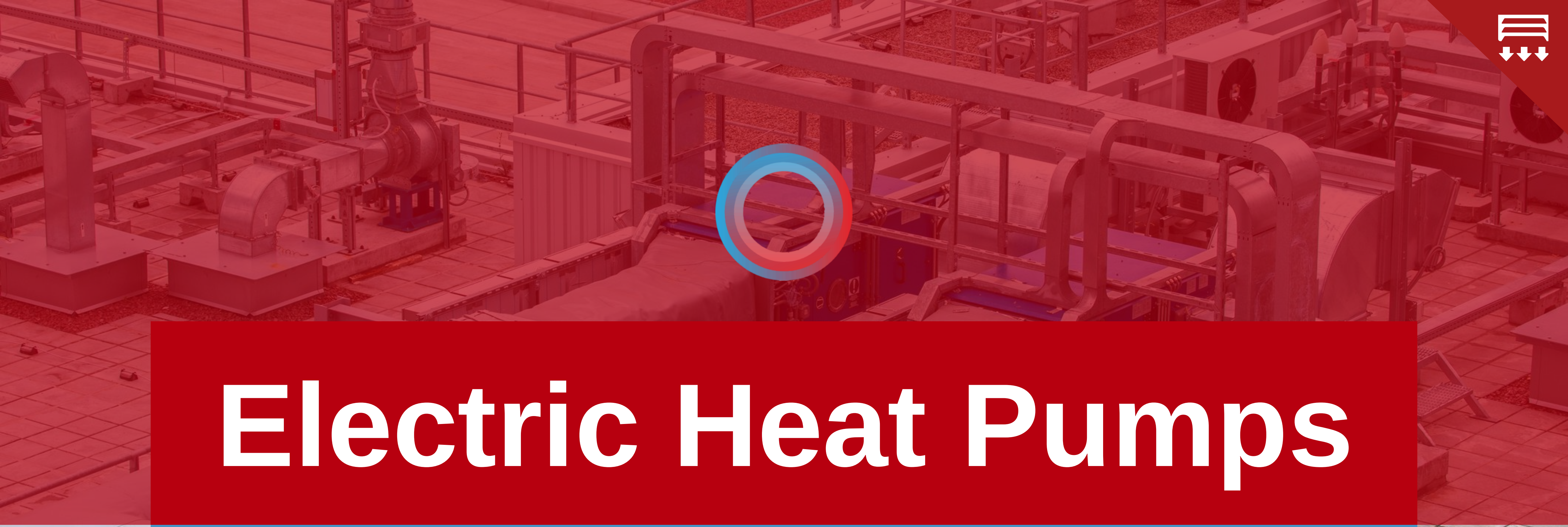


Electric Heat Pumps

Renewable Thermal Technology

RENEWABLE
THERMAL
COLLABORATIVE

Technology Overview

Description of technology

- Heat pumps transfer heat from the surroundings (e.g., ground, air, water) or waste heat streams for process applications
- Electricity drives the heat pump's mechanical compression cycle to allow heat to be provided to industrial processes at desired temperatures

Electricity ↓

Heat source: Lower temperature → **Heat Pump** → **Heat delivered:** Higher temperature

- The amount of heat supplied is typically greater than the amount of electricity consumed and is expressed as the Coefficient of Performance (COP), which is the ratio of heat delivered to the input electrical energy

Types of equipment

- Mechanical vapor compression (MVC) and absorption constitute the primary forms of industrial electric heat pumps. Examples include:

Air source heat pump[2]

Water source heat pump[3]

Absorption heat pump[4]

Technical characteristics

- **Temperature range:** Up to 160 ºC
  - Most heat pumps can deliver heat up to 100 ºC at high efficiency
  - Meets low temperature industrial heating requirements (e.g., drying, washing, preheating)
  - Systems capable of providing temperatures above 200 ºC are expected by 2030
- **Heat flux:** Low to medium
  - Dependent on size and configuration of mechanical compression system
- **Heated materials:** Most materials are applicable
  - Heat pump condensers may be in direct contact with the heated medium (e.g., water, process fluids, air)
- **Emissions:** Emissions savings are likely expected in nearly all states today by switching from natural gas combustion to electric heat pump heating using grid electricity
- **Technical maturity:** Medium to high maturity
  - Heat pumps are a mature technology used for building space and water heating
  - Industrial heat pumps with higher temperature ranges and heat transfer rates are nascent but growing in prevalence

1. ARENA - Renewable energy options for industrial process heat; 2. Sprsun High Temperature Industrial Air Source Heat Pump; 3. H.Stars Group Scroll Water Source Heat Pump; 4. York YHAP-C Absorption Heat Pump. Note: Other industrial heat pumps use waste heat streams or gas combustion (e.g., mechanical vapor recompression, thermal vapor recompression). Since they use natural gas combustion or are characterized as efficiency improvements rather than stand-alone sources of heat, these systems are not discussed further in this analysis.

Due to their low temperatures, heat pumps are limited to lower temperature applications in the food sectors or preheating process streams

Key properties of solar thermal heating include:

160 °C max. temp.

Low to medium heat flux

Heats most materials

These properties align with requirements for several process heating applications.

Industry Sector	Process Heating Applications						Relevant Equipment
Refineries	Distillation	Reactors					
Chemicals	Distillation	Drying	Reactors				
Iron & steel	Pelletization	Hot rolling	Basic oxygen furnace	Blast furnace			
Food	Drying	Pasteurizing	Boiling	Sterilizing	Washing	Cooking	Air heater, boiler, oven
Paper	Stock steaming	Drying	Wood processing	Evap. & chem. prep.	Lime calcination		
Cement	Pre-heating & treating	Melting furnace	Forming	Annealing	Kiln combustion		

Not applicable | Potentially applicable | Currently deployed

Industrial heat pumps are primarily used for food processing, but are not currently widely deployed

A combination of factors may make electric heat pump heating attractive. These include:

Emissions and operating cost savings

- High efficiencies (i.e., COP)

Specific heating application requirements

- Precise heating controls
- Stringent health or safety standards

Resource availability

- Low electricity prices relative to natural gas prices
- Consistent and readily available source of waste heat

Practically applicable sectors & locations

- Potentially viable and applicable deployment of electric heat pump industrial heating include:
  - **Industry sectors**
    - Food & agriculture
    - Wood products
    - Pre-heating boiler feed water
    - Others with <130ºC temperature requirements, particularly with available waste heat sources
  - **Regions**
    - **Pacific Northwest** – high quantities of hydroelectric power
    - **Portions of southern Midwest** – increasing quantities of wind and solar power

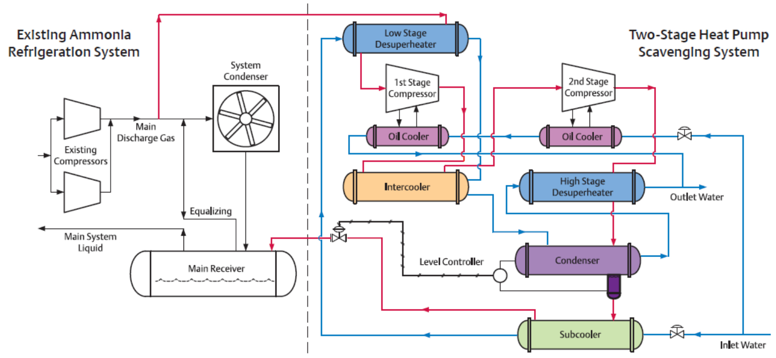
Two case studies of industrial electric heat pumps show the range from mature to emerging application areas

Case study 1: Dairy Pasteurization

- **Maturity:** Mature application area
- **Industry sector:** Food processing
- **Process heating application:** High Temperature Short Time (HTST) pasteurization
- **Location:** Wisconsin

An anonymized dairy processing facility implemented a two-staged heat pump paired with an existing ammonia refrigeration system. It heats water from 10 ºC to 88 ºC with a system COP of 4.2.

Compared to a natural gas boiler system, the project is expected to have a simple payback period of 2.7 years primarily due to operational savings from natural gas expenses.

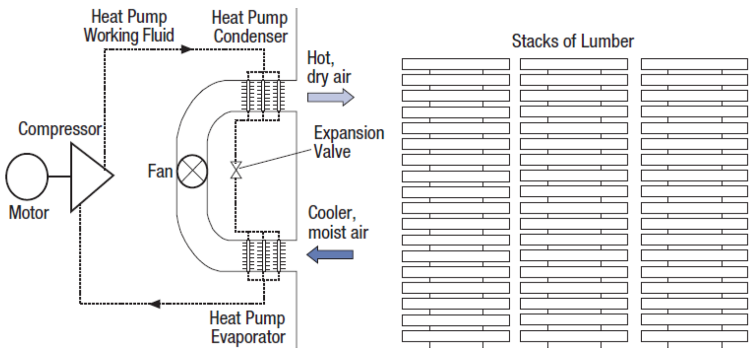


Case study 2: Lumber Drying

- **Maturity:** Emerging application area
- **Industry sector:** Wood products
- **Process heating application**: Lumber drying in wood processing
- **Location:** Quebec, Canada

Traditionally, lumber drying uses a steam-heated kiln to evaporate moisture from the wood. Instead, a closed-cycle mechanical heat pump can supply hot air to the dryer. The moist kiln exhaust air can then be passed over the heat pump evaporator coils to cool the exhaust and collect condensation.

Pilot heat pump lumber drying systems have been implemented where there is relatively inexpensive electricity alongside a large forestry sector. These operations have achieved COPs of 3-4.6 with up to 57% savings in fuel consumption compared to conventional drying systems.



Sources: Industrial heat pumps – Emerson Climate Technologies, Industrial Heat Pumps for Steam and Fuel Savings – DOE, Minea, Vasile. (2012). Using industrial heat pumps in sawmills for lumber drying.

Cost of heat delivered from heat pumps is heavily impacted by the efficiency, which is in turn primarily influenced by the input and output temperatures

Coefficient of performance (COP) or efficiency

	Output Process Temperature (°C)																						
	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160
30	11.3	9	7.4	6.3	5.5	4.8	4.3	3.8	3.5	3.2	2.9												
35	15.1	11.2	8.9	7.3	6.2	5.4	4.7	4.2	3.8	3.4	3.1	2.8											
40	22.6	15	11.1	8.8	7.3	6.2	5.3	4.7	4.2	3.7	3.4	3.1	2.8										
45	45.2	22.4	14.8	11	8.7	7.2	6.1	5.3	4.6	4.1	3.7	3.3	3	2.7									
50		44.9	22.3	14.7	10.9	8.6	7.1	6	5.2	4.6	4	3.6	3.2	2.9	2.7								
55			44.5	22	14.6	10.8	8.5	7	5.9	5.1	4.5	4	3.5	3.2	2.9	2.6							
60				44.1	21.8	14.4	10.7	8.4	6.9	5.9	5	4.4	3.9	3.5	3.1	2.8	2.6						
65					43.7	21.6	14.2	10.5	8.3	6.8	5.8	5	4.3	3.8	3.4	3.1	2.8	2.5					
70						43.2	21.3	14	10.4	8.2	6.7	5.7	4.9	4.3	3.8	3.3	3	2.7	2.4				
75							42.7	21.1	13.9	10.2	8.1	6.6	5.6	4.8	4.2	3.7	3.3	2.9	2.6	2.4			
80								42.1	20.8	13.7	10.1	7.9	6.5	5.5	4.7	4.1	3.6	3.2	2.8	2.6	2.3		
85									41.6	20.5	13.5	9.9	7.8	6.4	5.4	4.6	4	3.5	3.1	2.8	2.5	2.2	
90										41	20.2	13.2	9.7	7.7	6.3	5.2	4.5	3.9	3.4	3	2.7	2.4	2.2
95											40.4	19.8	13	9.6	7.5	6.1	5.1	4.4	3.8	3.3	2.9	2.6	2.3
100												39.7	19.5	12.8	9.4	7.3	6	5	4.3	3.7	3.2	2.8	2.5
105													39	19.1	12.5	9.2	7.2	5.8	4.9	4.2	3.6	3.1	2.8
110														38.3	18.8	12.2	9	7	5.7	4.8	4	3.5	3

Levelized cost of heat (LCOH) in $/MMBtu[1]

Input Temperature (°C)	Output Process Temperature (°C)																						
	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160
30	3.6	4.6	5.5	6.5	7.5	8.5	9.5	10.8	11.7	12.8	14.1												
35	2.7	3.7	4.6	5.6	6.6	7.6	8.7	9.8	10.8	12.1	13.2	14.6											
40	1.8	2.7	3.7	4.7	5.6	6.6	7.7	8.7	9.8	11.1	12.1	13.2	14.6										
45	0.9	1.8	2.8	3.7	4.7	5.7	6.7	7.7	8.9	10.0	11.1	12.4	13.7	15.2									
50		0.9	1.8	2.8	3.8	4.8	5.8	6.8	7.9	8.9	10.2	11.4	12.8	14.1	15.2								
55			0.9	1.9	2.8	3.8	4.8	5.9	6.9	8.0	9.1	10.2	11.7	12.8	14.1	15.8							
60				0.9	1.9	2.8	3.8	4.9	5.9	6.9	8.2	9.3	10.5	11.7	13.2	14.6	15.8						
65					0.9	1.9	2.9	3.9	4.9	6.0	7.1	8.2	9.5	10.8	12.1	13.2	14.6	16.4					
70						0.9	1.9	2.9	3.9	5.0	6.1	7.2	8.4	9.5	10.8	12.4	13.7	15.2	17.1				
75							1.0	1.9	2.9	4.0	5.1	6.2	7.3	8.5	9.8	11.1	12.4	14.1	15.8	17.1			
80								1.0	2.0	3.0	4.1	5.2	6.3	7.5	8.7	10.0	11.4	12.8	14.6	15.8	17.8		
85									1.0	2.0	3.0	4.1	5.3	6.4	7.6	8.9	10.2	11.7	13.2	14.6	16.4	18.6	
90										1.0	2.0	3.1	4.2	5.3	6.5	7.9	9.1	10.5	12.1	13.7	15.2	17.1	18.6
95											1.0	2.1	3.2	4.3	5.5	6.7	8.0	9.3	10.8	12.4	14.1	15.8	17.8
100												1.0	2.1	3.2	4.4	5.6	6.8	8.2	9.5	11.1	12.8	14.6	16.4
105													1.1	2.1	3.3	4.5	5.7	7.1	8.4	9.8	11.4	13.2	14.6
110														1.1	2.2	3.4	4.6	5.9	7.2	8.5	10.2	11.7	13.7

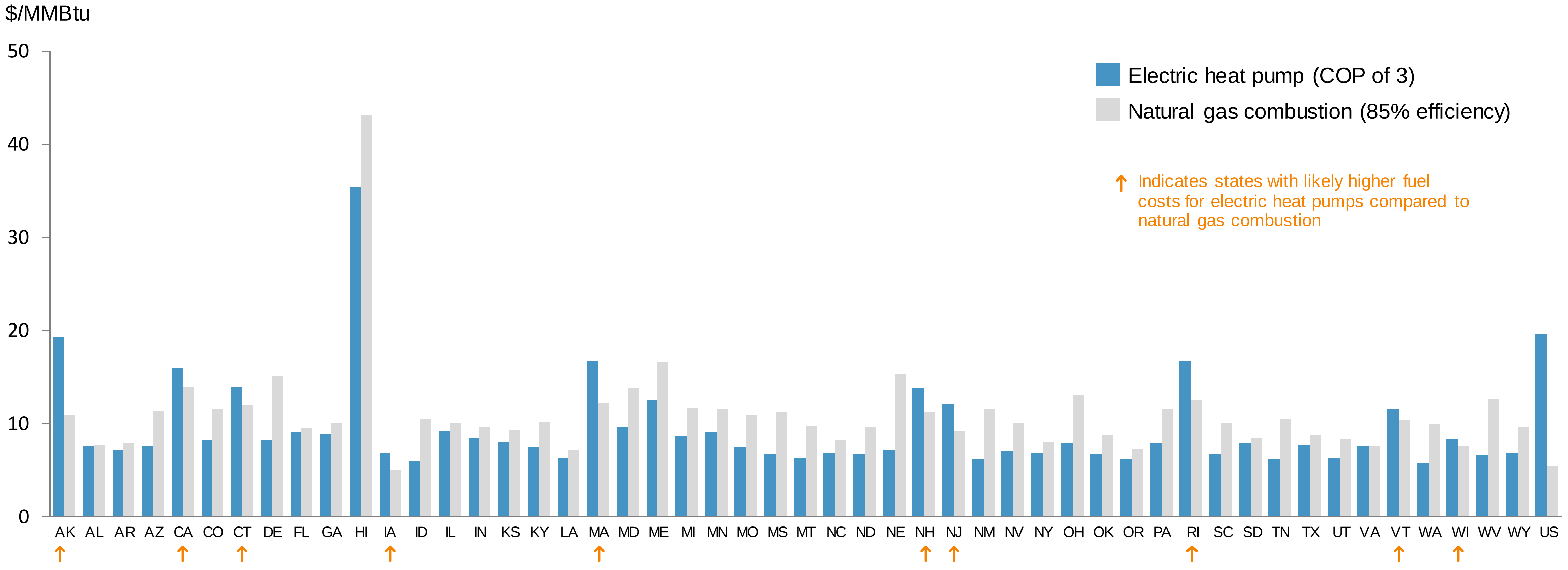
Input temperatures above ambient temperatures require waste heat streams (e.g., refrigeration condensers, vented steam)

E.g., COP of 3 indicates an efficiency of 300%, by which every unit of electricity input yields 3 units of thermal energy output

1. Calculated using average US industrial electricity prices in May 2022
Source: US EIA Industrial Electricity Prices (May 2022), BCG analysis

All but 10 US states show likely lower fuel costs for electric heat pumps compared to natural gas heating

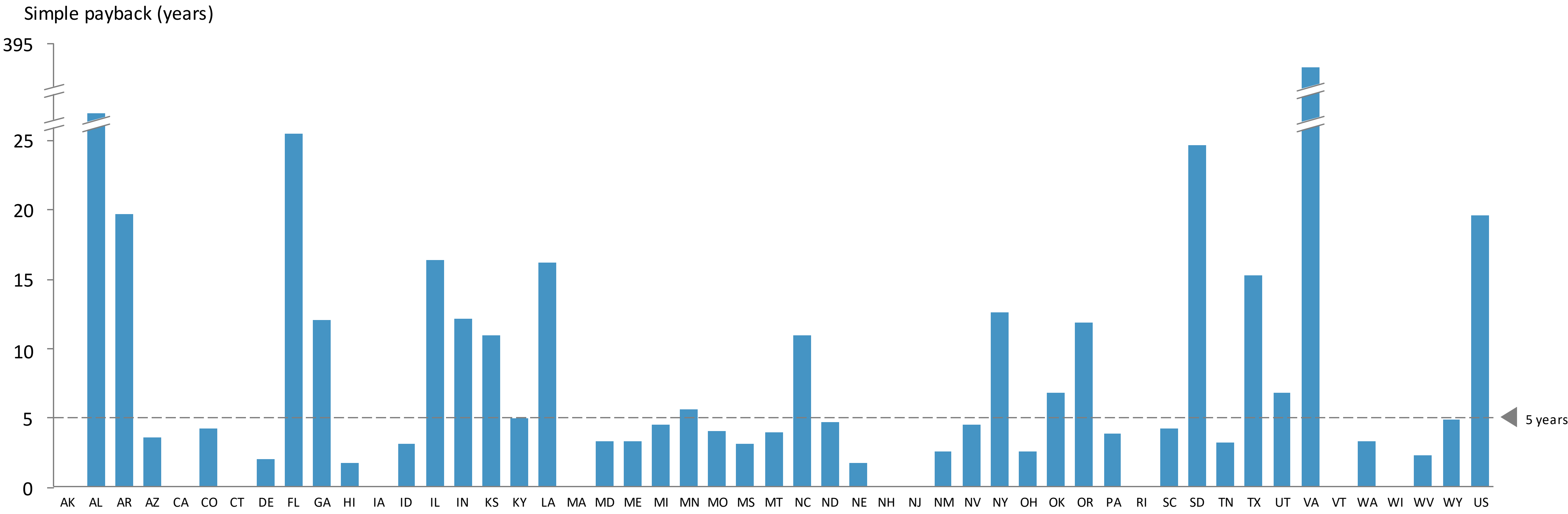
Relative fuel costs between electric heat pump and natural gas combustion heating in 2022



Note: Analysis assumes a moderate natural gas combustion efficiency of 85%, and a conservative heat pump COP of 3
Source: US EIA Industrial Electricity Prices (May 2022), US EIA Industrial Natural Gas Prices (May 2022)

Transitioning from natural gas combustion to electric heat pumps likely yields payback periods under 5 years for approximately half of US states

Payback period of transitioning from natural gas combustion to electric heat pump using 2022 utility rates



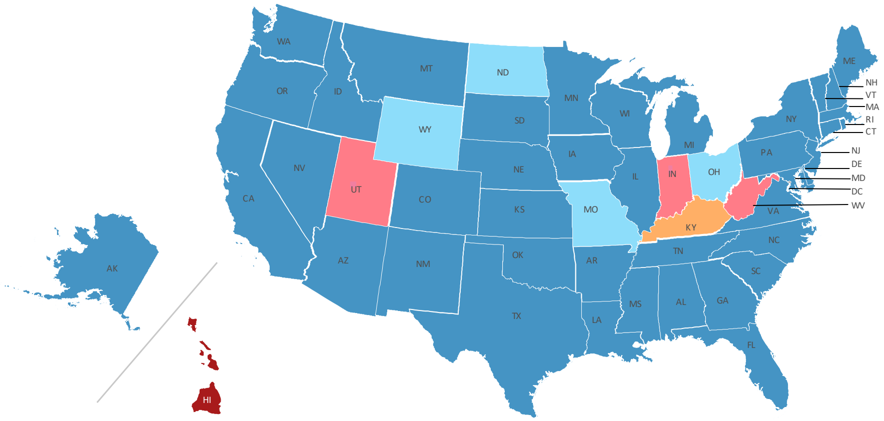
Notes: States without a payback period indicated have higher operating costs for electric heat pumps compared to natural gas combustion. Capital cost of electric heat pump was assumed to be $120,000/MMBtu from ACEEE source.
Source: US EIA Industrial Electricity Prices (May 2022), US EIA Industrial Natural Gas Prices (May 2022), Industrial Heat Pumps: Electrifying Industry's Process Heat Supply - ACEEE

Emissions savings are expected in nearly all states today by switching from natural gas combustion to electric heat pump heating

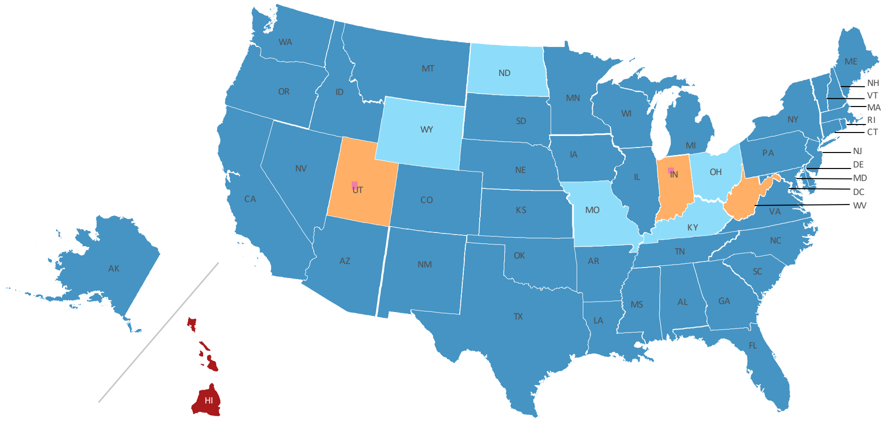
Likely reduction in emissions by switching from natural gas combustion[1] to electric heat pump[2] heating:

- Today (2022)
- By 2026
- By 2030
- By 2035
- Beyond 2035

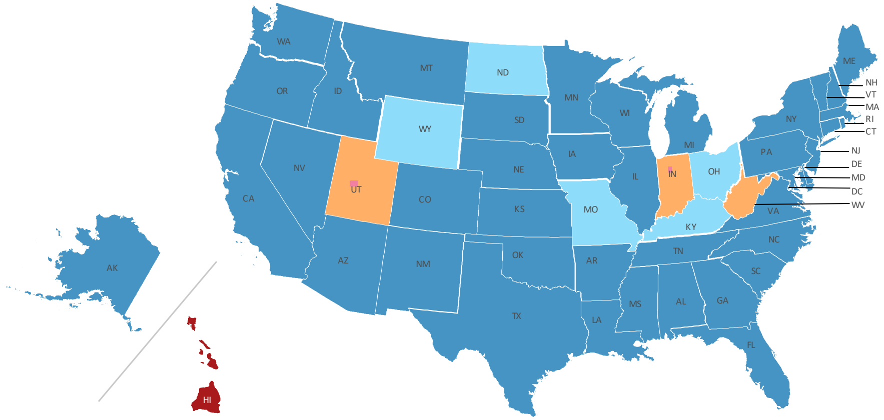
Scenario 1: 80% renewables by 2050



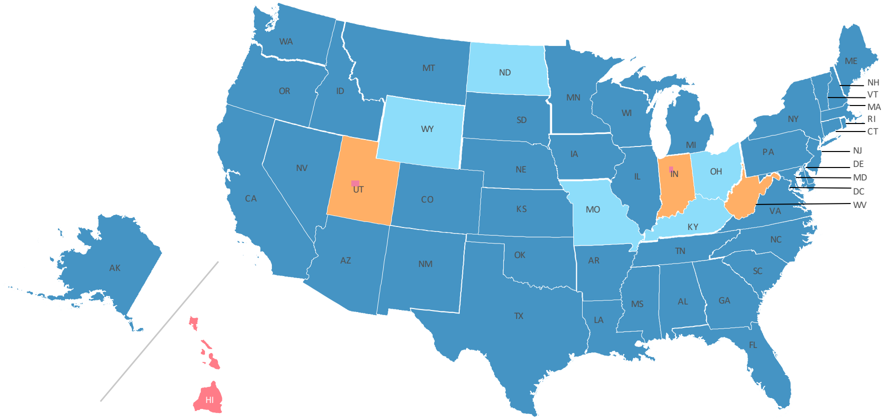
Scenario 2: 65% renewables by 2030



Scenario 3: 80% renewables by 2030



Scenario 4: Near 100% renewables by 2035



Sources: US EPA GHGRP (2019); US EIA; State Renewable Portfolio Standards; IEA ETSAP Industrial Combustion Boilers Fact Sheet; BCG analysis

1. Calculated using 85% efficiency for natural gas boiler; 2. Calculated using a conservative COP of 3

Electric heat pump industrial heating has many advantages especially for lower temperature applications, but faces several key barriers to adoption

Advantages

- May be able to achieve payback within 5 years in many parts of US
- Precise control of temperature and heat input
- Can approach 400% efficiency or beyond
- Improved health & safety due to lack of combustion

Barriers

- Higher capital costs relative to combustion equipment
- Rotating equipment leads to higher maintenance costs
- Efficiency decreases beyond 100 ºC, and cannot deliver >160 ºC
- Potential for high GWP[1] refrigerant leaks
- Extensive electrical infrastructure upgrades may be required

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