Residential Heat Pump Breakeven Analysis

Presentation to the Michigan EWR Collaborative

March 15, 2022

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Project Background

- In support of GHG emissions reduction in the buildings sector, electric heat pumps (HPs) have seen renewed interest for residential and commercial space conditioning, even in colder climates such as Michigan.
  - HPs can offer substantial GHG emissions savings when supplied with low carbon electricity.
- The national HP penetration rate for residential space heating is 13% today.*
  - Some US regions (South – HP penetration rate of 24%), are well suited for HP adoption due to favorable climate and fuel costs.
  - The Northeast and Midwest (HP penetration rate of 4% each) face adoption challenges due to colder climate and potentially unfavorable economics.
- Electric HPs have very small market share in MI – with only 3% of existing homes using an electric HP as the primary heating equipment (2020 MI Residential Baseline Study, RECS 2015 suggests ~1%).

Primary heating fuel source for existing homes in Michigan - 2015

Natural Gas	77%
Electricity	9%
Heat Pump	***1-3%***
Propane	9%
Other Fuels (wood)	4%
Fuel Oil	1%

Source: RECS 2015, 2020 MI Baseline Study

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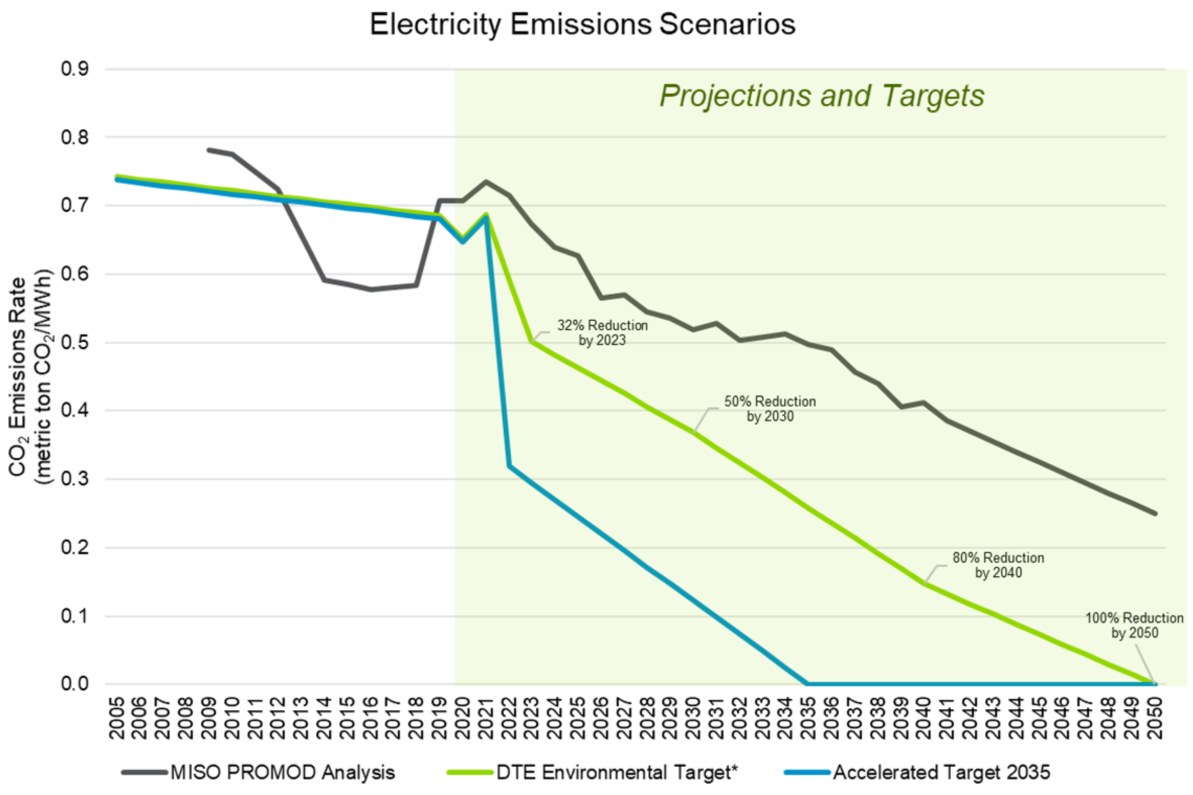
*percentage of homes that use HPs as primary heating equipment – RECS 2015

Project Goals and Objectives

- Although existing studies suggest that HPs are unlikely to provide lifetime cost savings to MI consumers in the near term, HPs align with long-term decarbonization goals in the state.
  - As the state's electric grid decarbonizes, the GHG emissions savings from HPs will grow.
  - Electric grid decarbonization, changes in energy prices, technological improvements in HPs, and increased market acceptance are just a few factors that might change the economic outlook for heating electrification in the future.



To help DTE better understand the outlook of HPs when replacing electric resistance, propane, fuel oil, and natural gas heating, Guidehouse conducted an analysis across the multiple HP systems and building types to determine break-even points for lifecycle cost, lifecycle emissions, and other factors.

Methodology Overview

User Inputs

- Baseline space and water heating system
- HP replacement system
- Efficiency Level
- Vintage
- Type of housing (SF, MF)
- Location
- Electrical and other upgrades required
- Gas pipeline cost avoided

Data Inputs*

- Equipment Costs
  - Installed cost
  - Maintenance cost
  - Upgrade cost
- Utility rates (low, current, high)
- Delivered fuel rates (low, current, high)
- Weather data
- GHG emissions rate (MISO, DTE, accelerated 2035)

Analysis

- Heat pump COP and capacity degradation analysis**
- Cost analysis
  - Installed costs
  - Operating costs
  - Lifecycle costs
- GHG emissions analysis
  - Annual emissions
  - Lifecycle emissions

**HP performance depends on outdoor ambient temperatures and will decrease at lower outdoor temperatures in winter. To model the requirement for back up electric resistance heat, the HP performance degradation needs to be modeled to location-specific outdoor temperatures.

Outputs

- Cost comparisons for baseline and HP systems
  - Installed costs
  - Operating costs
  - Lifetime costs
- Emissions comparisons for baseline and HP systems
  - Annual emissions
  - Lifecycle emissions
- Breakeven analysis for HP vs. baseline
  - Cost breakeven
  - Emissions breakeven

*Aligned with MEMD prototypes as closely as possible including coordinating with the Morgan Marketing Partners team on MEMD building simulation outputs. See next slide for details.

Methodology: Residential Prototypes

Parameter	Vintage	Housing type	Location	Fuel types	Efficiency	Modeling Scenarios
Number	3	2	7	5	2	3

Description	• **Existing** (Pre 1978 construction)
	• **Existing** (1978-2015 construction)
	• **New construction** (Recent construction conforming to the Michigan State Uniform Energy Code)
		• **Single family** 2 story house, 2930 sq. ft.
		• **Multi-family** 950 sq. ft. per unit
			• **Detroit, MI**
			• **Traverse City**
			• **Alpena**
			• **Muskegon**
			• **Saginaw**
			• **SS Marie**
			• **Lansing**
				• **Gas**
				• **Propane**
				• **Oil**
				• **Electric resistance**
				• **Electric HP**
					• **Standard Efficiency** (Current DOE energy conservation standards)
					• **High Efficiency** (ENERGY STAR specifications)
						• **Grid Electricity Emissions factors**
						  • Current projections (MISO projections)
						  • DTE targets
						  • 2035 Accelerated targets
						• **Fossil fuel prices** (low, high, current)
						• **Electricity prices** (low, high, current)

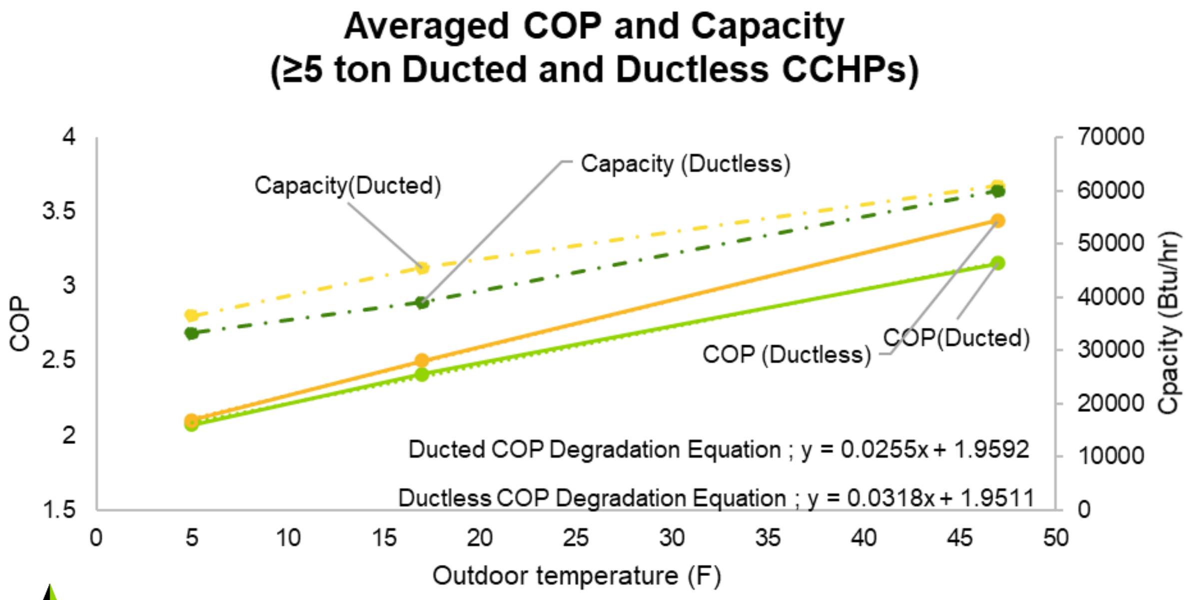
Data Sources*	• *Michigan Energy Measures Database (MEMD) Weather Sensitive Support Document 2020*	• *Michigan Energy Measures Database (MEMD) Weather Sensitive Support Document 2020* • ***Building loads* :** *2016 DTE studies of energy efficiency potential of natural gas and electricity*	• *TMY3 Weather data* *Weather data was used to model the HP performance degradation as outdoor temperature decreased*	• *EIA Technology Forecast Updates* • *MEMD*	• *EIA Technology Forecast Updates* • *NEEP database (for cold climate HP efficiency)*	• *EIA Annual Energy Outlook 2021* • *Current fuel and utility prices from EIA* • *Grid Electricity Emission factors** from DTE projections and MISO projections****

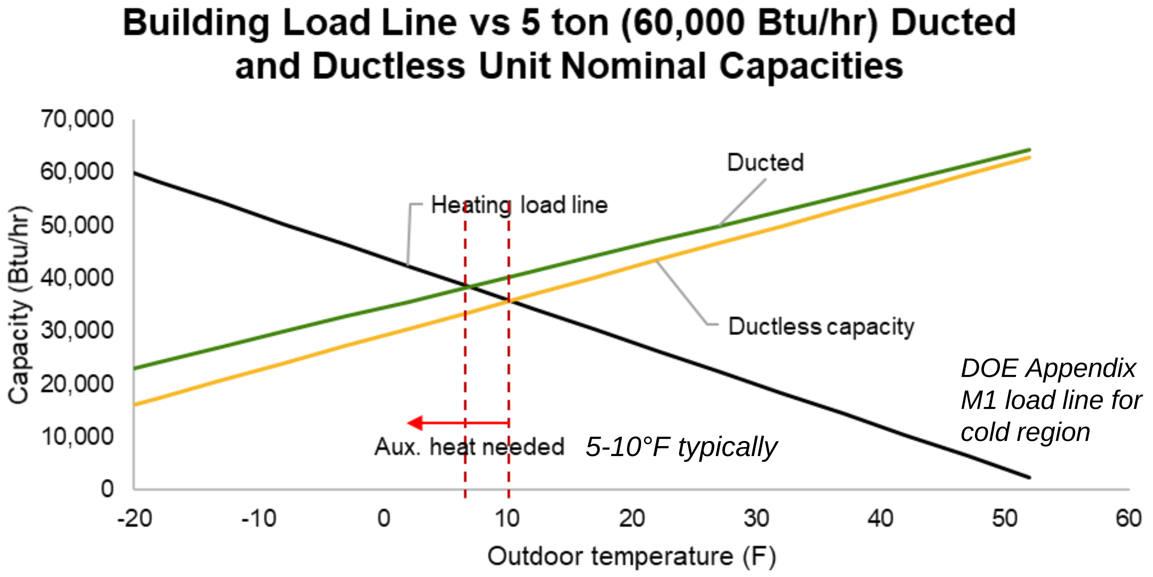
* Electricity loads (in kWh) were converted to MMBtu by using the factor of x 3,412 to compare with fuel-fired loads
**Detailed descriptions of the emissions scenarios and data sources used can be found in the Appendix
*** GHG emissions forecast for MISO electric generation based on August 2021 Guidehouse research to evaluate GHG emissions impact for lifetime EWR savings.

Methodology: CCHP Performance Modeling

Guidehouse modeled heat pump performance as a function of temperature using Michigan weather data and performance curves from the Northeast Energy Efficiency Partnership (NEEP) database and manufacturer literature. *The availability of lab-verified CCHP performance data will improve in future years with recent changes to DOE and ENERGY STAR test standards.*

COP and Capacity	HP Performance in Michigan Weather	HP Energy Consumption
1) Used COP and capacity data for 24-60 kbtu/hr (2-5 ton) ducted and ductless CCHP units from the NEEP database 2) Determined COP and capacity degradation equation as a function of outdoor temperature	3) Mapped COP degradation equation onto TMY3 weather data for each MI city / climate region to evaluate heating demand and COP in each temperature bin. 4) Determined switchover temperature (0°F as default) and required make-up capacity from auxiliary electric resistance heating (COP = 1).	5) Calculated consumption (kWh) for heat pump and resistance heat 6) Summed heat pump and resistance heat consumption to obtain overall electricity consumption





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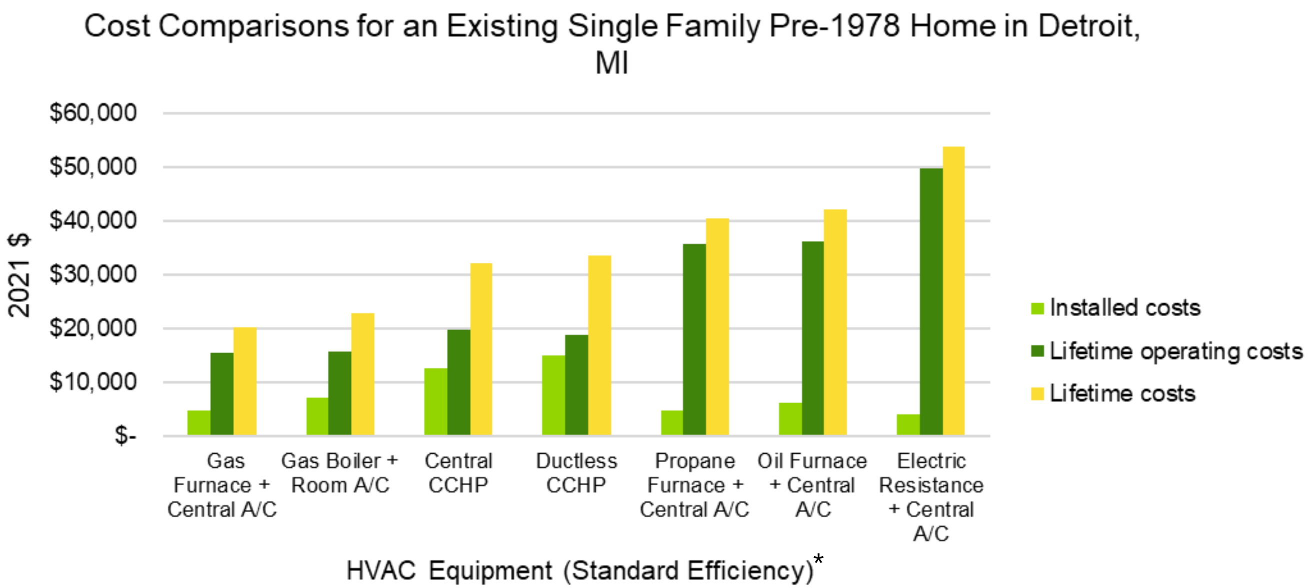
Results: HVAC and WH Costs

Data inputs:

Elec. rates: Current
Fossil-fuel rates: Current
Electric upgrades: Not Required
Gas pipeline: Not avoided

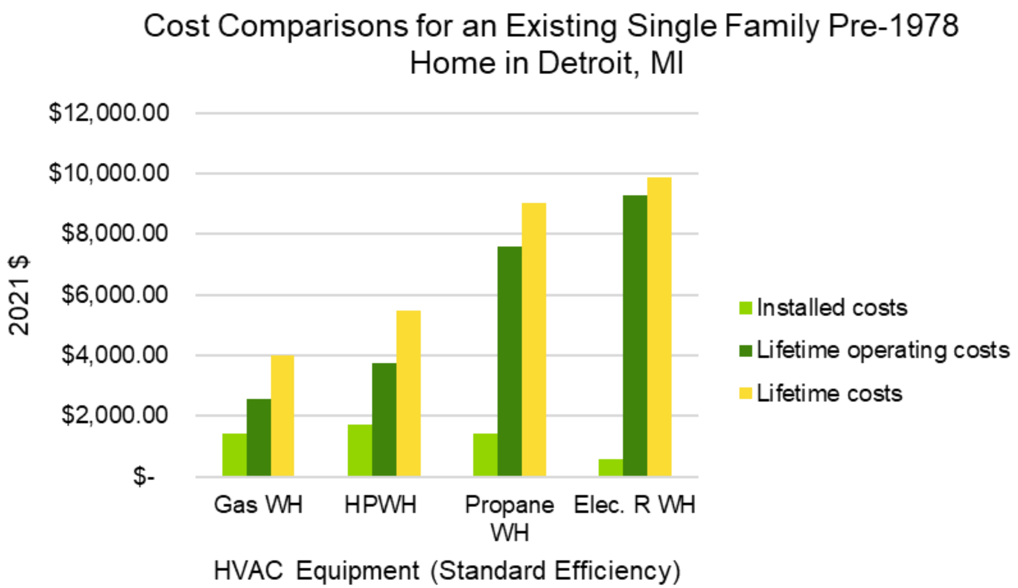
Existing Single-Family Pre-1978 Home in Detroit, MI – *results are largely representative of all scenarios.*

Space Heating



- Central CCHP have **lower lifecycle costs** than oil & propane furnace and electric resistance heating, but **higher lifecycle costs** compared to gas furnace and boilers.
- A gas furnace/AC system has **lower lifecycle cost** than a central CCHP over a 15 yr. lifetime, primarily due to **upfront cost differences**.
- Existing homes may require **electrical system upgrades** (e.g., panel, wiring) of around **$2,500** when replacing a fuel-fired option with an electric HP system.
- All-electric new construction can save up to **$6,000** in **avoided gas pipeline costs.**

Water Heating



- HPWHs have a **lower lifecycle cost** compared to propane and electric resistance WHs, but **higher lifecycle cost** compared to gas.
- Existing homes with gas WHs may require **minor electrical system upgrades** (e.g., dedicated 110 or 220V line) when switching to a HPWH (upgrades likely only needed once for both SH and WH and more recent vintages i.e 1980s-1990s may avoid this altogether)
- The **lifecycle cost difference** between gas WH and HPWH is **~$2000**.

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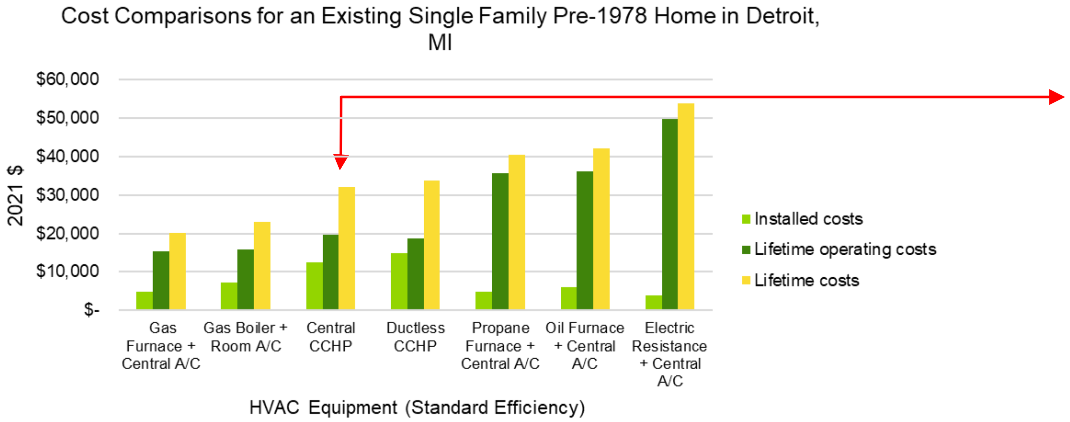
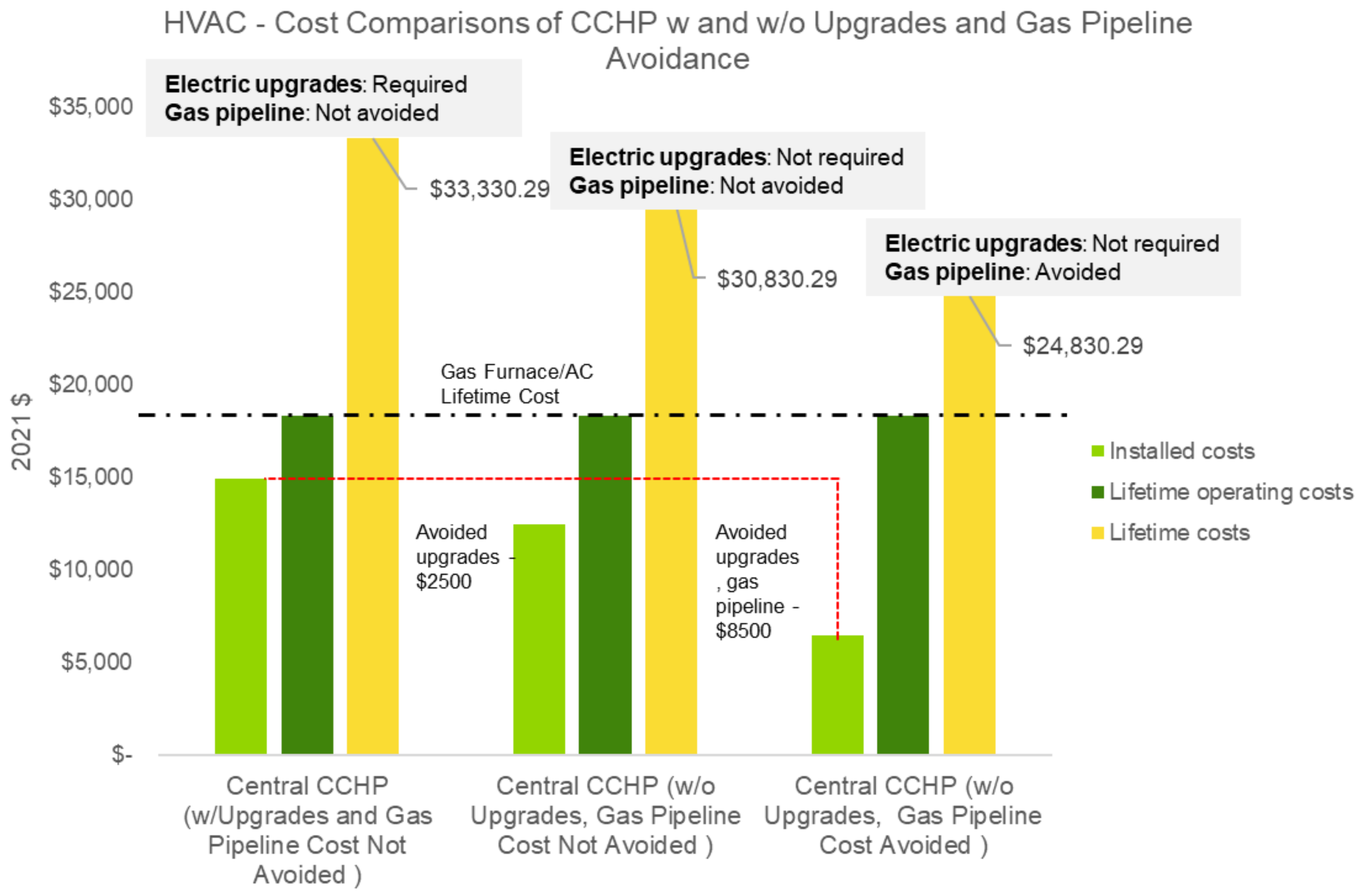
Results: HVAC and WH Costs

Electrical upgrade needs and the ability to avoid gas pipelines can significantly shift the economics for electric HPs.
Federal, state, utility or other incentive programs can also reduce lifecycle costs by lowering upfront installed costs.



- HP installed costs can range **by about $8,500** depending on whether electric upgrades are needed and gas pipeline costs can be avoided for new construction.
- Details on the sensitivities for these upgrade costs and savings can be found in the Appendix.
- Even with this consideration, a central HP is more expensive compared to a gas furnace + A/C over a 15 yr. lifetime. However, the cost differential between the two is now only **~$4,500**.



Many Older Homes Pre-1978 (< 100amp panel / service)	**Most Newer Homes Post-1978** (150-200 amp panel / service)	**All-Electric New Construction** (150-200 amp panel / service)

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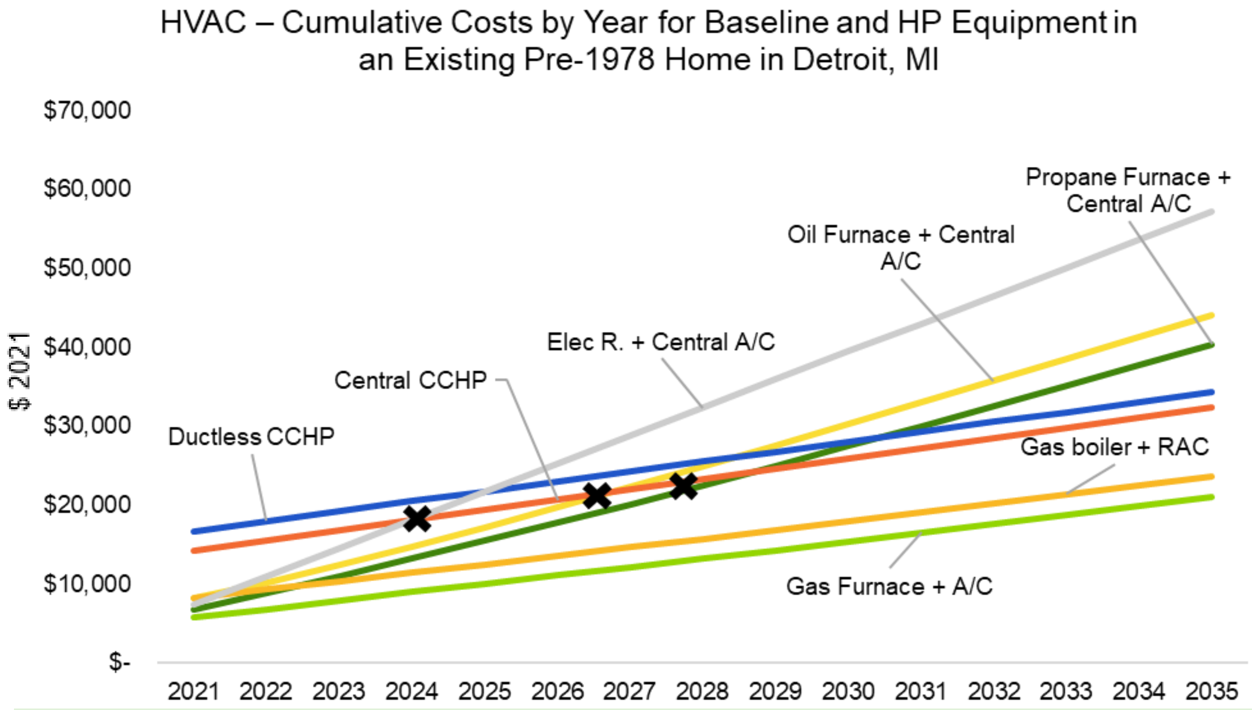
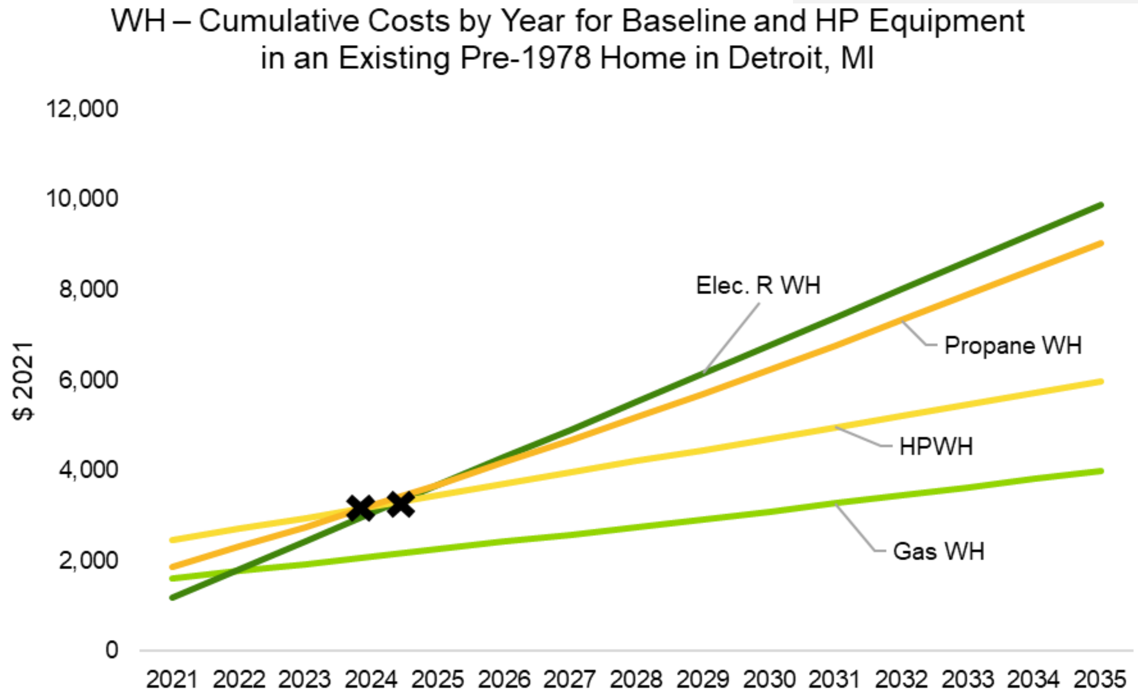
Results: HVAC and WH Cost Breakeven Points

Data inputs:

Elec. rates: Current
Fossil-fuel rates: Current
Electric upgrades: Not Required
Gas pipeline: Not avoided

Existing Single-Family Pre-1978 Home in Detroit, MI





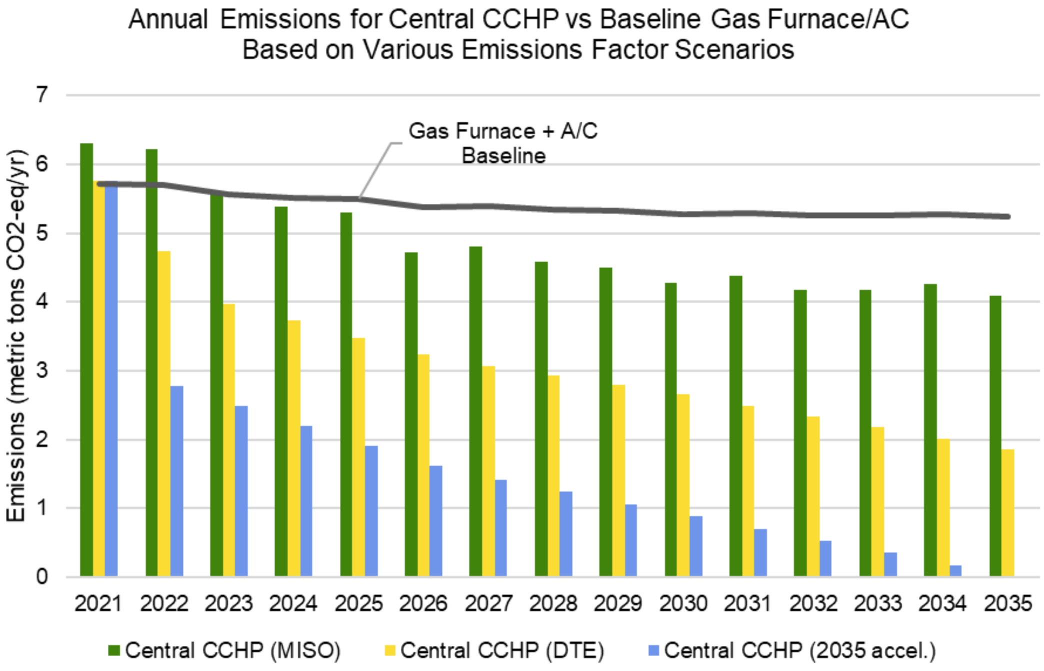
- Central CCHP (installed in 2021) **breaks even** with:
  - Electric resistance heating/AC in **4 years,**
  - Oil furnace + A/C in **7 years,** and
  - Propane furnace + A/C in **8 years**
  - Natural gas furnace + A/C **no payback**
  - Sensitivity around delivered fuel costs and electricity rates can shift this breakeven by **±2 years. Necessary or avoided infrastructure costs will also shift payback.**
- Upfront incentives would reduce installed cost and lead to earlier payback.

- HPWHs **do not breakeven with gas WH** for the duration of the equipment lifetime for any period in this analysis.
- Sensitivity around gas and electricity rates does not change this result.
- HPWH (installed in 2021) **breaks even** with propane WH and elec. R WH in **3 years.**

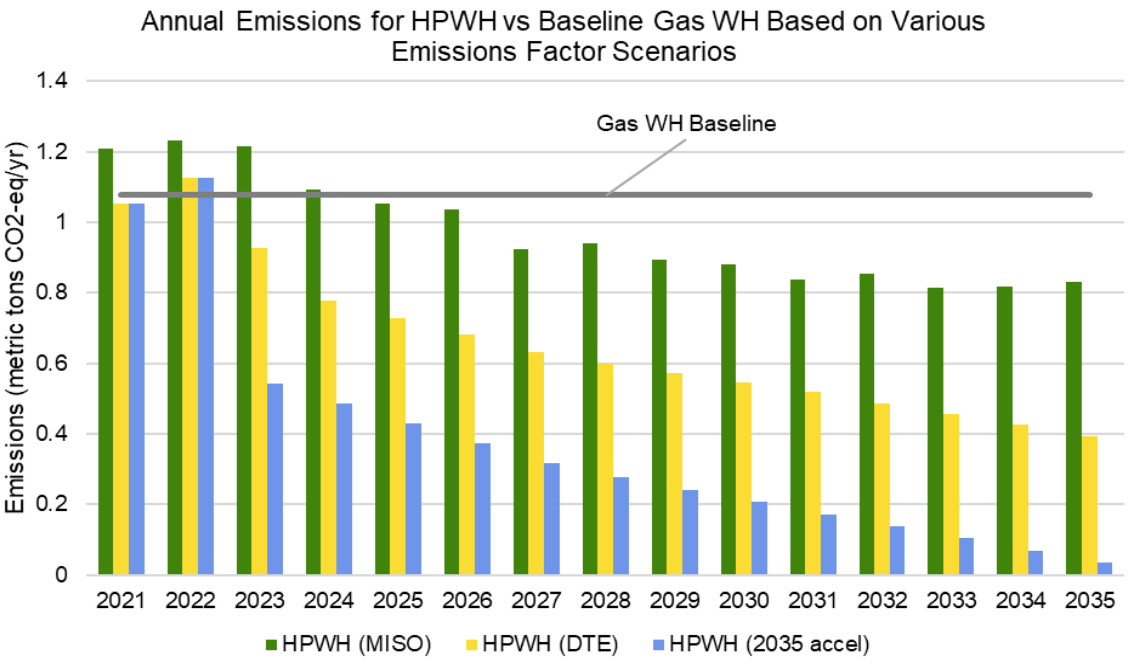
Results: HVAC and WH Annual Emissions

Existing Single-Family Pre-1978 Home in Detroit, MI – *results are largely representative of all scenarios.*

Space Heating



Water Heating



- All three electricity emissions factor forecast scenarios* show **decreases in heat pump emissions** over time with the **2035 accelerated targets** being the most aggressive.
- Central CCHPs (installed in 2021) have lower annual emissions starting immediately (2021) per the DTE and 2035 accelerated electricity emissions targets, and lower total emissions starting 2023 per the MISO model.

- All three electricity emissions factor forecast scenarios* show a **decrease in water heating emissions over time** with the 2035 accelerated projection being the most aggressive.
- HPWHs (installed in 2021) has lower annual emissions starting immediately (2021) per the DTE and 2035 accelerated targets, and lower emissions starting 2025 per the MISO model.

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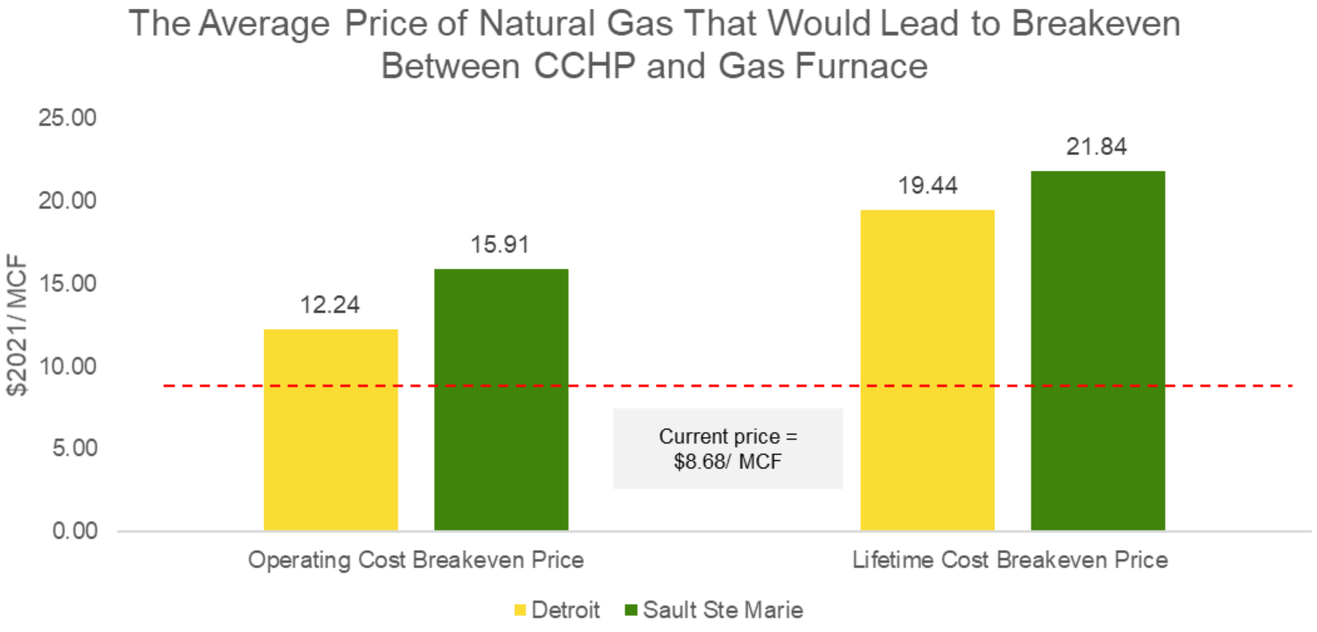
*Detailed descriptions of the emissions scenarios (MISO, DTE, 2035 accelerated) and data sources used can be found in the Appendix

Analysis: Natural Gas Price Breakeven

- For the DTE breakeven analysis , the natural gas price was modeled as $ 8.68 per MCF delivered to MI residential customers (2020 annual).*
- Guidehouse investigated what future natural gas prices would achieve operating cost and lifecycle cost parity with CCHP systems.
- The graph on the right shows the absolute values of the natural gas prices required for parity:
  - **Operating cost breakeven is $12 – 16 per MCF,**
  - **Lifetime cost breakeven is $19 – 22 per MCF.**
  - Colder climate in Sault Ste Marie pushes the price to the upper bound, because of the performance degradation of the CCHP at lower temperatures (i.e., more electric resistance)
- These 'breakeven' gas prices represent a significant increase from the base value of $8.68 per MCF. The table to the lower right shows the % increase required from the base price to reach these parity prices. In some cases, the breakeven gas price is more than double today's rates (i.e., greater than 100% increase).
- Natural gas rates may increase due to future supply shortages, stranded asset costs, Renewable Natural Gas (RNG) requirements, carbon taxes, or other market effects.

*Natural gas prices for Michigan and nationally are from the US EIA



NG price %increase needed to breakeven with CCHP ($) – Current model price = $8.68/ MCF				
Location	**Breakeven type**	**Existing (Pre-1978)**	**Existing (1978-2015)**	**New Construction (post-2015)**
Detroit	Operating cost breakeven	40%	41%	42%
	Lifetime cost breakeven	115%	123%	134%
Sault Ste Marie	Operating cost breakeven	83%	83%	84%
	Lifetime cost breakeven	159%	149%	147%

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CCHP Cost Estimates and Sensitivity

- Although utility cost differences are the most significant factor in this analysis, assumptions for installed cost also contribute to the lifecycle cost comparison between technologies.
- Whole-home CCHPs are still a relatively new technology, particularly in the Midwest, so detailed installed cost estimates for MI are unavailable. Nevertheless, several resources provide CCHP cost examples and highlight the large range in estimates.

CCHP Cost Resources	CCHP Installed Cost	Details	Link
Estimate Used in This Study	$12,500	• Based on NYSERDA study below, and upsized to a 4-5 ton model	n/a
NYSERDA Renewable Heating and Cooling Framework (2017)	$12,000	• 3 ton model, Table 4.4	Link
NYS Carbon Neutral Buildings Report (2021)	$15,000-$20,000 (2x installed cost as gas baseline)	• HVAC+WH equipment costs for cold climate systems are at least 2x the cost of the gas/oil baseline equipment • The study also analyzes how significant shell improvements can lower this cost premium by using smaller capacity HVAC equipment (although shell upgrades have high cost).	Link
MassCEC ASHP Comparison Tool (2021)	$3,694 / ton	• Entries based on incentivized projects • Median project size 2.1 tons, project cost $3,694 per ton	Link
MassCEC Whole Home Heat Pump Solutions (2021)	>$18,000	• $18,400 per home average for 1,603 SF per home over 168 projects • Only covered HVAC, not water heating	Link
MEEA You're Getting Warmer (2018)	>$9,000	• 10.5 HSPF ccASHP cost $9,406 national average with range of $8,878 to $11,690 for the cities studied.	Link

Results Summary

While system efficiency, location, fuel & electricity rates influence the results of each analyzed scenario, the following insights are largely representative of all scenarios considered.

Cost Breakeven Point

Space Heating & Cooling

- Central cold-climate heat pump (CCHP) and ductless CCHP costs **do not breakeven with gas furnace + A/C** or **gas boiler + RAC**.
- Central CCHP (installed in 2021) **breaks even in 4-9 years** with electric resistance, oil, and propane heating w/ AC systems
- This happens because natural gas rates are low, electricity rates are relatively high and delivered fuels are expensive

Water Heating

- HPWH costs **do not breakeven with gas WH** for the duration of the equipment lifetime. Sensitivity around gas and electricity rates does not change this result.
- HPWH costs (installed in 2021) break even with electric resistance WH costs in ~**3 years.**

Emissions Breakeven Points

Space Heating & Cooling

- Central CCHPs (installed in 2021) have **emissions benefits** compared to electric resistance, oil, and propane **starting immediately for all electricity emissions scenarios.**
- Central CCHP and ductless CCHP (installed in 2021) emissions break even with gas furnace + A/C and gas boiler+ RAC **in 0-2 years** (DTE targets) and in **3-10 years** (MISO scenario) – with the upper range representative of colder cities (such as SS Marie).

Water Heating

- HPWHs installed in 2021 have **emissions benefits** compared to electric resistance WH starting immediately for all projections.
- Emissions breakeven with gas WH occurs in **2028** (MISO scenario) and in **2022** (DTE targets)

- Given the low natural gas rates in Michigan, gas customers would likely not see lifetime economic savings from heating electrification unless CCHPs and HPWHs cost significantly less than gas-systems because of the operating cost premium for HP systems.
- Upfront cost incentives and avoiding gas pipeline costs (e.g., new construction) can shift the upfront cost outlook for CCHPs.

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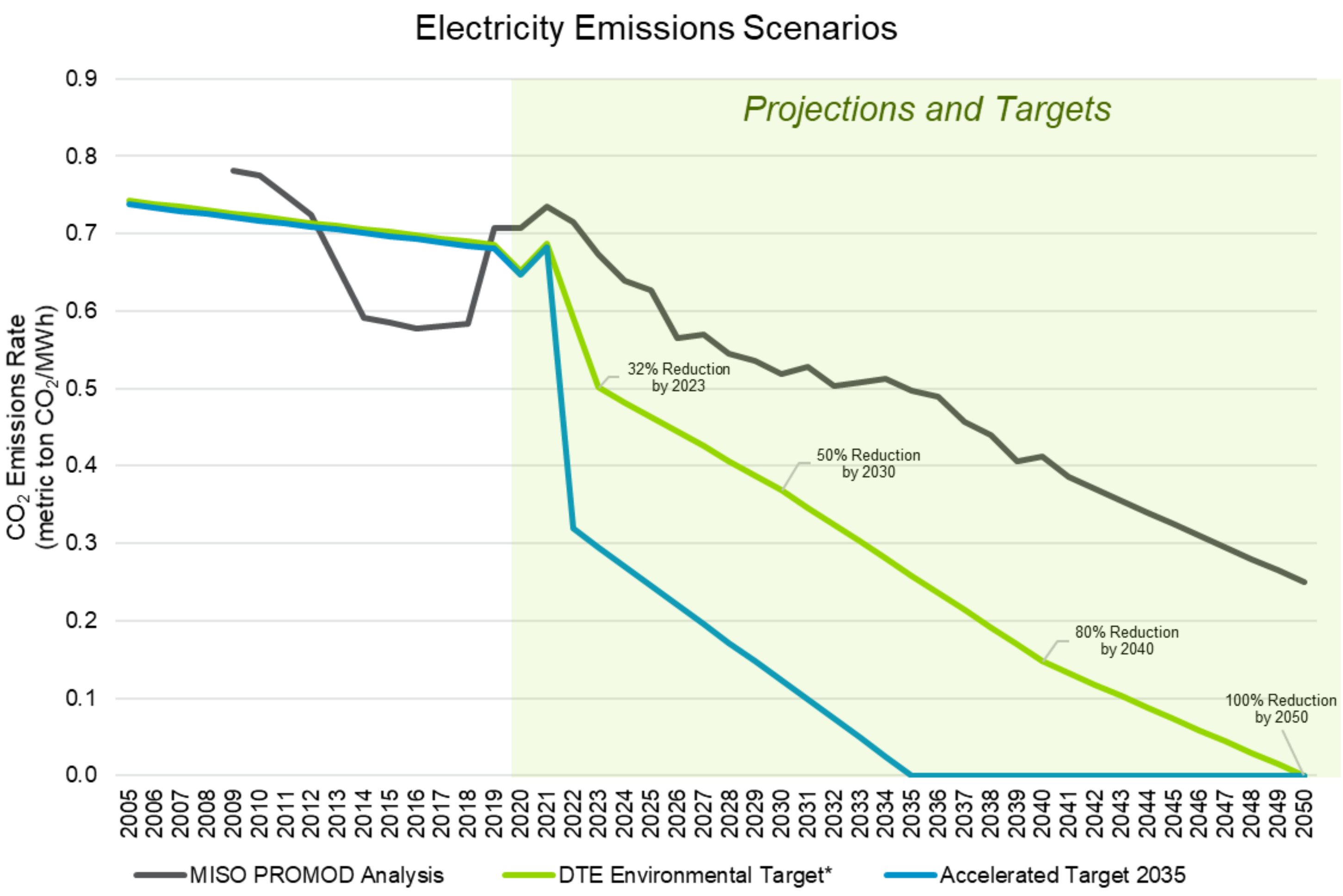
Electricity Emissions Scenarios



- This study examined three electricity emissions scenarios
  1. **MISO Analysis**
     - GHG emissions forecast for MISO electric generation based on August 2021 Guidehouse research to evaluate GHG emissions impact for lifetime EWR savings
  2. **DTE Environmental Targets**
     - Zero-emissions by 2050
  3. **Accelerated Targets 2035**
     - Zero-emissions by 2035

**DTE Environmental Targets use 2005 as the baseline for reductions*

Sensitivities for Technology Cost Comparison

- Depending on the site-specific situation, installing electric heat pumps may require changes to the building infrastructure, which can increase or decrease costs substantially.
- Some homes may need infrastructure upgrades for HPWH (up to $500 for condensate line and dedicated 110/220V line) and full electrification ($2,500 or greater for panel and service line upgrades). The number of homes that would need upgrades and their cost is highly uncertain.
- New construction could avoid the gas line or fuel storage with all-electric designs, which may save consumers approximately $6,000.

Impact on Electrification Cost	Cost Sensitivity	Potential Situations	Cost Range (Res-Com)
Increases Costs & Decreases Attractiveness	Wiring Upgrades (Water Heating) – installing 110V or 220 V outlet near HPWH	Existing buildings with gas WH	$300 (R), $700 (C) based on 2019 E3 (Link) and 2016 TRC (Link)
	Condensate Piping (Water Heating) – piping / pump to floor or laundry drain	Existing buildings with gas / electric WH	$200 (R), $200 (C) based on 2019 E3 (Link) and 2016 TRC (Link)
	Airflow Requirements (Water Heating) – installing louvered doors or airflow ducts if located in small space	Existing buildings with electric WH	Varies
	Panel / Service Upgrades – increasing from 60-100A to 200A panel, and may require upgraded connection from utility	Older homes, especially without central AC	Varies, est. $4,000 (R), $0 (C) based on 2019 E3 (Link) 2016 TRC (Link)
	Decommissioning Costs for Fuel Storage	Existing buildings with oil / propane	Varies, removing gas meter may have costs for former gas customers
	Complicating Factors Not Considered in Analysis (no ducts, hydronic heating, high-rises, backup electric needs)	Wide variety	Varies, can add significant cost
Decreases Costs & Increases Attractiveness	Avoided Gas Line and Fuel Storage (all-electric for heating, water heating, cooking, laundry, and misc. loads)	New all-electric buildings	$6,000 (R), $12,000 (C) based on 2019 E3 (Link) 2016 TRC (Link)

Key Data Sources

- **Weather**
  - TMY3 data set for all seven MEMD climate regions (publicly available at: Whitebox)
- **Building load**
  - MEMD (primary source)
  - Michigan Energy Efficiency Studies (secondary check)
    - Gas study
    - Electric study
  - Data from Morgan Managing Partners
- **Equipment costs**
  - EIA Technology forecast updates
  - Except for CCHP units
- **Efficiency**
  - EIA Technology forecast updates
- **Residential Prototypes**
  - MEMD
- **Utility rates**
  - Current rates
    - DTE electricity rates
    - Michigan natural gas rates
  - Projections: EIA AEO2021
    - Electricity
    - Natural Gas
- **Delivered fuel prices**
  - Current prices
    - Heating oil
    - Propane
  - Projections: EIA AEO2021
- **GHG emissions factors**
  - ISO Level (MISO) from eGRID (2009-2018); ISO Level (MISO) from Guidehouse PROMOD Analysis (2019-2040)
  - DTE targets