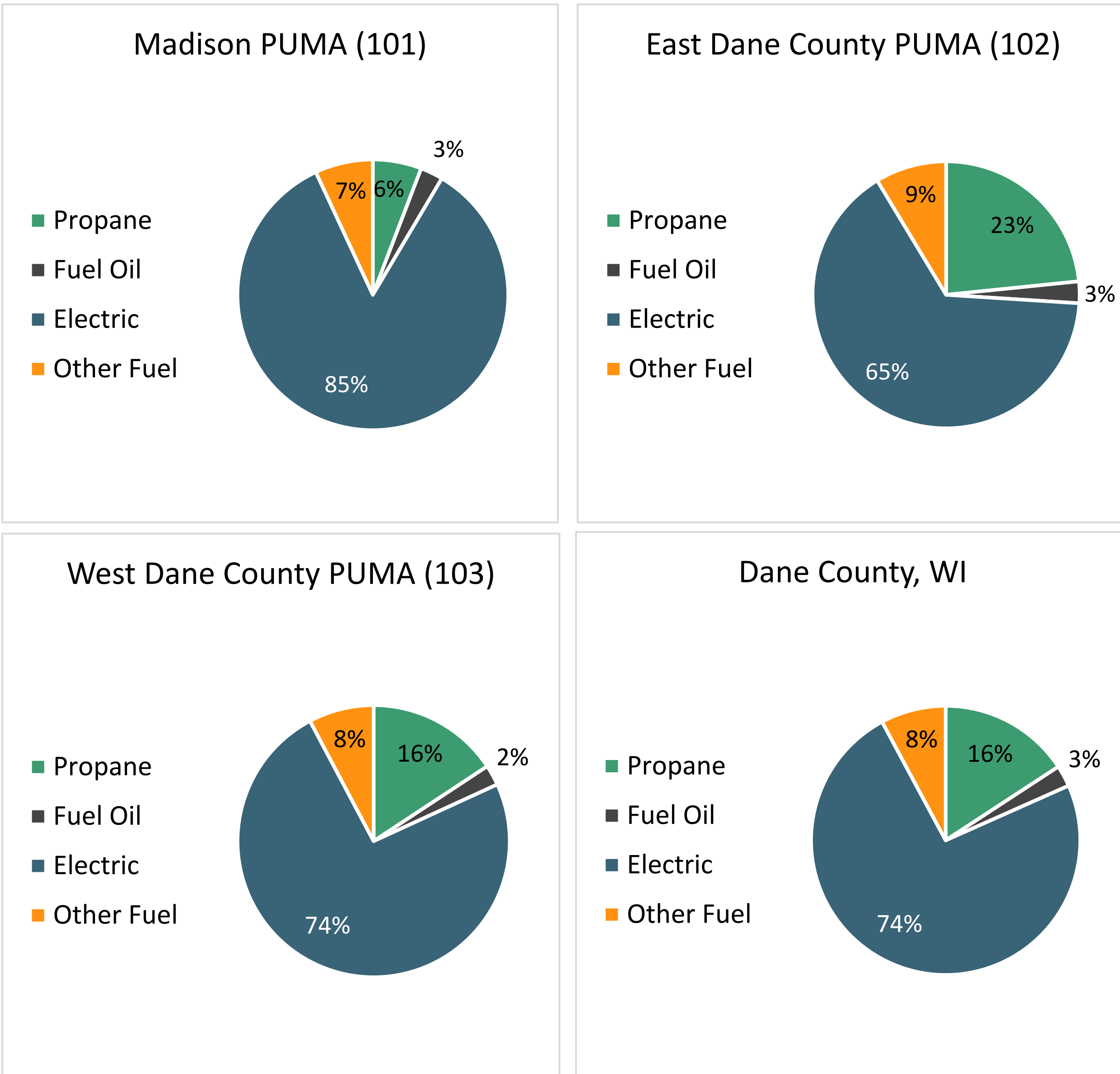
The attributes of housing stock were also assessed using the ResStock™ database, as the housing characteristics impact the ccASHP implementation approach. Of the 80,944 residential units not heated with natural gas (34% of the total housing stock in the ResStock dataset), the top five most frequent housing type and heating system pairs in Dane County were identified in order to focus the analysis on the most common building stock. These top five most common housing/heating pairs are in Table 3; a complete list of housing types and heating systems can be found in the Appendix B. Notably, four of the top five most common systems within the dominant housing types have electric heat.

Table 3. Top Five Most Common Housing and Heating System Pairs

Housing Type	Space Heating System	Total Residential Units	Percent of Non-Natural Gas Housing Stock
Multi-family (5+ Units)	Electricity Baseboard	24,244	30%
Multi-family (5+ Units)	Electricity Electric Furnace	9,688	12%
Single-family (Detached)	Propane Fuel Furnace	7,482	9%
Single-family (Detached)	Electricity Baseboard	5,324	7%
Single-family (Detached)	Electricity Electric Furnace	4,053	5%
Total		**50,790**	**63%**

Electric resistance-based heating represents a sizable portion of the space heating market and therefore potential opportunity for large carbon savings. Across the three PUMAs in Dane County (refer to Figure 1), electric resistance heat is the most common non-natural gas heating source in all three PUMAs (Figure 5). Electric resistance heating makes up 85%, 65%, and 75% of the non-natural gas building stock heating in Madison, East Dane County, and West Dane County, respectively. Propane heating is more common in the East and West Dane County PUMAs compared to Madison, while the frequency of fuel-oil heating is consistent across all three PUMAs (~3% of non-natural gas heating).

Figure 5. Distribution of Non-Natural Gas Heating Fuels for Dane County PUMAs



A brief socioeconomic analysis was conducted to evaluate the relationship between prevalence of electric space heating and income level in Dane County. A 2021 statewide study across Wisconsin documented multi-family housing as having a higher proportion of electric heat and residents who are low-income (Center for Energy and Environment, 2021). A Minnesota study also found that households with lower incomes were more likely to have electric resistance heating (CARD, 2018). Across Dane County, Figure 6 shows the median household income versus the percentage of units with electric space heat by Census Tract. The Pearson's correlation test was used to examine the linear correlation between income and prevalence of space heating fuel types. The correlation coefficient and significance for the Pearson's correlation tests are shown in Table 4. Lower median incomes were significantly associated with a higher prevalence of electric space heating at the census tract level (p-value <0.001). A significant positive relationship between natural gas and higher incomes was also noted (p-value < 0.001). The correlation between propane and income was not evaluated as their relationship is visibly non-linear and therefore testing the linear relationship is not appropriate (see propane graph in Appendix C). Fuel-oil did not have a significant relationship with income. The association found between lower incomes and electric resistance space heating indicates that implementing ccASHPs in units with electric heat may help target communities with lower incomes that could benefit the most from cost savings from high efficiency heat pump heating.

Figure 6. Census Tract Median Household Income Versus Percent of Units With Electric Heat

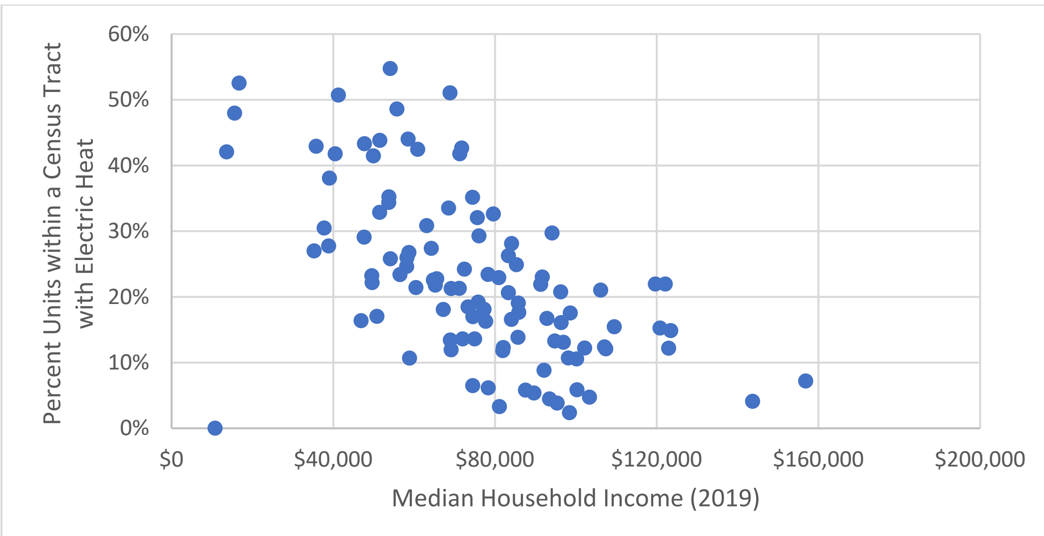


Table 4. Pearson's Correlation Test Results for Relationship Between Median Household Income and Prevalence of Space Heating Fuel Type

Space Heating Fuel	Correlation Coefficient[7]	P-value	Interpretation
Electric	-0.58	5.834e-11***	Significant negative association between prevalence of electric heat and income
Natural Gas	0.37	0.0001218***	Significant positive association between prevalence of natural gas heat and income
Fuel-oil	0.07	0.4544	No significant association

*p-value < 0.05, **p-value < 0.01, ***p-value < 0.001

[7] We caution against using the magnitude of the reported coefficient in the interpretation of the results since additional variables are not accounted for; instead, the application of this significance test in our study is primarily to examine the directionality of the relationship (i.e., positive or negative).

Because of the prominence of electric resistance heating, and the focus of the Dane County Climate Action Plan on propane and fuel-oil heating, the savings analysis includes an examination of propane, fuel-oil, and electric resistance space heating.

Savings Analysis – Utility Bill and Carbon Savings

The following sections detail the utility and carbon savings associated with implementation of ccASHPs in Dane County.

UTILITY SAVINGS PER UNIT

In Table 5, the average heating, cooling, total, and percent utility savings are shown on an average per unit basis. Results are broken down by units with an existing air conditioning system (including both central and window air-condition) and units with no previous air-conditioning. The average annual heating bill savings for multi-family buildings with electric baseboard heat and existing air conditioning is $449 per unit. These savings represent averages across the Dane County building stock and will vary based on specific housing conditions. Overall, residences with electric resistance heat are expected to save about half on their combined utilities spent on heating and cooling (see "Percent Heating/Cooling Utility Bill Savings"). Utility savings are slightly lower for homes that are paying for air conditioning with a ccASHP when they previously did not have access to air conditioning. Added cooling costs range on average from $40 to $108 per year, however, the overall average annual cost savings is still net positive across all housing types (see "Average Annual Cost Savings"). The larger savings realized by single-family homes is due to the high heating energy consumption of single-family homes with high thermal loss through the building envelope (as compared to multi-family units).

Table 5. Utility Bill Savings for Five Most Common Housing and Heating Types (Per Unit Basis)

Heating Fuel	Total Units	Average Annual Heating Bill Savings	Average Annual Cooling Bill Savings	Average Annual Cost Savings	Percent Heating/Cooling Utility Bill Savings
Units with existing air conditioning					
MF 5+: Electric Baseboards	15,875	$449	$22	$471	50%
MF 5+: Electric Furnace	5,084	$378	$14	$392	51%
SF Detached: Electric Baseboards	3,225	$1,145	$30	$1,175	50%
SF Detached: Electric Furnace	3,585	$1,302	$36	$1,338	52%
SF Detached: Propane Fuel Furnaces	6,199	$359	$36	$395	22%
Units without air conditioning					
MF 5+: Electric Baseboards	8,369	$450	-$58	$392	46%
MF 5+: Electric Furnace	4,604	$376	-$40	$336	48%
SF Detached: Electric Baseboards	2,074	$1,130	-$81	$1,049	48%
SF Detached: Electric Furnace	468	$1,364	-$108	$1,256	49%
SF Detached: Propane Fuel Furnaces	1,259	$359	-$107	$251	15%

Homes with propane or fuel-oil are expected to save 18-24% on their heating and cooling costs (Table 6). Average annual utility bill savings are slightly more for fuel-oil ($342-$476 per year) than propane ($310-$413 per year). These utility savings estimates represent averages across the building stock and are sensitive to price fluctuations in the propane and fuel-oil markets. Actual savings will vary based on individual building characteristics and fuel prices. Absolute cost savings are slightly higher in homes presently using fuel-oil for heat, primarily driven by the higher baseline heating energy for fuel-oil homes.

Table 6 summarizes the average utility savings across all propane and fuel-oil systems, including both single-family and multi-family housing stocks. These results were not disaggregated by housing type as the vast majority of residences heated with fuel-oil and propane are in the single-family housing stock.

Table 6. Utility Bill Savings for All Propane and Fuel-oil Systems (Per Unit Basis)

Heating Fuel	Total Units	Average Annual Heating Bill Savings	Average Annual Cooling Bill Savings	Average Annual Cost Savings	Percent Heating/Cooling Utility Bill Savings
Units with existing air conditioning (all housing types)					
Propane	9,256	$380	$32	$413	24%
Fuel-oil	1,499	$442	$34	$476	24%
Units without air conditioning (all housing types)					
Propane	3,489	$395	-$84	$310	20%
Fuel-oil	576	$434	-$93	$342	18%

If all homes in this analysis were converted to ccASHPs, Dane County residents, in aggregate, would save over $31 million dollars in utility costs annually.

CARBON SAVINGS PER UNIT

In an analysis of the five most common housing and heating system types in Dane County, the highest carbon savings on a per unit basis are single-family homes with electric baseboard or furnace heating systems (Table 7). Under the business-as-usual case, an average of 4.6 tons of carbon is expected to be saved annually for single-family homes with electric baseboard, and 5.2 tons of carbon for single-family homes with electric furnaces. The per unit carbon savings decrease to 4.1 and 4.9 tons, respectively, if a home did not already have air conditioning, because of the additional carbon emissions from adding air conditioning. Overall, for electric heating systems, heating and cooling carbon emissions is expected to be reduced by about 50%. This corresponds to a total home energy reduction between 26-36%.

Under the business-as-usual scenario, single-family propane furnaces have the lowest absolute and percentage carbon savings; however, the carbon savings almost double under the low renewable cost scenario. This is due to the electricity grid having a higher percentage of renewable energy supply in the low renewable energy cost scenario; thus, for conversion of fuel heating systems, the carbon savings will increase under the low renewable energy cost scenario. For residences heated with electric heat, absolute carbon savings are reduced under the low renewable energy cost scenario because the heating fuel before ccASHP implementation is also electric and will have the same carbon savings under a cleaner grid. Across all residences, carbon savings in homes that originally did not have air conditioning is lower than residences that already had air conditioning. On average, the carbon savings for homes without air conditioning is on average 6-17% lower than homes already with air conditioning.

Table 7. Annual Carbon Savings for Five Most Common Housing and Heating Types (Per Unit Basis)

Housing/Heating System Type	Annual Carbon Savings (Tons/Unit)		Percent Heating/Cooling Carbon Savings		Percent Total Unit Carbon Savings	
	Business-as-usual[8]	Low RE cost[9]	Business-as-usual	Low RE cost	Business-as-usual	Low RE cost
Units with existing air conditioning						
MF 5+: Electric Baseboards	1.8	1.4	50%	50%	29%	29%
MF 5+: Electric Furnace	1.5	1.2	51%	51%	26%	26%
SF Detached: Electric Baseboards	4.6	3.5	50%	50%	34%	34%
SF Detached: Electric Furnace	5.2	4.0	52%	52%	36%	36%
SF Detached: Propane Fuel Furnaces	1.3	2.4	19%	36%	11%	24%
Units without air conditioning						
MF 5+: Electric Baseboards	1.5	1.2	46%	46%	26%	26%
MF 5+: Electric Furnace	1.3	1.0	48%	48%	26%	26%
SF Detached: Electric Baseboards	4.1	3.1	48%	48%	31%	30%
SF Detached: Electric Furnace	4.9	3.7	49%	49%	33%	32%
SF Detached: Propane Fuel Furnaces	0.7	2.0	11%	32%	6%	19%

A similar analysis was conducted for all propane and fuel-oil homes across Dane County. A key objective of the Dane County Climate Action Plan is transitioning half of the fuel-oil and propane homes to heat pumps by 2030, and all of homes using these heating fuels to heat pumps by 2045. According to the ResStock™ housing totals, this would involve converting 6,385 propane homes and 1,037 fuel-oil homes by 2030, and the same number of homes by 2045. Under the business-as-usual scenario, converting propane heated homes to ccASHPs is projected to save between 1.0-1.4 tons of carbon per unit annually depending on if the homes already have air conditioning (Table 8). This represents a 17-21% heating and cooling carbon savings, and 10-13% on total home carbon emissions. Absolute and percent carbon savings increase under the low renewable energy scenario because of the added carbon savings post-

[8] Also referred to as Mid-Case by NREL, this scenario uses current policies and default or mid-level assumptions to generate a reference case. This scenario reflects changes in the grid over time, but only changes that flow from the current business-as-usual factors and policies.

[9] This scenario is modeled using low prices for renewable energy, therefore increasing the share of renewables on the grid compared to other sources. Unlike business-as-usual, this scenario reflects shifts in the factors that influence the fuel mix of the grid. Given the likely policy and subsidy changes on the horizon, we feel this low-renewables cost scenario is a very likely and reasonable future model to use.

electrification due to an electric grid with more renewable energy. Trends are similar for fuel-oil homes; however, fuel-oil has a higher absolute carbon savings compared to propane.

Table 8. Annual Carbon Savings for All Propane and Fuel-oil Systems (Per Unit Basis)

Housing/Heating System Type	Annual Carbon Savings (Tons/Unit)		Percent Heating/Cooling Carbon Savings		Percent Total Unit Carbon Savings	
	Business-as-usual	**Low RE cost**	**Business-as-usual**	**Low RE cost**	**Business-as-usual**	**Low RE cost**
Units with existing air conditioning (all housing types)						
Propane	1.4	2.4	21%	38%	13%	24%
Fuel-oil	2.7	3.9	31%	46%	21%	34%
Units without air conditioning (all housing types)						
Propane	1.0	2.1	19%	38%	12%	25%
Fuel-oil	2.2	3.5	28%	45%	19%	32%

TOTAL ANNUAL CARBON SAVINGS ACROSS DANE COUNTY

The following analyses aggregate the per unit results to estimate the potential for carbon savings if all residential units under a specific housing type are upgraded with ccASHPs. Summing up across Dane County, Table 9 shows the annual carbon impact of retrofitting select building stocks across Dane County to ccASHPs. Depending on the carbon scenario modeled, tons of carbon saved range from 115-120 thousand tons annually. This corresponds to an average heating/cooling carbon savings ranging from 11-52% and an average total housing carbon savings from 6-36%, depending on the specific housing stock.

Table 9. Aggregate Annual Carbon Savings Across Dane County By Housing Stock[10]

Scenario	Total Units	Total Annual Carbon Savings (Tons CO_2)	
		Business-as-usual	**Low RE cost**
Multi-family 5+: electric resistance	33,932	55,000	40,000
Single-family (detached): electric resistance	9,352	45,000	35,000
All housing types: propane	12,769	15,000	30,000
All housing types: fuel-oil	2,074	5,000	10,000
Total	**58,127**	**120,000**	**115,000**

[10] Results are rounded to the nearest 5,000

Air Source Heat Pump Upgrade Cost Analysis

This section details the estimated cost to upgrade a residential unit to a ccASHP in Dane County. Per unit costs are discussed first followed by aggregated costs across Dane County.

UPGRADE COST PER UNIT

Of the top five most common systems, we estimate the least expensive heating systems to upgrade are electric baseboard systems in multi-family buildings, at a cost of $8,500 per unit (Table 10). Cost assumptions for housing type and heating system pairs can be found in the Appendix A. Generally, the lower cost of the multi-family baseboard system is driven by the assumption that this retrofit will involve two mini-split heads, versus three assumed in the single-family home. Also, we assume furnace upgrades will require removal of the existing furnace while electric baseboards are left in place. Propane system replacements are the highest to replace, totaling to $16,500 per unit, and this cost includes both existing furnace removal and the added electrical capacity. All ccASHP retrofit cost estimates include the cost of backup electric resistance heating.

Table 10. Estimated Cost to Upgrade to ccASHP Per Unit Based On Existing Housing and Heating Type

Housing and Heating Type	Average Cost to Upgrade to ccASHP Per Unit
MF 5+: Electric Baseboards	$8,500
MF 5+: Electric Furnace	$11,500
SF Detached: Electric Baseboards	$13,000
SF Detached: Electric Furnace	$11,500
SF Detached: Propane Fuel Furnaces	$16,500

COST TO IMPLEMENT VERSUS UTILITY SAVINGS

The per unit cost to implement ccASHPs and per unit utility savings were aggregated across all buildings within specific housing stocks. The lowest simple payback across housing stocks considered is the single-family electric resistance housing stock, with an average simple payback of 10 years (Table 11). Propane and fuel residences have the highest simple payback, at 41 and 37 years, respectively. Multi-family electric resistance falls in the middle, with a payback of 23 years. These paybacks, particularly in homes using fuel-oil or propane, are a significant barrier to most residents interested in ccASHPs. In the short-term, financial incentives or rebates will be necessary to encourage owners to adopt higher efficiency heating alternatives, such as ccASHPs.

Table 11. Simple Payback Analysis

Housing Stock	Total Units	Total Upgrade Cost	Total Annual Utility Savings	Simple Payback (Years)
Multi-family 5+: electric resistance	33,932	$321,980,000	$14,300,000	23
Single-family (detached): electric resistance	9,352	$115,620,000	$11,350,000	10
All housing types: propane	12,769	$202,770,000	$4,900,000	41
All housing types: fuel-oil	2,074	$33,330,000	$910,000	37

COST TO IMPLEMENT PER TON OF CARBON SAVED

Comparing the total upgrade cost per ton of carbon saved over the lifetime of the ASHP can be a useful way to compare the economics of different building segment scenarios and help prioritize cost effective housing segments for ccASHP programs. The upgrade cost per lifetime ton of carbon saved is presented for both the business-as-usual and low renewable energy cost grid scenarios in Table 12. Under the business-as-usual carbon scenario, single-family homes with electric resistance heat are the most economical (in terms of upgrade cost per ton of carbon saved) to upgrade to ccASHPs ($131/ton saved). Multi-family units with electric resistance ($290/ton saved) and fuel-oil homes ($312/ton saved) are the next most economical. Under the low renewable energy cost scenario (i.e., a grid with a higher proportion of renewables) single-family homes with electric resistance heat still have the lowest cost ($172/ton saved), followed by fuel-oil homes ($211/ton saved). From this lens, single-family electric resistance systems are the most cost efficient across all the target housing segments to convert to ccASHPs.

Table 12. ccASHP Upgrade Cost Per Ton of Carbon Saved By Housing and Heating Type

Housing and Heating Type Scenario	Total Units	Carbon Scenario ($/Lifetime Tons Carbon Saved)[11]	
		Business-as-usual	Low RE cost
Multi-family 5+: electric resistance	33,932	$290	$381
Single-family (detached): electric resistance	9,352	$131	$172
All housing types: propane	12,769	$640	$348
All housing types: fuel-oil	2,074	$312	$211

The data analysis results quantify the potential benefits and costs associated with implementing ccASHPs across specific housing stocks in Dane County. The following section details the interview results on key housing segments identified and adds greater context to homeowner decisions around ccASHPs in Dane County.

[11] The lifetime of the ccASHP is assumed to be 20 years

Interview Results

Elevate and Sustain Dane held 14 interviews over the course of June, July, and August 2021. Each interview lasted 30 minutes on average. Five single-family homeowners, four municipality contacts in Dane County, three multi-family property owners/managers, and two utility sector contacts were interviewed. Of the eight homeowners and multi-family property owners, three had electric resistance heating, two had natural gas alone and were considering an ASHP, and one had a combined propane and natural gas system. There were also two interviewees whose homes already ran on ASHPs. One ASHP's backup heating system was natural gas and the other backup system used fuel-oil.

The following section contains overall themes from the interviews and is followed by two case studies focusing on propane heating in single-family homes and electric resistance heating in multi-family homes. Both case studies present situations where the owner opted to not to install ASHPs, thus highlighting challenges ASHP implementation programs may face in Dane County. We also selected these case studies as they contain major themes noted throughout many interviews and represent opportune housing stocks identified in the data analysis.

Themes From Interviews

Lower energy costs and carbon emissions are top of mind.
Reducing energy costs and carbon emissions were at the forefront of motivating factors for all interviews. Secondary motivating factors were comfort, extending the life of an existing heating system, and the ease of heating and cooling combined in one system. Comfort was especially pertinent to interviewees who did not already have air conditioning or those whose electric resistance heating did not keep them warm in the winter.

Interviewees who installed an ASHP have a positive opinion.
We interviewed two single-family homeowners who already had ASHPs running in their houses. Both were extraordinarily pleased with their ASHPs, especially the homeowner who had hers the longest. As an extremely energy-conscious homeowner, she had completely upgraded all appliances to the highest efficiency possible with the assistance of a Green Mortgage refinance. She had her ASHP installed in 2008 by a contractor from out-of-state because there was no one in Wisconsin at the time who was familiar with the technology. The house previously only had an old gas furnace that needed to be replaced. The homeowner kept it as a back-up heating system and was amazed that the ASHP extended the life of the furnace tremendously. Because the ASHP was doing the bulk of the heating, the gas furnace barely had to run at all. As a result, it lasted years beyond what was anticipated when it was the only heating system. The homeowner considered not having to buy a new gas furnace as additional cost savings. She was impressed that the ASHP had reduced energy use and costs by around 20%, according to her estimations. She shared her positive experience with other friends and acquaintances, who she said also ended up installing ASHPs in their homes at her recommendation. When she moved in 2018, she went on to buy the house of someone who had an ASHP installed in it because of her.

A condo manager initially thought she had no background knowledge of ASHPs, but later recalled that one resident had gotten approval from the condo board to convert to an ASHP. The condo owner demonstrated impressive initiative and left an overall positive impression of ASHPs on the management company.

Interviewees who opted to not install an ASHP are uncertain without additional information.
Early adopter questions were a common theme, which was reflective of our interview sample. The cost feasibility, accessibility, and reliability of the technology were all discussed. A single-family homeowner felt like she could not move forward without hearing someone's firsthand account of the reality of having an ASHP. Through her research online, she found the information available on ASHPs was sparse, often hypothetical, and not specific to Wisconsin, so there was a degree of doubt amongst interviewees about real-world application. Beyond the need for a general public information campaign, questions about utility bill costs when fuel-switching lingered. Interviewees reported difficulty with finding a breakdown of prospective operating costs for homeowners while researching ASHPs, and ASHP incentives were not high enough to overcome the questions of upfront costs. Naturally, even those who are willing to pay a price premium for decarbonization are hesitant. "Everyone wants to know if they should wait a few years until it's standardized," concluded a municipal contact.

A couple interviewees, both single-family and multi-family owners, expressed long-term concerns influencing their outlook on ASHPs. They would be more eager to invest in the upfront cost if they could be assured it could increase property value. The single-family homeowner had ultimately not sprung for the ASHP yet, partly because of the inconvenience and inaccessibility in the process, as well as the fact that "This isn't our forever home. I'm not sure a buyer will see the value."

Opportunities for environmental justice should be considered.
From a municipality perspective, one municipal contact reminded us that environmental justice will be at the forefront of electrification. "Right now [incentives] are probably not high enough to push the majority of consumers over the edge. The people who could benefit the most from the cost savings are the ones who couldn't afford the upgrade at all." Their conclusion was that 50-100% of costs should be covered for low-income housing. Municipalities also saw natural disasters as an avenue of opportunity for electrification. When Dane County was subjected to record-breaking flooding in 2018, many home appliances were damaged beyond repair and there was a widespread surge of upgrades needed in damaged buildings. Their thinking was these needed upgrades presented an opportunity to fund more efficient replacements as part of the recovery effort. There is the added benefit of not creating waste when providing ASHPs in this scenario since the replacements would be necessary.

Case Study 1: Single Family Homeowner with a Propane Heating System

We spoke with a single-family homeowner who, much like the rest of his township, used a propane heating system. Occasionally the homeowner also heated with wood. The homeowner had concerns both about utility bill costs and reducing his carbon footprint. While the homeowner believed that propane would be less expensive than other heating sources, he also observed that his energy bills were higher than he anticipated. The homeowner was also environmentally conscious and had taken steps to mitigate energy consumption through conscious energy use. Saving energy was as important, if not more, as cutting costs to him. Although his home had a central air conditioning system, he estimated he only used it about five days a year. To reduce energy consumption, he set his thermostat low in the winter and high in the summer.

Due to high energy bills and a desire to reduce his carbon footprint, this interviewee conducted research on more efficient heating systems. He focused at first on geothermal energy as he had already heard this form of heating was more efficient. Through this research, he discovered the additional option of heating his home with an ASHP. The homeowner became interested in electrifying space heating with a heat pump upon the realization that it would be a more affordable option than a geothermal heat pump. The idea of streamlining his HVAC system with an ASHP was something that also greatly appealed to the homeowner. He was attracted by the idea of having heating and cooling all in one system. The homeowner stated that he would likely consider paying more for an all-in-one system.

In the end, however, he decided not to pursue an ASHP for space heating for several reasons. One of the homeowners most significant hang-ups when evaluating an ASHP system was the need to continue maintaining the propane system since both would be required in the dual-fuel propane system the homeowner was considering. Although most interviewees found comfort in having a back-up heater for the winter, this homeowner worried that if he was using the heat pump almost exclusively, he would forget to have enough propane on hand on the coldest days of the year. "I don't want to forget to maintain my [propane] furnace until when I need it the most," he stated. He also spoke about hearing that ASHPs produce a "gentle heat" that would not keep him as warm. Regarding maintenance, he spoke about not feeling comfortable that there were such limited options for contractors who could service an ASHP after installation. A previous negative experience with a contractor further raised his concern since a negative interaction with the only ASHP contractor available could leave him without any contractor to maintain his system. Maintenance with the propane system was minimal; he had only needed one repair on the propane heater in the past.

The convenience of using propane, the system he was already familiar with, was also a reoccurring theme in our discussion. He had a favorable view of his propane supplier, which predicts when and how much propane he'll need annually based on historic use, and then delivers it to his door. It took the guesswork out of the equation for the homeowner, and he was fond of having a prepaid winter heating bill. Having a system he was already familiar with gave him peace of mind.

Without a full cost parity to inform his decision, the homeowner fell back on his belief that switching from propane to an ASHP would not save on his energy bills. Given the priority he placed on savings, rebates and incentives could have motivated him to switch. Additional warranties and options for assistance with installation or repairs from multiple contractors were other resources that would significantly alleviate the homeowner's hesitancy. He was well informed on the reality of ASHPs despite not knowing anyone who had firsthand experience with one. Nonetheless, he still had questions of practicality and when would be the right time to make the switch.

Case Study 2: Multi-family Owner With Electric Baseboard Heat

We spoke with a multi-family property owner who managed a substantial number of apartment buildings. The complexes our discussions focused on were between 7-26 units and used electric resistance heating. The electric baseboards were all recently updated and controlled digitally through a remote thermostat on an app. The property owner did his best to educate residents on saving energy, even though it the tenants pay for their electric utilities. He stated that electric resistance heating "deserves a little bit of its bad reputation" but costs were manageable with proper resident education and usage. He commented that other property owners who cover utilities for tenants tended to increase rent by approximately $50 to cover the utility costs for studio and one-bedroom apartments.

The property owner wanted to minimize his and his residents' carbon footprint so long as it was economically feasible. He initially explored solar energy but decided against it due to the payback period being double what he expected at 12 years, instead of 6 years (his preference). Moreover, when he had his properties assessed, his larger buildings did not have preferable orientation for solar and the solar company discouraged him from installing solar on his smaller buildings. This interview was the only one where the property owner questioned the effect energy efficiency upgrades would have on curb appeal of his property, which was important to him.

The property owner was somewhat familiar with ASHPs. He wasn't aware of cold-climate heat pumps and doubted the capability of ASHPs to perform well in low temperatures. Consequently, the property owner was under the impression that ASHPs "didn't have a good application in Wisconsin." Nonetheless, he acknowledged that the technology may have improved in the years since he first looked into ASHPs.

A deciding factor in the property owner's inaction to acquire a heat pump was the availability and ease of installation. The property owner did not want to struggle to find a contractor who would be able to maintain the ASHP and do repairs. "I wouldn't know who to call. It can't be too complicated." was his worry. Typically, any work with contractors – heat pump or otherwise – also was complicated by the turn around period for him. The property owner felt it was often a challenge to complete upgrades during the short timeframe of vacancies without significant upfront research and planning.

Yet another hurdle for the property owner was incentives, which he frequently referred to as a "way too much of a hassle." He relied solely on his contractors to find incentives for him, and even to assist him with the application. The property owner had received some incentives in the past, but claimed he had "discouraging" experiences and had "given up" since then – unless the contractor intervened to apply themselves or made it exceptionally easy for him to apply.

Recommendations

ccASHP Electrification Opportunities in the Dane County Housing Stock

Implementing ccASHPs in Dane County has the potential to reduce total residential housing carbon emissions by 6-36% across the electric, propane, and fuel-oil heated housing stock. Carbon savings and upgrade costs will vary based on existing conditions, and the quantity of a particular housing stock across Dane County will impact its overall opportunity for carbon savings from electrification. With this in mind, we present the following recommendations that focus on specific niches most opportune for initial ccASHP implementation programs in Dane County.

Recommendations In the Electric Resistance Sector

We recommend expanding ccASHP electrification efforts to residences with electric resistance heat. Both single-family and multi-family electric resistance housing stocks can be converted to ccASHPs in most scenarios at a lower cost as compared to propane and fuel-oil heated homes, while also resulting in higher carbon savings and targeting more lower income households.

a. To achieve the highest carbon and utility savings on a per unit basis, offer ccASHP programs aimed at replacing electric resistance heating in the single-family housing sector. This sector has the highest per unit carbon savings (3.1-5.2 tons carbon saved per unit), highest utility savings ($1,100-$1,350 saved annually per unit), and lowest average simple payback (10 years) of the housing stocks analyzed.

Single-family detached homes heated with electric resistance heat represent a sizable portion of the electric resistance heating sector (9,352 units). Single-family homes also have the highest per unit carbon savings across all building types considered. This is due to their higher baseline heating energy consumption (largely due to a single-family home having greater thermal loss through the building envelope). Converting the single-family electric heat sector to ccASHPs is projected to save 3.1-5.2 tons of carbon per unit. This equates to 48-52% savings on heating and cooling emissions, and 30-36% on total home carbon emissions. This amounts to utility savings of $1,100-$1,350 per year. The simple payback based on the estimated upgrade cost and utility savings is 10 years. Aggregated, these per unit savings across the county are expected to be between 35,000-45,000 tons of carbon saved annually if all single-family homes with electric resistance heat are converted to ccASHPs.

b. To achieve the largest scale of impact, offer ccASHP programs aimed at replacing electric resistance heating in the multi-family housing sector. This sector has the largest opportunity for carbon and utility savings based on the number of units (nearly 34,000), with moderate per unit carbon savings (1.0-1.8 tons carbon saved annually per unit) and utility savings ($330-$470). This housing stock also has the lowest expected upgrade cost ($8,500 per unit).

Multi-family units make up the largest portion of the electric heat market in Dane County (33,932 units). These units are expected to save 1.0-1.8 tons of carbon per unit annually. This equates to 46-51% savings on cooling and heating carbon emissions, and 26-29% on total home emissions on a per unit basis. This amounts to utility savings of $330-$470 per year per unit. The simple payback for electrifying this housing sector is 23 years, which is higher than the single-family electric resistance sector but significantly lower than the fuel-oil and propane sectors. Converting all multi-family electric resistance units to ccASHPs across Dane County is expected to save 40,000-55,000 tons of carbon annually. The multi-family electric resistance sector also has the lowest upgrade cost across the housing types we analyzed, with an estimated cost of $8,500 per unit.

Initial ccASHP programs may benefit from focusing on this segment due to its lower upfront cost and larger number of units. However, there are specific barriers within multi-family markets that programs should consider, such as the split incentive between building owners and residents. Residents often pay the heating bill when the heating systems are electric, and thus building owners investing in heat pumps will not receive the utility savings benefits; therefore, programs should be designed in a way that building owners who don't pay for the electric heat are still incentivized to adopt heat pumps.

c. Assist lower income households by prioritizing upgrades in the electric resistance heating building stock. Lower household incomes are associated with higher prevalence of electric heated homes in Dane County.

Electric heating is associated with lower median household incomes in Dane County, indicating that ccASHP programs focused on electric baseboard systems will be likely supporting lower-income residents. Over the long term, as natural gas customer bases shrink, research suggests that homes remaining reliant on fossil fuels risk paying a higher proportion of pipeline and other fixed infrastructure costs in their utility bills (Davis and Hausman, 2022). Prioritization of low-income residents in electrification efforts is important to ensure they do not bear the brunt of legacy infrastructure systems. In addition, residences who convert from electric resistance to ccASHPs can expect substantial utility bill savings. Expected utility savings vary from single-family to multi-family. The average annual heating bill savings is about $400 per unit for a multi-family electric resistance unit, and $1,200 per home for single-family. These utility savings estimates are averages across a range of buildings within the single or multi-family housing stock, and actual savings will depend on the individual characteristics and variations between buildings. Single-family utility bill savings are higher due to single-family home's higher baseline energy use.

d. Target urban census tracts for ccASHP programs aimed at replacing electric resistance heating. Electric heating is concentrated in urban areas across Dane County.

Geographically, electric resistance systems are concentrated in urban census tracts (Figure 2). We recommend concentrating conversion of electric resistance heating systems to ccASHPs in these areas, including areas within the City of Madison on the Northside, Southwest side, and Isthmus, as well as areas within the cities of Sun Prairie, Middleton, Verona, Mount Horeb, and Stoughton. That being said, electric resistance systems are located in many areas in Dane County, regardless of urban/rural status. An interactive map exploring the frequency of heating fuels by census tract may be useful for targeting programs and can be found here.

In terms of existing heating system type, both electric baseboards and electric furnaces comprise the electric resistance heating sector. Therefore, electrification of these systems will involve both ductless and ducted ccASHP retrofits, and implementation programs should be able to support either of these approaches. One of the benefits of upgrading from electric resistance heat to heat pumps is it is likely that this conversation will not require increasing the electrical capacity of the residence or building. This makes the retrofit more straightforward while reducing the cost as compared to retrofits where the existing heating fuel is not electric.

Recommendations and Programmatic Considerations Across All Heating Types

We recommend the following key programmatic recommendations across all heating types.

a. Target ccASHP programs to homes without air-conditioning, as approximately one-third of residential units do not currently have access to air-conditioning and adding cooling represents a significant opportunity to improve housing infrastructure health and resiliency to residents during increasingly occurring extreme temperature events. The portion of households without air-conditioning is relatively consistent across Dane County geographies and heating types.

In the U.S., extreme heat is one of the leading causes of death for weather-related events. According to Dane County's Climate Action Plan, daily high temperatures exceed 90 degrees for 10-15 days per year in Southern Wisconsin currently. This number is expected to increase to 30-40 days per year by 2050. As extreme temperature events increase in Southern Wisconsin, comfort offered by air conditioning will become a health and safety necessity. ccASHPs offer a less carbon-intensive way to provide heat, while also providing access to air conditioning that is integrated into the same system. While adding cooling will increase cooling carbon emission in a portion of the housing stock, overall carbon is still reduced from the heating efficiency gains, while also providing health and resiliency benefits aligned with Dane County's Climate Action Plan.

Importantly, carbon savings vary based on the existing cooling system prior to ccASHP conversion. Residences with a cooling system (nearly two-thirds of the Dane County housing stock have either central or window unit air-conditioning) are expected to reduce cooling carbon emissions due to the increased cooling efficiency of the ccASHP. This corresponds to an average annual utility savings in residences already with cooling of $15-$35 per year.

The remaining one-third of residences, which per the ResStock™ database do not use cooling, will increase carbon emissions with the ccASHP system. The Madison PUMA has slightly more residences without any form of air conditioning (35%), compared to the West Dane County (30%) and East Dane County (29%) PUMAs. By heating type, 32% of electric heated units, 27% of propane heated units, and 28% of fuel-oil heated units are estimated to not have cooling. Adding ccASHPs to units without air-conditioning is expected to decrease total carbon savings by 6-23% (depending on the housing stock), corresponding to an increase in cooling utility bills between $40-$100 per year. However, across all housing stocks considered, there are net positive carbon savings and utility savings when accounting for both heating and cooling efficiencies. While there is still a net reduction in carbon emissions from implementing ccASHPs, it is important for ccASHP programs to communicate expectations to consumers to expect an increase in cooling costs during the summer months if they do not already have air conditioning.

b. Create a core program dedicated to electrifying residential buildings to scale electrification of homes in Dane County. Because of the inherent biases to ccASHP technology, lack of contractors, and relatively small incentives, a one-stop-shop approach that aligns existing programs and resources available in Dane County is recommended.

The following program design considerations are recommended to increase the uptake and acceptance of ccASHP technology in Dane County:

- **An incentive or subsidy unique to Dane County** to address costs of installing a new system. Research completed through the Focus on Energy program (CEE, 2021) shows that at least a 50% subsidy is needed for homeowners to convert to heat pump technology. This is especially critical to address the longer simple payback periods currently associated with current ccASHP technology.
- **Robust technical assistance** to help homeowners with each step of the upgrade process. At a minimum this should include no-cost assessments to determine eligibility, assistance with equipment and contractor selection, and assistance with education related to operation and maintenance of the new system. A bulk-buy program similar to the MadiSUN program that provides owners with comprehensive assistance and preferential costing could be a consideration for ccASHPs.
- **Linking a ccASHP program to existing programs** such as weatherization, Focus on Energy and/or the Efficiency Navigator. This will help streamline outreach and education as well as potentially coordinate installations with other upgrade opportunities including energy efficiency and solar.
- **Contractor training** to increase the pool of contractors that can reliably install ccASHPs throughout Dane County and offer operation and maintenance services. Any contractor engagement program should include an emphasis on increasing the number of MWDVBE (Minority-, Women-, Disabled-, and Veteran-owned Business Enterprise) contractors installing ccASHP technology through a recruitment and training program specific to the needs of small MWBE contractors. Creating linkages to existing small business resources for contractors in Dane County should be part of any training opportunity.
- **Access to financing** to provide homeowners and building owners additional funds, if needed for building upgrades.

c. Complete a similar study for homes heated by natural gas.

Currently, the low cost of natural gas has negatively impacted the economic viability of installing ccASHPs in homes. However, natural gas prices are susceptible to greater volatility in the future. This winter, households heated with natural gas are expected to pay 30% more on average compared to last winter.[12] A similar study should be undertaken in the near term to examine ccASHP economics under various natural gas pricing scenarios.

Recommendations In the Fuel-oil and Propane Sector

a. For ccASHP program aimed at conversion of fuel-oil and propane heated residences, focus initially on single-family housing stocks located in rural census tracts. While fuel-oil and propane residences have higher simple paybacks and generally lower carbon savings as compared to electric resistance homes, this housing stock is a key segment outlined in the Dane County Climate Action Plan and important to not leave behind in electrification efforts.

Converting residences with propane or fuel-oil heat to heat pumps is a key policy measure identified in the Dane County Climate Action Plan to reduce carbon emissions. Across Dane County, propane systems comprise of 12,769 units (5% of the building stock) and fuel-oil systems comprise of 2,074 units (1% of the building stock). Unlike electric resistance heating, propane and fuel-oil heating is concentrated in the single-family housing sector, with 89% of propane/fuel-oil residences being single-family. Therefore, we

[12] https://www.eia.gov/outlooks/steo/report/WinterFuels.php

recommend initial ccASHP programs target single-family households for converting propane or fuel-oil systems.

Propane heating is concentrated in rural census tracts (Figure 3). Programs aimed at addressing heating and cooling in rural areas would benefit from focusing on propane furnaces in single-family homes initially. There are relatively few fuel-oil systems across Dane County, and programs aimed at converting fuel-oil systems to heat pumps may run into challenges with targeting these systems. Programs aimed at fuel-oil systems will need outreach strategies and additional data analysis (e.g., tax assessor files) to locate homes with these systems.

The overall potential of this sector to reduce carbon emissions is less than that of the electric resistance sector because there are fewer homes with propane or fuel-oil heat in Dane County. The expected carbon savings for fuel-oil and propane is also highly dependent on the composition of the electricity grid. Unlike electric resistance, the carbon savings for fuel-oil and propane systems increase as the grid has more renewable energy (i.e., low renewable energy cost scenario). For fuel-oil, the expected carbon savings is between 2.2-3.9 tons saved per unit, corresponding to 18-34% total home carbon savings. This corresponds to an annual utility savings of $340-$475 per year. On a per unit basis, the expected carbon savings for propane is 1.0-2.4 tons annually, corresponding to 10-24% total home carbon savings per unit. This corresponds to an annual utility savings of $310-$410 per year.

In terms of heating system type, the most common type of propane and fuel-oil system is a ducted furnace. We recommend implementing programs targeting both propane and fuel-oil ducted furnace retrofits. The upgrade cost for both propane and fuel-oil single-family homes is similar, about $16,500 per unit. This cost estimate includes adding electrical capacity to the home to accommodate the additional electric load of an all-electric heating system. In comparison, upgrading a propane furnace at the end of its life to a standard efficiency equivalent furnace with air conditioning is estimated to cost $7,000, while upgrading a fuel-oil furnace is expected to cost $10,000. Of note, propane homes have the option to convert to a dual-fuel system, instead of an all-electric system. A dual fuel system relies on propane heat during extreme temperature events, while utilizing the efficiency offered by heat pumps for the majority of the heating season when not under extreme conditions. The dual-fuel systems can benefit consumers by assuring adequate heat in extreme conditions, extending the useful life of their existing propane system, and having a lower upfront cost than the full electric replacement.

References

CARD (2017). Cold Climate Air Source Heat Pump. https://www.mncee.org/sites/default/files/report-files/86417-Cold-Climate-Air-Source-Heat-Pump-%28CARD-Final-Report-2018%29.pdf.

CARD (2018). Minnesota Energy Efficiency Potential Study 2020-2029. https://mn.gov/commerce-stat/pdfs/mn-energy-efficiency-potential-study.pdf.

CEE (2021). Air Source Heat Pumps in Wisconsin Multi-family and Single-Family Applications. https://www.focusonenergy.com/sites/default/files/inline-files/2021/EERD_ASHP_Project-Final_Report.pdf.

CEE (2020). Turning Up the Heath on Cold Climate Heat Pumps: A Statewide Approach. https://www.mncee.org/sites/default/files/report-files/ACEEEccHP%20%282%29.pdf

Davis and Hausman (2022). Who Will Pay for Legacy Utility Costs?. *Energy Institute at Haas.* http://www.haas.berkeley.edu/wp-content/uploads/WP317.pdf.

EIA (2021). Carbon Dioxide Emissions Coefficients. https://www.eia.gov/environment/emissions/co2_vol_mass.php

EIA (2019). Wisconsin Energy Consumption by End-Use Sector. https://www.eia.gov/state/?sid=WI#tabs-2.

Appendix A: Quantitative Analysis

ResStock™ Database

The National Renewable Energy Laboratory's (NREL) ResStock™ data tool was obtained to understand the prevalence and geo-locations of propane and other non-gas fuel residential buildings. Data points included detailed building characteristics for each residential unit (e.g., square footage, heating system type, heating system efficiency) that serve as inputs into energy models. ResStock™ then uses Open Studio Energy+ to create physics-based models of annual baseline energy use by end-use and fuel (e.g., heating fan electricity consumption, heating propane energy consumption) for each building type and residential unit.

The resulting data offers a granular look at housing stock and baseline energy use profiles for residential units across Dane County. However, there were some limitations to the data due to its lack of census level survey and parcel level information. All data results analyzed are an approximation at the PUMA level geography. The sample size of the modeled energy use was also dependent on the frequency of the type of building stock, so building types that are less common in Dane County have smaller sample sizes in this analysis. For example, of the 20,000 models, there were 4,984 models for buildings with electric heat in Dane County. Conversely, there were only 173 models for buildings with fuel-oil heat. The sample size for each segment of housing stock that provides the basis of the analysis is specified in the resulting tables. To extrapolate to the total number of units in Dane County a weight of 11.99 is applied. This weight represents the weight of each residential unit modeled relative to the total number of units in Dane County (239,841).

Energy Savings Calculations

For each housing type and system, energy consumption for the new ccASHP system was estimated using the following steps. First, all energy-end uses associated with heating or cooling were pulled from ResStock™. Depending on the type of heating or cooling system, this included one or more of the following: (1) heating fuel energy use, (2) heating equipment efficiency, (3) cooling compressor energy use, (4) cooling equipment efficiency, (5) backup heating energy, (6) heating fan energy, and (7) cooling fan energy. Average end-use energy was calculated for each housing stock of interest (e.g., single-family with propane furnace heating and central cooling).

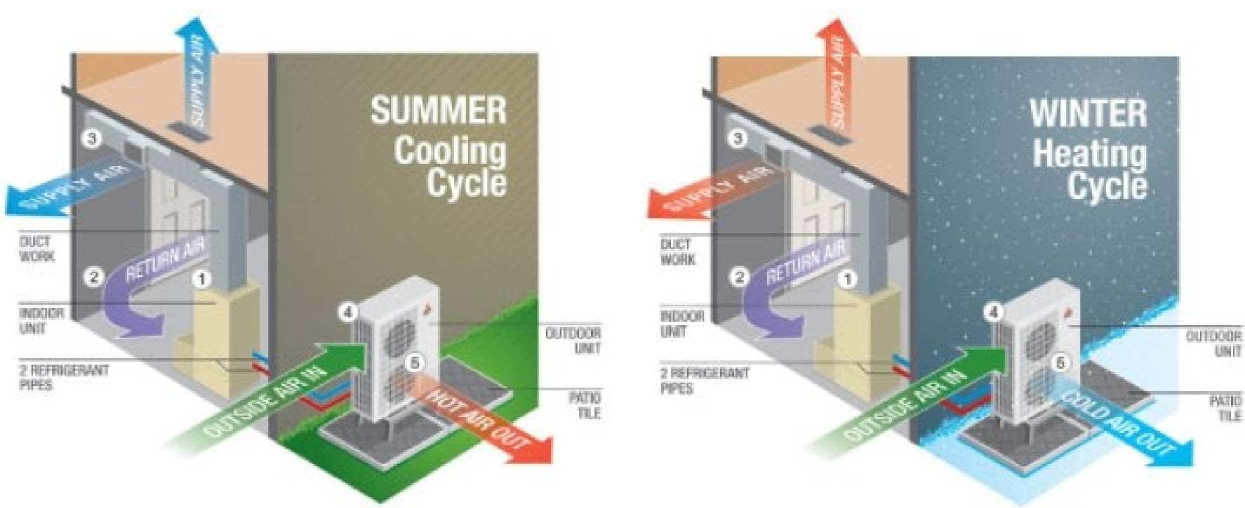
Next, the estimated ccASHP annual electric use was determined first converting all the energy end-use values to kilowatt-hours. Pre-retrofit heating and cooling energy was divided by an estimated COP (Coefficient of Performance) or SEER (Seasonal Energy Efficiency Ratio) of the new ccASHP system, respectively. The seasonal COP is an hourly-weighted average of the heat pump COP based on outside air temperature. The number of hours at each temperature we used were from typical meteorological year (TMY3) data for Madison, Wisconsin. The heat pump is assumed to be not heating when the outside temperature is warmer than 60°F. COP values as a function of outside temperature were taken from measured data of a ccASHP in Minnesota (CARD, 2017). From this data, 13,028 COP-hours across 5,998 hours was estimated, arriving at a seasonal average COP of 2.2. For SEER, a new ccASHP SEER of 18 was assumed, based on the average efficiency ratings of ccASHPs currently available on the market applicable to Wisconsin (Center for Energy and Environment, 2021). For residential units without air conditioning, the post-retrofit cooling energy use was assumed to be equivalent to the average cooling energy use of the same type of housing stock. Fan energy was estimated to be reduced by 15% based on improved efficiencies from an ECM (Electronically Commutated Motor).

Energy consumption after the retrofit was subtracted from the before-retrofit energy use to arrive at the estimated energy savings for each building type of interest. Before-retrofit energy use was pulled directly from the ResStock™ database. After-retrofit utility bill savings were calculated using average fuel rates (Table 1). Each rate was multiplied by the energy use by fuel type before and after the ccASHP retrofit. Utility costs after the retrofit were subtracted from the utility cost before the retrofit to arrive at total annual heating bill cost savings.

ASHP Upgrade Cost Estimates

ccASHP upgrade cost depends on the existing building type and heating system. The proposed air source heat pumps come in two styles – ducted split system and ductless mini-split system. A ducted split system resembles a typical air conditioner system that is associated with residential furnaces. In one possible arrangement, a cooling/heating coil is mounted in or near a furnace and uses the furnace fan to circulate air through the home (Figure 7).

Figure 7. Depiction of ducted split system heat pump with furnace[13]



The second style option is a ductless mini-split heat pump system. This system has its own indoor unit that is not associated with a furnace or air handler. It is located in the room it serves and can be mounted on a wall or ceiling. Figure 8 shows wall-mounted and ceiling-mounted configurations.

Figure 8. Depiction of a ductless mini-split heat pump system[14]

[13] https://www.furnaceacexperts.ca/heat-pumps/

[14] https://www.homedepot.com/p/Ramsond-18-000-BTU-1-5-Ton-Ductless-Mini-Split-Air-Conditioner-and-Heat-Pump-220V-60Hz-55GW2/203013148; https://www.compassheatingandair.com/ductless

For our upgrade cost estimates, if a unit's existing heating system already has ducts (e.g., a central furnace), a ducted heat pump air handler with electric resistance supplemental heat was proposed. The existing duct system is assumed to be adequate. If a unit's existing heating system did not have ductwork (e.g., electric baseboard heat), a ductless mini-split heat pump system was proposed with multiple heads. In one scenario the existing heating system is retained for the supplemental heat; in all other cases the electric heat is added.

The primary source for cost information was RSMeans. Material costs for cold climate heat pumps, which were not in RSMeans, were provided from a recent report for heat pump in Wisconsin (Center for Energy and Environment, 2021). Included in the cost estimates are the following: heat pump material cost, backup electric resistance heat, electrical upgrade costs (fuel heating only), furnace demolition (furnaces only), programmable thermostat(s) and labor. To account for costs of items that do not have readily available itemized costs, a certain percentage was added to the subtotal of the itemized costs. This added percentage ranged from 25-35% depending on the complexity of the system. A 5.5% sales tax was also added that includes the state sales tax of 5.0% and the county sales tax of 0.5%.

Material costs depended on the size of heat pump installed. For multi-family buildings, two 1-ton ductless split heat pumps are proposed. In actuality, this size may vary based on the need for heating and cooling. We assume one system serves the living room and the other serves a bedroom. Studio units may need only one system, while units with more bedrooms may need more systems.

For systems with furnaces, we assume each furnace is replaced with a 1.5-ton heat pump air handler with a 10 kW electric resistance heater for supplemental heat. In actuality this cost could be lower in cases where the existing furnace is adequate and the retrofit would be to add the heat pump coil, and for supplemental heat add an electric resistance heater or keep the existing heater. A full list of the upgrade cost by existing housing and system type can be found in Table 13.

Table 13. ccASHP Upgrade Cost by Housing and Heating System Type

Housing Type	Heating System Type	Total Units (Dane County)	New ccASHP Type	Upgrade Cost ($/Unit)

Multi-family (5+ Units)	Electricity Baseboard	12,877	Ductless	$8,698
Multi-family (5+ Units)	Electricity Electric Furnace	9,688	Ducted	$11,468
Single-Family Detached	Propane Fuel Furnace	7,482	Ducted	$16,458
Single-Family Detached	Electricity Baseboard	5,324	Ductless	$13,047
Single-Family Detached	Electricity Electric Furnace	4,053	Ducted	$11,468
Single-Family Detached	Propane Fuel Wall/Floor Furnace	2,710	Ductless	$15,380
Single-Family Detached	Fuel-oil Fuel Furnace	1,391	Ducted	$16,458
Single-Family Detached	Propane Fuel Boiler	719	Ductless	$15,380
Single-Family Detached	Fuel-oil Fuel Boiler	564	Ductless	$15,380
Mobile Home	Propane Fuel Furnace	432	Ducted	$16,458
Multi-family (2-4)	Propane Fuel Furnace	312	Ducted	$16,458
Multi-family (5+ Units)	Propane Fuel Furnace	276	Ducted	$16,458
Multi-family (5+ Units)	Propane Shared Heating	204	Ductless	$10,683
Mobile Home	Propane Fuel Wall/Floor Furnace	156	Ducted	$16,458
Single-Family Attached	Propane Fuel Furnace	156	Ductless	$9,394
Multi-family (2-4)	Propane Shared Heating	108	Ductless	$10,683
Single-Family Attached	Propane Fuel Wall/Floor Furnace	72	Ductless	$15,380
Single-Family Detached	Fuel-oil Fuel Wall/Floor Furnace	60	Ductless	$15,380
Multi-family (2-4)	Propane Fuel Wall/Floor Furnace	48	Ductless	$10,683
Multi-family (5+ Units)	Propane Fuel Wall/Floor Furnace	36	Ductless	$10,683
Multi-family (2-4)	Propane Fuel Boiler	24	Ductless	$10,683
Single-Family Attached	Propane Fuel Boiler	24	Ductless	$15,380
Mobile Home	Fuel-oil Fuel Furnace	12	Ducted	$16,458
Multi-family (5+ Units)	Propane Fuel Boiler	12	Ducted	$16,458
Multi-family (5+ Units)	Fuel-oil Shared Heating	12	Ducted	$16,458
Multi-family (5+ Units)	Fuel-oil Fuel Boiler	12	Ductless	$10,683
Multi-family (5+ Units)	Fuel-oil Fuel Furnace	12	Ductless	$10,683
Single-Family Attached	Fuel-oil Fuel Furnace	12	Ductless	$10,683

Carbon Savings Scenarios

The carbon savings are built on the energy savings results and compare the carbon impacts of the all-electric scenarios against what the emissions would be in the alternate fossil fuel scenarios. While many studies rely on EPA's eGrid for electricity emissions factors, eGrid numbers reflect the carbon intensity of the grid only at a current single point in time. For an electrification analysis, we believe using this type of static emissions factor gives an incomplete and inaccurate picture of carbon emissions. The carbon intensity of the grid changes every year and we expect that over the next 20 years the grid will get cleaner to some degree, and that change should be reflected in the carbon analysis.

In order to reflect these grid changes, we used the Cambium tool produced by the National Renewable Energy Laboratory (NREL). Cambium is a web-based tool that provides metrics for various modeled future scenarios. Since predicting the future is of course imperfect, we are using two different future scenarios for comparison in this analysis. The two scenarios are as follows:

- Business as Usual: also referred to as Mid-Case by NREL, this scenario uses current policies and default or mid-level assumptions to generate a reference case. This scenario reflects changes in the grid over time, but only changes that flow from the current business-as-usual factors and policies.
- Low Renewable Cost: this scenario is modeled using low costs for renewable energy, therefore increasing the share of renewables on the grid compared to other sources. Unlike business-as-usual, this scenario reflects shifts in the factors that influence the fuel mix of the grid. Given the likely policy and subsidy changes on the horizon, we feel this low-renewables cost scenario is a very likely and reasonable future model to use.

The Cambium tool produces an emissions factor for every even-numbered year in a given scenario. Assuming a 20-year lifetime for heat pumps, we averaged the factors from 2020-2040 to arrive at the single emissions factor shown in the table below. For fossil fuel emissions factors EIA values were used, as the carbon intensity of a particular fossil fuel does not significantly change over time. The following table reflects all emissions factors used in this analysis (Table 1414).

Table 14. Emission Factor Inputs Into Carbon Analysis Models

Fuel	Emissions Factors	Source
Electricity	1,027 lbs CO_2 per MWh, business as usual 782 lbs CO_2 per MWh, low renewable cost	Cambium
Propane	12.7 lbs CO_2 per gallon	EIA, 2021
Fuel-oil	22.5 lbs CO_2 per gallon	EIA, 2021
Natural Gas	121.3 lbs CO_2 per 1,000 cubic feet	EIA, 2021

Appendix B: Dane County Housing Stock

Table 1515 contains a full list of all the housing and heating type pairs in Dane County, sorted by prevalence. The Total Units (ResStock™ Sample) represents the count of the numbers of units for each housing/heating pair in the ResStock™ database, which provides the sample size for the basis of the analysis. The Total Units (Dane County) represents the total number of units for each housing/heating pair across Dane County. A constant weight of 11.99 is applied to calculate the total units across Dane County.

Table 15. Full List of Housing and Heating Types in Dane County

Housing Type	Heating System Type	Total Units (ResStock Sample)	Total Units (Dane County)	Percent of Non-Natural Gas Housing Stock
Multi-family (5+ Units)	Electricity Baseboard	1,074	12,877	16.8%
Multi-family (5+ Units)	Electricity Shared Heating[15]	948	11,367	14.8%
Multi-family (5+ Units)	Electricity Electric Furnace	808	9,688	12.6%
Single-family (Detached)	Propane Fuel Furnace	624	7,482	9.7%
Single-family (Detached)	Electricity Baseboard	444	5,324	6.9%
Single-family (Detached)	Electricity Electric Furnace	338	4,053	5.3%
Multi-family (5+ Units)	Electricity ASHP	300	3,597	4.7%
Multi-family (2-4)	Electricity Baseboard	277	3,321	4.3%
Single-family (Detached)	Propane Fuel Wall/Floor Furnace	226	2,710	3.5%
Multi-family (2-4)	Electricity Electric Furnace	204	2,446	3.2%
Multi-family (2-4)	Electricity Shared Heating	143	1,715	2.2%
Single-family (Attached)	Electricity Baseboard	122	1,463	1.9%
Single-family (Detached)	Fuel-oil Fuel Furnace	116	1,391	1.8%
Multi-family (5+ Units)	None	109	1,307	1.7%
Single-family (Detached)	Electricity ASHP	104	1,247	1.6%
Single-family (Attached)	Electricity Electric Furnace	64	767	1.0%
Single-family (Detached)	Propane Fuel Boiler	60	719	0.9%
Multi-family (5+ Units)	Other Fuel Shared Heating	52	623	0.8%
Single-family (Detached)	Fuel-oil Fuel Boiler	47	564	0.7%
Multi-family (2-4)	Electricity ASHP	44	528	0.7%
Mobile Home	Propane Fuel Furnace	36	432	0.6%
Multi-family (2-4)	Propane Fuel Furnace	26	312	0.4%
Single-family (Attached)	Electricity ASHP	24	288	0.4%
Multi-family (5+ Units)	Propane Fuel Furnace	23	276	0.4%
Multi-family (5+ Units)	Electricity Electric Wall Furnace	22	264	0.3%
Multi-family (5+ Units)	Electricity Electric Boiler	21	252	0.3%
Multi-family (5+ Units)	Propane Shared Heating	17	204	0.3%

[15] The Shared Heating category is from survey respondents self-reported type of heating system. These respondents reported a Shared Heating electric system, which had a similar energy profile to an electric baseboard system, and we assumed people reporting a Shared System had an electric baseboard system.

Single-family (Attached)	Propane Fuel Furnace	13	156	0.2%
Mobile Home	Propane Fuel Wall/Floor Furnace	13	156	0.2%
Mobile Home	Electricity Baseboard	10	120	0.2%
Multi-family (2-4)	Propane Shared Heating	9	108	0.1%
Single-family (Detached)	Electricity Electric Wall Furnace	8	96	0.1%
Single-family (Attached)	Electricity Shared Heating	7	84	0.1%
Single Family (Detached)	None	7	84	0.1%
Multi-family (2-4)	Other Fuel Shared Heating	7	84	0.1%
Multi-family (2-4)	Electricity Electric Wall Furnace	6	72	0.1%
Single-family (Attached)	Propane Fuel Wall/Floor Furnace	6	72	0.1%
Multi-family (2-4)	None	6	72	0.1%
Multi-family (2-4)	Electricity Electric Boiler	5	60	0.1%
Single-family (Detached)	Electricity Electric Boiler	5	60	0.1%
Single-family (Detached)	Fuel-oil Fuel Wall/Floor Furnace	5	60	0.1%
Multi-family (2-4)	Propane Fuel Wall/Floor Furnace	4	48	0.1%
Multi-family (5+ Units)	Propane Fuel Wall/Floor Furnace	3	36	0.0%
Single-family (Attached)	Electricity Electric Wall Furnace	2	24	0.0%
Multi-family (2-4)	Propane Fuel Boiler	2	24	0.0%
Single-family (Attached)	Propane Fuel Boiler	2	24	0.0%
Mobile Home	Electricity ASHP	1	12	0.0%
Single-family (Attached)	Electricity Electric Boiler	1	12	0.0%
Mobile Home	Electricity Electric Furnace	1	12	0.0%
Mobile Home	Electricity Electric Wall Furnace	1	12	0.0%
Multi-family (5+ Units)	Fuel-oil Fuel Boiler	1	12	0.0%
Mobile Home	Fuel-oil Fuel Furnace	1	12	0.0%
Multi-family (5+ Units)	Fuel-oil Fuel Furnace	1	12	0.0%
Single-family (Attached)	Fuel-oil Fuel Furnace	1	12	0.0%
Multi-family (5+ Units)	Fuel-oil Shared Heating	1	12	0.0%
Multi-family (5+ Units)	Propane Fuel Boiler	1	12	0.0%
Single Family (Attached)	None	1	12	0.0%
Mobile Home	None	1	12	0.0%

Appendix C: Relationship between heating fuel and income in Dane County

In addition to examining the relationship between income and electric space heating, this relationship was examined for other heating fuels including natural gas, propane, and fuel-oil. Unlike electric resistance heat, the relationship between natural gas, propane, and fuel-oil with income was not clearly evident (Figure 9, Figure 11) or did not appear linear (Figure 10). All graphs were made using data from the 2019 ACS.

Figure 9. Census tract median household income versus percent units with natural gas heat

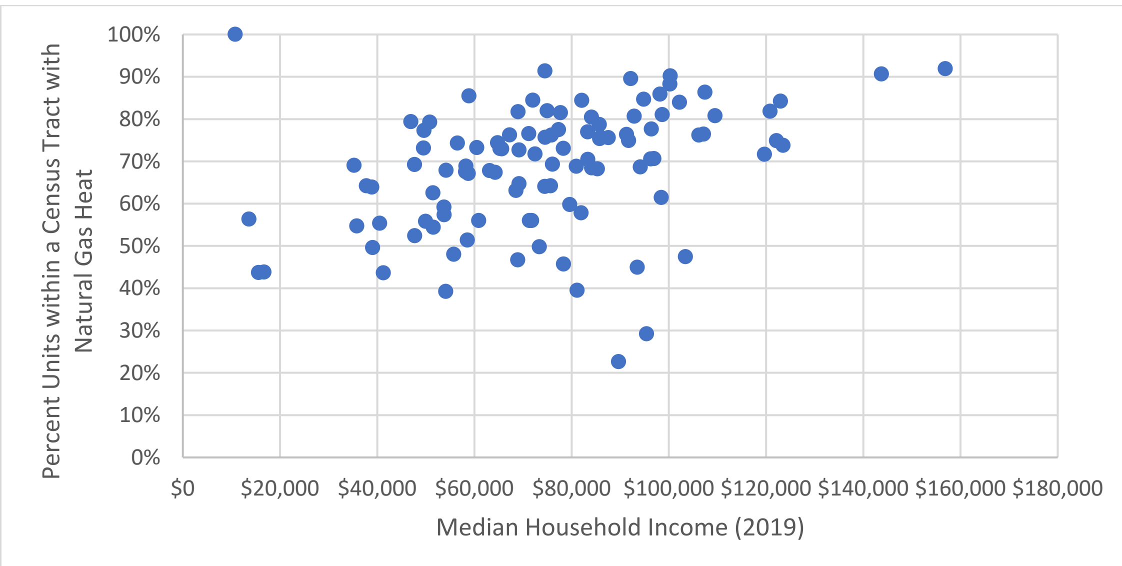


Figure 10. Census tract median household income versus percent units with propane heat

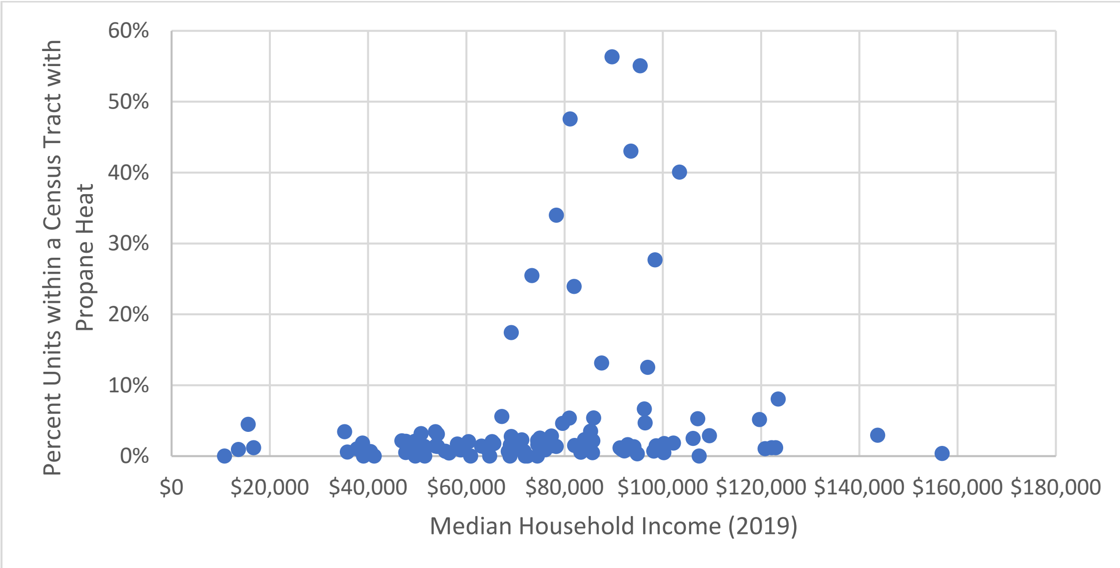
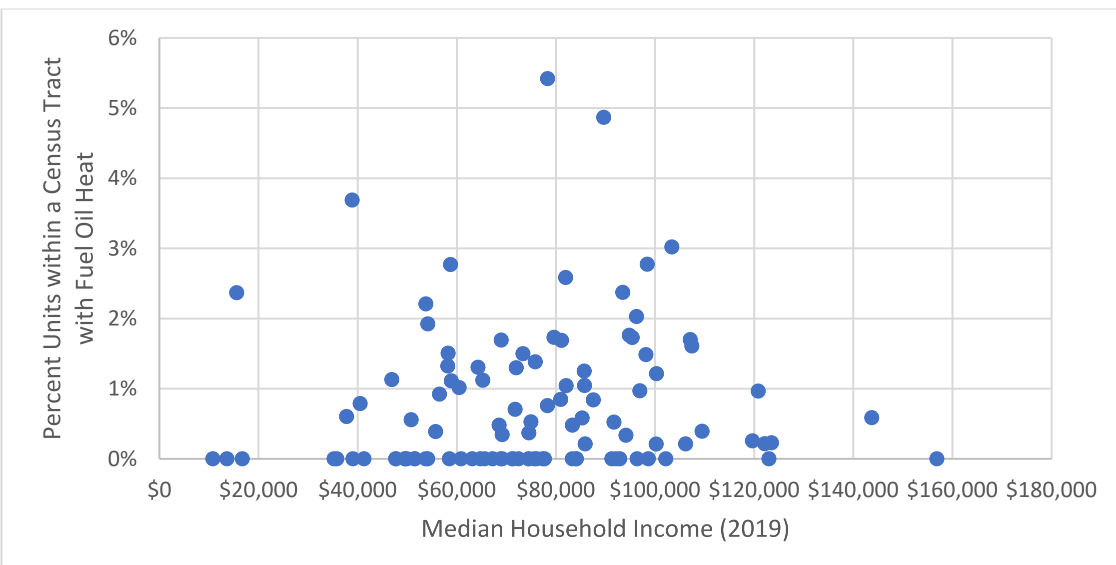


Figure 11. Census tract median household income versus percent units with fuel-oil heat



Appendix D: Recruitment outreach example