



Michigan Clean Manufacturing Roadmap



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About RMI

Rocky Mountain Institute (RMI) is an independent, nonpartisan nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to secure a prosperous, resilient, clean energy future for all. In collaboration with businesses, policymakers, funders, communities, and other partners, RMI drives investment to scale clean energy solutions, reduce energy waste, and boost access to affordable clean energy in ways that enhance security, strengthen the economy, and improve people's livelihoods. RMI is active in over 60 countries.

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Executive Summary

Though the industrial sector has historically been deemed hard to abate, many of Michigan's industrial emissions — about 2.9 million tons (Mt) of CO₂¹ — come from burning natural gas in low and medium temperature ranges for which low-emissions technologies like industrial heat pumps, electric boilers, and thermal energy storage have already proven viable.² This roadmap provides a plan for Michigan policymakers to ease the transition to clean manufacturing and production methods as these next-generation technologies continue down the cost curve and improve in performance.

Manufacturing is a driving force of the Michigan economy: across the state, approximately 600,000 Michiganders are employed in manufacturing jobs, specializing in products ranging from paper and cardboard to chemicals and cars.³ The state was the seventh largest exporter of goods in the nation in 2024, and goods exports accounted for 9.1% of state gross domestic product in the same year.⁴ In addition to advancing the state economy, the industrial sector is a significant source of climate pollution, comprising 13% of Michigan's total emissions (or 27 Mt of CO₂e).⁵ To meet the climate and health targets mandated by the MI Healthy Climate Plan while maintaining Michigan's manufacturing might,⁶ the state must work to reduce emissions from its industrial sector in a way that allows businesses to stay regionally and globally competitive. The near-, mid-, and long-term actions contained in this roadmap are designed to achieve these dual ambitions.

Technical solutions

In this roadmap, we focus on solutions that are technologically and commercially ready (technology readiness level of 9 or higher,⁷ meaning the technology has successful full-scale deployment in an operational environment), can be deployed in the near-term, and fall into three main categories: energy efficiency, electrification, and geothermal heat.

- **Energy efficiency:** Many assume industrial facilities have already maximized energy efficiency, but a study from ENERGY STAR finds that energy efficiency still represents 34% of feasible carbon emission reductions in US manufacturing by 2050.⁸ This leaves a major opportunity for cost savings and emissions reductions, especially as technologies improve in efficiency. Michigan facilities can implement solutions like industrial heat pumps, low-carbon or geothermal combined heat and power, and energy management systems, which reduce waste without disrupting production.
- **Electrification:** A key strategy for reducing emissions in low- and medium-temperature industrial processes is electrification. Facilities like those in the food and beverage and chemicals sectors can adopt electric resistance heating and thermal energy storage to replace fossil-fueled systems. These technologies are reliable and can be tailored to specific heat and power needs.
- **Geothermal heat:** Advanced geothermal systems now allow heat extraction in regions without geologic activity, making them viable across Michigan. Geothermal is ideal for industrial use because it provides direct heat without needing conversion to electricity. Though still emerging, it is already being implemented in similar contexts to Michigan and offers strong potential for demonstration projects.⁹

Barriers to adoption

Despite the technological maturity of many of these technologies, nearly every facility in Michigan remains reliant on natural gas to fuel its operations. Where facilities consider adopting lower-emissions equipment, they face barriers including technology integration, equipment financing, and system-level capabilities. The following barriers were surfaced through informational interviews with facility owners and managers:

- **No one-size-fits-all solution:** Each facility has unique energy needs, making application of a universal electrified heating solution difficult. Long equipment lead times and potential production disruptions are major deterrents.
- **Limited capacity among smaller manufacturers:** Small and medium-sized manufacturers often lack the resources to conduct energy audits or evaluate alternative equipment investments.
- **High up-front and operating costs:** Efficient and electrified systems are more expensive than traditional gas boilers. In Michigan, industrial electricity is about 2.8 times more costly than gas.¹⁰
- **Grid and infrastructure constraints:** Facilities need reliable, affordable electricity, but grid capacity and transmission planning are still catching up. Long deployment cycles and a lack of commercial-scale demonstrations also slow adoption.

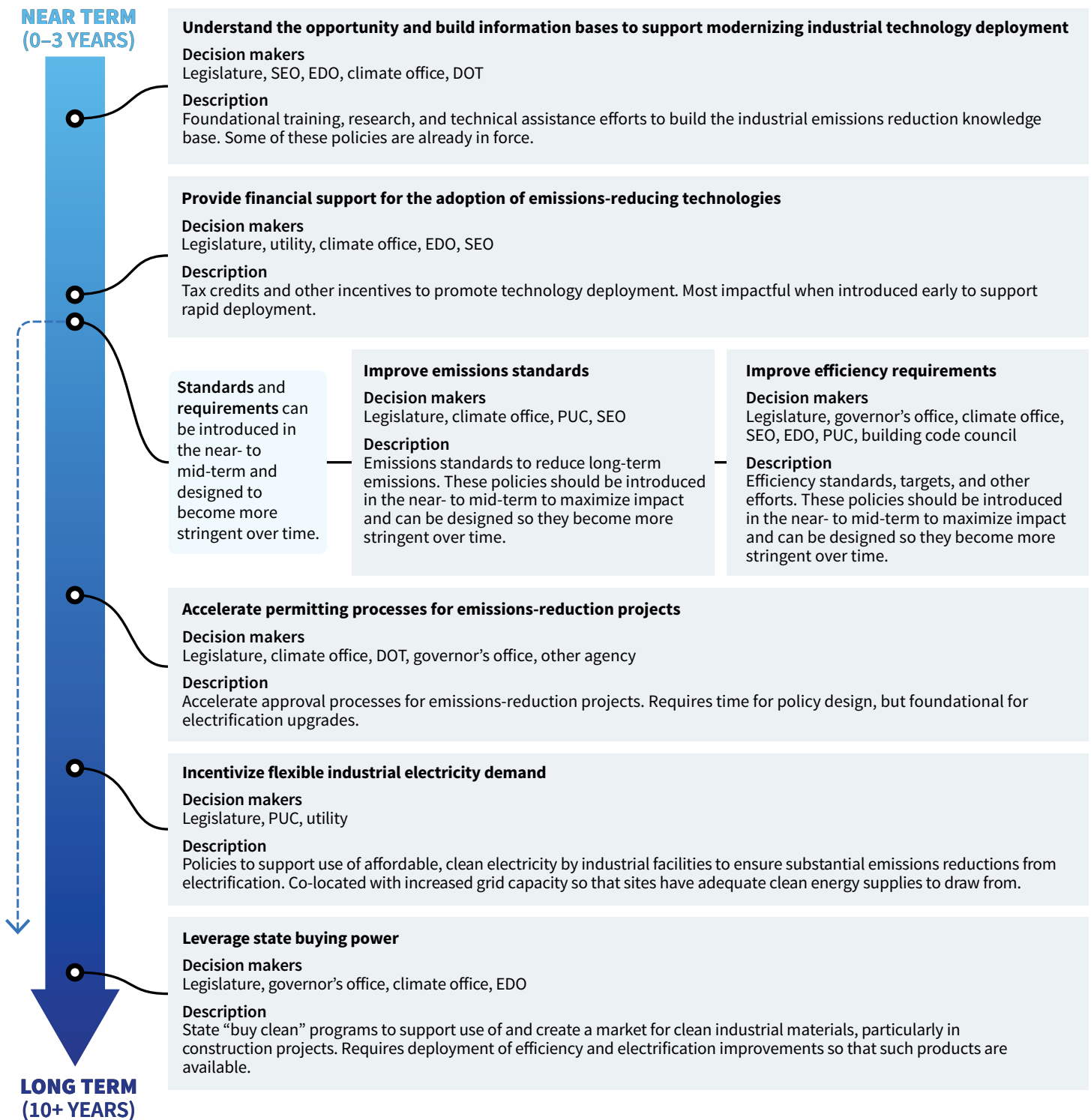
Enabling policies

To overcome these barriers and unlock the clean manufacturing potential, Michigan can enact targeted policies and programs. We focus on eight key strategies, many with specific subpolicies, discussed in detail in the [State Interventions](#) section of the report:

1. Support the adoption of emissions-reducing technologies financially
2. Improve efficiency requirements
3. Increase grid clean capacity
4. Incentivize flexible industrial electricity demand
5. Streamline permitting processes for emissions reduction projects
6. Improve emissions standards
7. Leverage state buying power
8. Understand the opportunity and build information bases to support modernizing industrial technology deployment

There is no silver bullet to achieve low-emissions industry, so the state should consider its funding resources, administrative capacity, and input from industrials to unlock the greatest emissions reduction potential. In concert, a number of these strategies (depicted in Exhibit ES1) can be powerful levers to change Michigan's industrial emissions landscape and drive private investment in clean technology.

Exhibit ES1 Timeline of policy interventions to aid industrial emissions reductions



RMI Graphic. Source RMI analysis

How will the people of Michigan benefit?

Improving efficiency and electrifying operations in the industrial sector create ripple effects beyond the borders of the facilities themselves.

First, there are tangible air quality benefits to industrial electrification, especially to communities near the facilities. A new report from the American Lung Association found that “the transition to zero-emission technology for low- and mid-temperature industrial boilers would generate substantial reductions in both climate-forcing emissions and local air pollutants that threaten public health.”¹¹ In Michigan specifically, the report estimates the cumulative health benefits of switching low- and medium-temperature boilers to heat pumps to be \$42.8 billion.¹² The analysis uses the US Environmental Protection Agency’s Co-Benefits Risk Analysis (COBRA) tool to assess the frequency of health incidents like asthma and premature mortality caused by industrial pollutant emissions and evaluates the monetary benefit of avoiding those incidents.

Beyond the state’s stated ambition to reduce emissions and the obligation to deliver clean air to its residents, Michigan has the opportunity to lead the United States in industrial decarbonization and produce goods with lower emissions for global markets, which are increasingly willing to pay premiums for green products. Given that \$5.8 billion of goods produced in the state were exported to the European Union in 2024,¹³ the state can consider tightening regulations and supporting Michigan businesses to compete in low-carbon global markets with a carbon border adjustment mechanism.¹⁴



Overview of Industrial Emissions in Michigan



Methodology

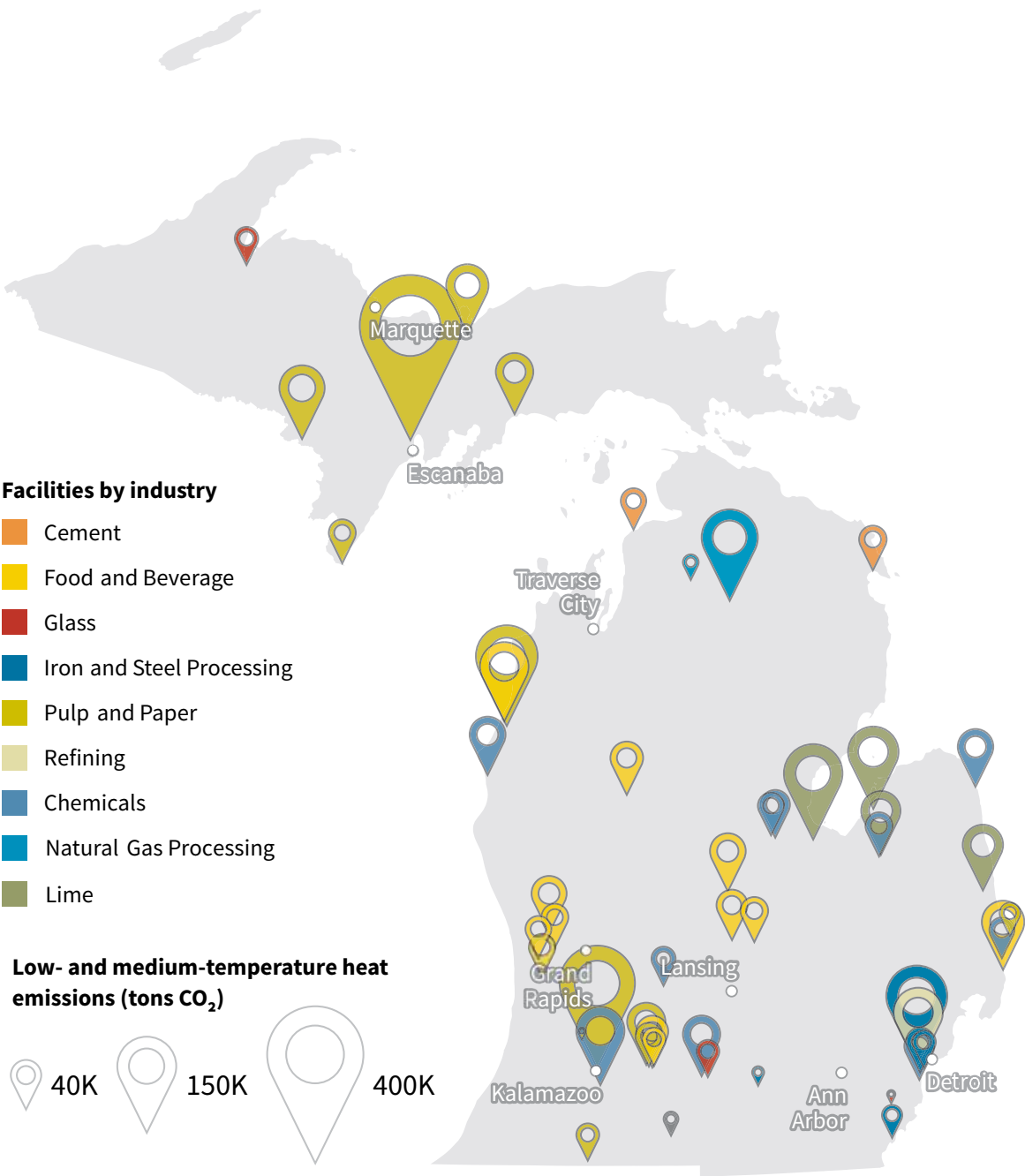
An open-source public dataset on industrial combustion emissions called the US Industrial Sector Heat Emissions and Temperature Dataset (HEATset) was used for this analysis.¹⁵ HEATset V1.0 utilizes facility-reported emissions data for reporting year 2022 from the US Environmental Protection Agency's (EPA's) Greenhouse Gas Reporting Program (GHGRP). The data covers industrial facilities with annual Scope 1 CO₂ emissions greater than 25,000 tons. Scope 2 and Scope 3 emissions are not within the purview of this analysis.ⁱ

This analysis focused on manufacturing facilities in ten high-level industrial sectors: pulp and paper, iron and steel, chemicals, lime, refining, cement, food and beverage, glass, natural gas processing, and aluminum (see Exhibit 1).

ⁱ Scope 1 emissions are direct greenhouse gas emissions from sources owned or controlled by the company for example, fuel combustion in company-owned boilers. Scope 2 emissions are indirect greenhouse gas emissions from purchased energy, such as purchased electricity. Scope 3 emissions are all other indirect emissions that occur in a company's value chain, both upstream and downstream, that are not included in Scope 2. Examples of Scope 3 emissions are purchased goods and services and end-of-life treatment of sold products.

Exhibit 1

Map of Michigan facilities with CO₂ emissions from low- and medium-temperature heat



RMI Graphic. Source: CAELP (HEATset)

Emissions by temperature grade

Low-temperature (0°C–200°C) and medium-temperature (200°C–400°C) heat account for approximately 50% of combustion CO₂ emissions from industry, 2.9 of 5.8 million tons (Mt) total in 2022. Of low- and medium-temperature heat emissions, 89% can be attributed to low-temperature heat and the remaining 11% to medium-temperature heat (see Exhibit 2).

Emissions by industrial subsector

The pulp and paper subsector accounts for most emissions from low- and medium-temperature heat (approximately 40%), followed by food and beverage (approximately 16%), chemicals (approximately 13%), and lime manufacturing (approximately 12%).

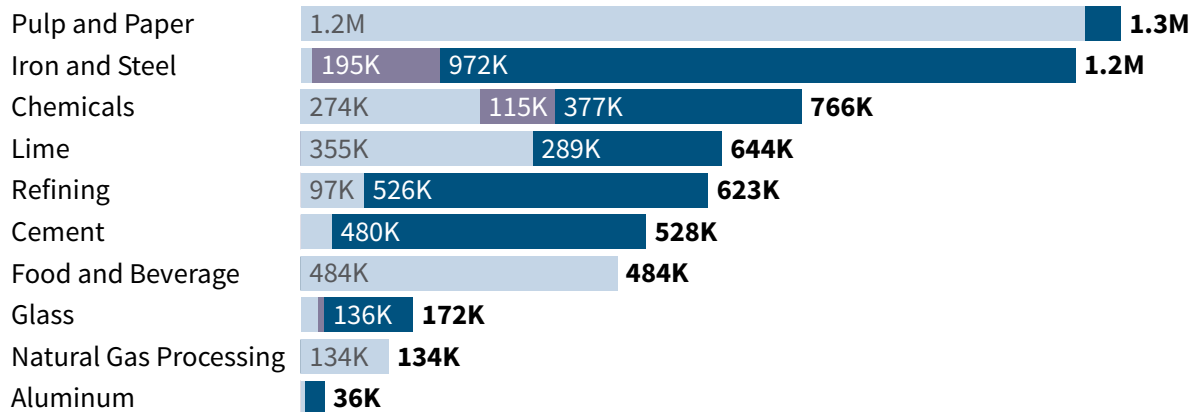
The chemicals and lime manufacturing sectors also have substantial emissions from high-temperature heat (above 400°C). The emissions from other major emitting sectors including refining, iron and steel, glass, and cement manufacturing are all primarily associated with high-temperature heat.

Exhibit 2

Annual emissions by industrial subsector (2022)

2022 estimated CO₂ emissions from on-site combustion of fuels for process heating (tons)

■ Low-temperature heat (0°C–200°C) ■ Medium-temperature heat (200°C–400°C)
■ High-temperature heat (>400°C)

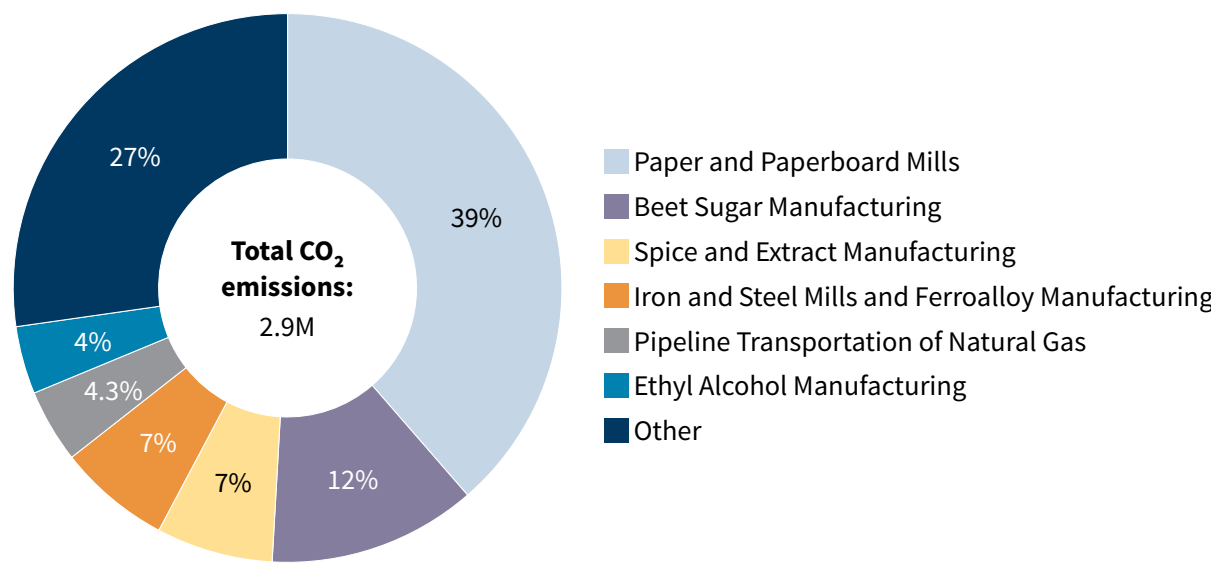


RMI Graphic. Source: CAELP (HEATset)

The paper and paperboard mills manufacturing process accounts for approximately 39% of low- and medium-temperature heat emissions. Beet sugar manufacturing, spice and extract manufacturing, and iron and steel mills account for 12%, 7%, and 7%, respectively (see Exhibit 3).

Exhibit 3

Annual low- and medium-temperature heat emissions
by specific manufacturing process (2022)



RMI Graphic. Source: CAELP (HEATset)

Emissions by facility

Manufacturers using low- and medium-temperature heat in the state include Billerud Americas Corp., Michigan Sugar Co., Graphic Packaging Holding Co., Packaging Corp. of America, and Cleveland-Cliffs Inc. Their respective subsectors combined are responsible for 50% of emissions from low- and medium-temperature heat (see Exhibit 4).

Exhibit 4

Emissions from low- and medium-temperature heat manufacturing

Parent Company Name	Industrial Subsector	Low- and Medium-Temperature Heat Emissions (Mt)
Billerud Americas Corp.	Paper Mill	522,421
Michigan Sugar Co.	Beet Sugar Manufacturing	361,743
Graphic Packaging Holding Co.	Paperboard Mill	262,943
Packaging Corp. of America	Paper Mill	156,559
Cleveland Cliffs Inc.	Iron and Steel	152,627

Note: Includes biogenic emissions
RMI Graphic. Source: CAELP (HEATset)

Emissions by fuel type

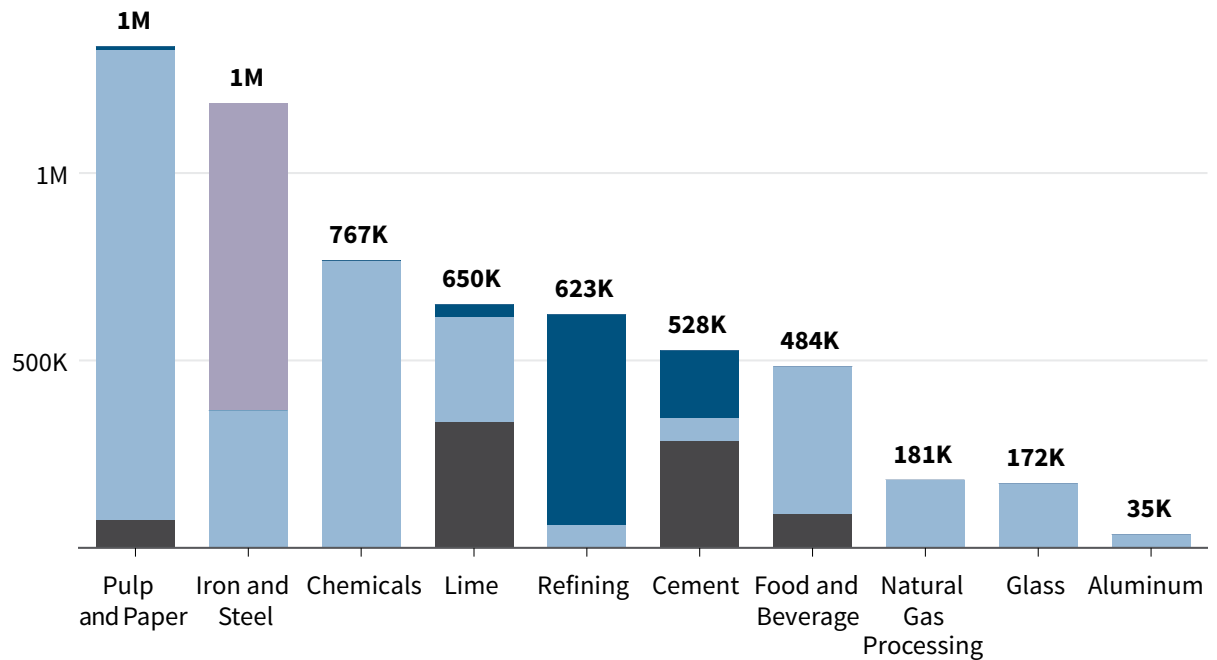
As illustrated in Exhibit 5, natural gas and coal account for the majority of combustion emissions in the state, at 72% and 6%, respectively. A majority of coal combustion emissions are from lime manufacturing and cement manufacturing.

Exhibit 5

Emissions by fuel type

2022 estimated CO₂ emissions from combustion of fuel for process heating at all temperature ranges (tons)

■ Coal ■ Natural Gas ■ Petroleum Products ■ Other



RMI Graphic. Source: CAELP (HEATset)

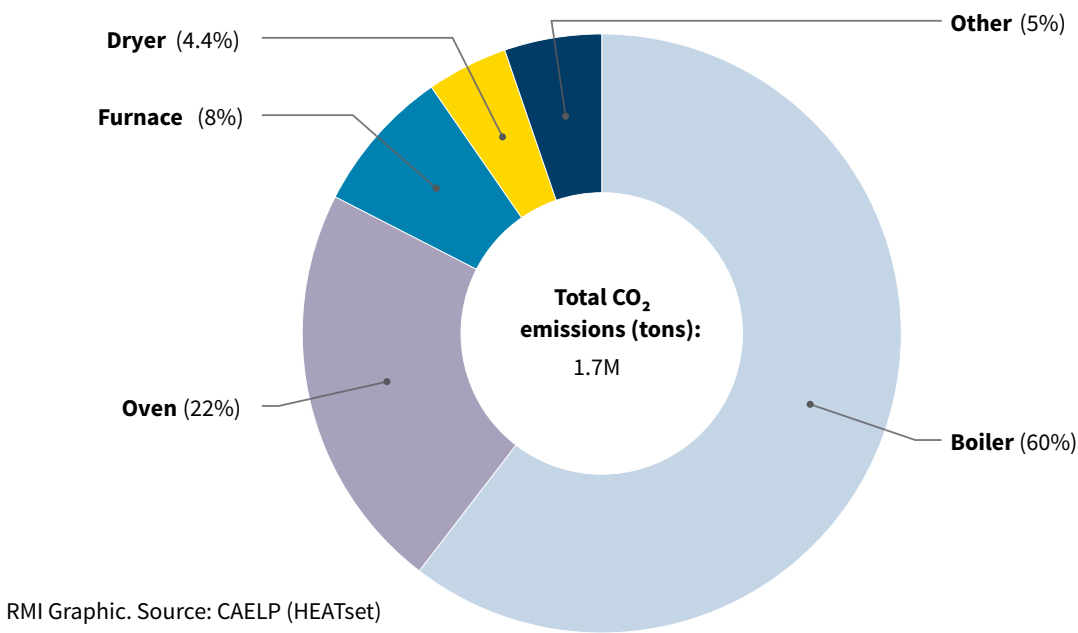
Emissions by equipment type

Based on the GHGRP dataset of facilities with a large amount of emissions, boilers account for approximately 60% of combustion emissions from industry.ⁱⁱ Other key users of heat are ovens, furnaces, dryers, and heaters (see Exhibit 6).

ⁱⁱ Based on individually reported units in US EPA GHGRP in 2022, representing approximately 30% of 2022 Michigan industrial CO₂ emissions across all temperatures. At least 108 unclassified units are not included. Unit count also excludes generators, units without reported emissions, and units from facilities without reported emissions.

Exhibit 6

Emissions by equipment type



Boilers deep dive

Because the GHGRP dataset is limited in its coverage, and given the significant impact of boilers on industrial emissions, a more detailed assessment of boiler emissions in Michigan was conducted using the National Map of Industrial Boilers, which utilizes the 2020 National Emissions Inventory data from the EPA.¹⁶

Based on the data, there were 394 boilers in Michigan that emitted approximately 3,900 tons of nitrous oxide annually. Some 65.5% of boilers were in ozone nonattainment areas. Fifty-one boilers had capacity greater than 100 million British thermal units per hour (MMBtu/h) (see Exhibit 7). Given the size, most are believed to be operating in industry use cases. The sectors with the most boilers were food and beverage (85 boilers) and chemicals (73 boilers).

Exhibit 7

Boiler count by heating capacity

Capacity (MMBtu/h)	Number of Boilers
>100	51
10–100	171
2–10	69
<2	63
Not reported	40

RMI Graphic. Source: Evergreen Action (National Map of Industrial Boilers)

Michigan's Opportunity: Low-Emissions Industry, Heat, and Power

Industry today

The transition of manufacturing from high- to low-emissions heat will fundamentally change industry's heat and power use patterns.

Today, approximately 83% of energy use in industry comes from the combustion of fuels and about 17% from electricity.¹⁷ Electricity is primarily used to power mechanical equipment like pumps and compressors, while fuels are used to provide heat for boilers, furnaces, kilns, dryers, and other heaters.

Most industrial facilities generate heat on-site through the combustion of fuels like natural gas, petroleum products (liquid fuel), and coal (solid fuel). Some facilities purchase heat, typically in the form of steam, from adjacent facilities that generate excess heat beyond their needs or from colocated combined heat and power (CHP) facilities. Yet others, such as waste incinerators and cement kilns, utilize waste streams from other industries as fuel.

Transformation within and without

The transition to low-emissions industry will mean change both inside and outside the site limits of industrial facilities. Managed correctly, this change can deliver more reliable, resilient, and efficient energy systems for industrial facilities and for the state of Michigan.

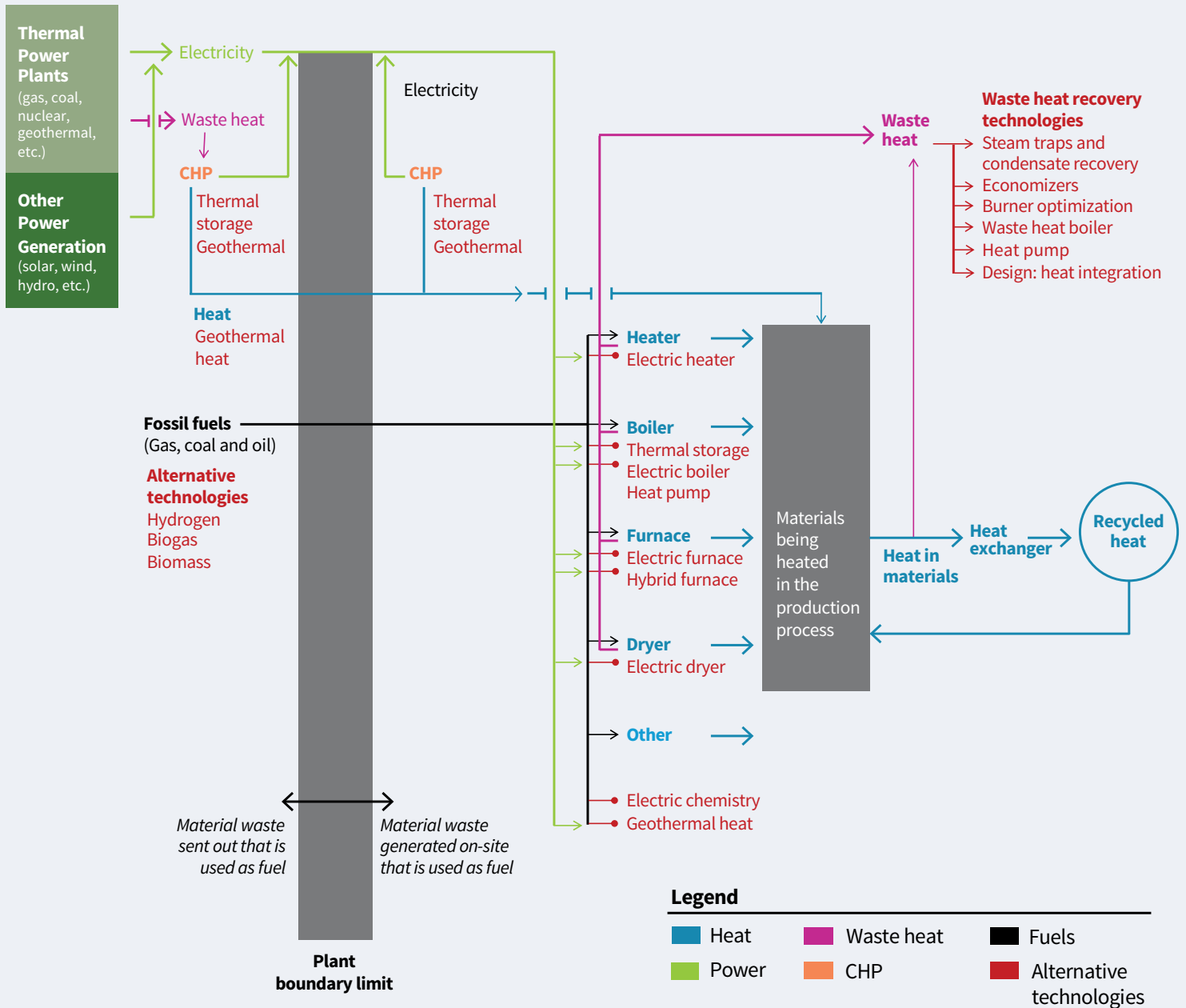
The energy mix for low-emissions industry in 2050 will look very different from today's. Many factors, from policy and market forces to technological breakthroughs, will determine the eventual mix. Yet, it is certain that to meet the state's climate pollution reduction targets, fossil fuel-fired heating will need to be minimized.

To that end, energy efficiency could significantly reduce the demand for energy. Electricity could make up a significantly larger share of industrial energy use as facilities shift to electrified heating through technologies like electric boilers, thermal energy storage (TES), and electrified furnaces. CHP from low-carbon fuels and geothermal energy may play a more significant role, and on-site combustion of low-carbon fuels may be pivotal for high-temperature heat processes. On the horizon, there may be breakthrough technologies that are currently in lab or pilot scale that could transform the equation.

Exhibit 8 illustrates a facility's transition to low-emissions operations and the interconnection to external fuel and power. This diagram shows how numerous low-emissions technologies, in red and orange, can be implemented within and outside facility boundaries. Although not a complete diagram of all connections and processes a facility may include, it illustrates the general interconnectedness of a representative industrial facility and the suite of options available for a low-emissions future.

In practice, each industrial facility is unique in its on-site processes and its connection with adjacent industry, the power grid, and local communities. As a result, every facility's transition to a low-carbon future will also be unique, dependent on factors like current processes, proximity to fuel and power sources, and age of existing equipment.

Exhibit 8 Heat and power map of industry



RMI Graphic. Source: RMI analysis

From facility assessments to a statewide strategy

A meaningful roadmap for low-emissions industry will need to be built on a foundation of high-quality facility-level engineering assessments that advise facility-level roadmaps by answering the questions: “which technological interventions, where, why, how, and when?”

These facility-level assessments could feed up to a system-level engineering assessment for the state of Michigan that takes into account the interplay between industrial electrification, gas distribution, low-carbon fuels availability, geothermal energy potential, and untapped CHP, among other variables deemed pertinent to create a cohesive system-level roadmap.

Collaboration with The 2035 Initiative — which has developed open-source energy models for archetype facilities in key industrial subsectors — can give state officials and industry players an empirically grounded blueprint to accelerate the transition to low-emissions industry.¹⁸

Finally, Michigan’s roadmap to low-emissions industry will need to evolve to respond to changes in the technology, economic, and policy landscapes. Therefore, the state must implement a system for continuous review, revision, and evolution of the roadmap to sustain the present and future needs of the people of Michigan.



Facility Emissions-Reduction Strategies

There is a suite of technical options available for facility owners to reduce emissions from their operations, especially within low- and medium-temperature process heating applications. Broadly, emissions-reduction strategies for industry include energy efficiency improvements, electrification, geothermal heat, switching to low-carbon fuels, and carbon capture and storage (CCS).¹⁹

Commercially available technologies: We focus on near-term technologies that are technically and commercially feasible today (technology readiness level [TRL] of 9 and higher, meaning a full-scale system has been proven in an operational environment) for low- and medium-temperature process heating. These technologies fall into three main categories: efficiency, electrification, and geothermal heat. Within these categories we highlight the strategies that are both readily available today and have the broadest applicability across the industrial sector, rather than present an exhaustive list of possible options. For each technology, we provide a technical overview, identify low- and medium-temperature heating applications, and highlight some of the key deployment considerations for real-world implementation at facilities, such as advantages and challenges.

Emerging technologies: There are also other new and emerging technologies that have the potential to transform the heat and power landscape, but due to their low TRLs are not near-term solutions. One example is natural, or geologic, hydrogen, with companies like Koloma and HyTerra exploring options to drill natural hydrogen wells in the United States.²⁰ Although natural hydrogen is projected to have production costs of less than \$1/kg at optimal sites and could be used to generate low-cost, low-emissions electricity, this technology has not been proven commercially at scale and is not considered in this roadmap.²¹

Limited opportunities: Fuel switching and CCS are commercially available today, but these emissions-reduction strategies are best reserved for hard-to-electrify applications, like high-temperature process heating or manufacturing with high-process emissions, due to the limited quantities of available alternative fuels and the low CO₂ concentration of combustion streams.

Facility-specific opportunity assessments: Overall, selecting the most impactful and cost-effective emissions-reduction strategy is highly specific to each individual facility's processes and needs. Generalizing the best solution for a manufacturing process or equipment type is difficult without detailed information on a facility. Facilities will ultimately need energy and opportunity assessments specific to their site to evaluate and act on the most appropriate solutions space. Some resources for facilities exist today, like the Industrial Assessment Centers (IACs) and the US Department of Energy's (DOE's) Better Plants program.²² The Michigan State University Industrial Training and Assessment Center is one of the 36 IACs in the United States with a mission to conduct at least 20 manufacturing energy assessments a year at small and medium-sized manufacturers in the state.²³ Despite these existing resources, there remains a need for programs with additional scope and capacity to address deeper emissions reduction of industrial combustion processes.

Energy efficiency

Energy efficiency is the most cost-effective and proven tool for cutting industrial emissions; simply by reducing energy consumption, facilities can reduce emissions from fossil fuel combustion.²⁴ These efficiency technology solutions are readily available today and include, but are not limited to, heat pumps, economizers, heat exchangers, burner optimization, advanced process controls, advanced heat integration design, steam system optimization, waste heat boilers, heat pumps, and CHP.

Below we highlight heat pumps, CHP, and efficiency management systems because these are the broadly applicable strategies across industrial processes and heating equipment.

One study published in 2022 by the *Journal of Cleaner Production* suggests that energy efficiency measures could result in roughly 30% emissions reductions across all manufacturing sectors. In Michigan, these energy efficiency savings are equivalent to around 0.8 Mt of annual CO₂ emissions from low- and medium-temperature heat and 1.8 Mt of annual CO₂ emissions when considering all temperature grades.²⁵

Heat pumps

Overview

Similar to the residential and commercial buildings sector, in industry heat pumps can be implemented to reduce combustion emissions through increased efficiency and lowered fossil fuel consumption. The most common heat pumps, mechanical vapor compression and mechanical vapor recompression, use electricity to increase the temperature of heat from the surrounding air or waste heat sources to a higher, usable target temperature that can be further applied in heating processes. Other types like adsorption and thermocompression heat pumps rely on thermal energy to upgrade and transfer heat.²⁶

The TRL of heat pump technologies depends on the technology type and temperature range. Generally, low-temperature heat pumps that supply output temperatures lower than 100°C are at TRL 9 and are commercially available today, but do not have widespread deployment in industrial applications in the United States. Heat pumps that have output temperatures greater than 100°C mainly range from pilot and demonstration testing to TRL 9 with several models that are market-ready today.²⁷

Application

Most industrial heat pumps currently deployed are in the food and beverage sector for pasteurizing, sterilizing, and washing.²⁸ Heat pumps also have higher deployment in the residential and commercial buildings sector for space and water heating due to the small demands and lower temperatures compared with industrial applications.

Deployment considerations

Typically, the usable energy upgraded by the heat pump is greater than the electricity consumed by the heat pump. This ratio of usable output heat supplied by the heat pump and the input electrical energy is known as the coefficient of performance (COP). The higher the COP, the more efficient the heat pump is at upgrading heat to the target temperature and the cheaper its operating cost. Heat pump COPs vary depending on type of heat pump, system design, temperature lift from input temperature to output temperature, and environmental conditions. An analysis of commercially available industrial heat pumps

from the Institute of Energy Economics and Financial Analysis found that COPs ranged widely from 1.7 to 10.3, but were typically between 2.5 and 4.0 depending on waste heat availability.²⁹

Air-sourced heat pumps that upgrade the heat of the surrounding air to generate steam can replace fossil-fired industrial boilers, particularly for the food and beverage industry, but are newer to the market for industrial applications. One example is AtmosZero's first Boiler 2.0 heat pump, which was installed in New Belgium Brewing's flagship brewery in Colorado earlier this year and can reach output temperatures of nearly 155°C.³⁰

Heat pumps that depend on waste heat from other parts of the process cannot replace fossil-fired boilers because their operation depends on waste heat originally generated by said boiler. This category of heat pump is best implemented as an efficiency solution to reduce the energy demand of fossil-fired heating technology or coupled with other electrified heating technologies like thermal energy storage and electric boilers.

Combined heat and power

Overview

According to the EPA, CHP generation (also referred to as cogeneration) is up to 30% more efficient than generating heat or power alone. In traditional power generation facilities, two-thirds of the useful energy in the fuel (coal, gas, or other) is wasted in the form of heat released to the atmosphere.³¹ CHP facilities have additional infrastructure to capture this waste heat and supply it in the form of hot water or steam to meet adjacent residential, commercial, and industrial demand. To maximize the benefits of CHP in a transition to low-emissions industry, CHP systems will need to be fueled with low-carbon fuels or geothermal energy.

Application

There are two types of CHP generation facilities that can be used in industry. They are differentiated by the order in which they generate heat and electricity. In a topping cycle CHP, fuel is combusted to generate electricity first and the waste heat is captured and utilized for industrial heating. In a bottoming cycle CHP, fuel is combusted to generate the heat for industrial heat first and the waste heat is captured to generate electricity. The electricity generated by both types of CHP may be used on-site, sold back to the grid, or both.

Deployment considerations

CHP is a mature technology with 82 gigawatts (GW) of total operational capacity across every state in the United States. Seventy-eight percent of this capacity is utilized for steam and power generation within the industrial sector.

Per EPA estimates from 2016, there were 149 GW of untapped potential for CHP in the United States.

Michigan alone has 5 GW of technical potential, including 2.2 GW in industrial use cases.³²

Increasing CHP in industrial applications will improve the efficiency of heat and power use, but the emissions reduction potential is limited to 30%, the efficiency benefits of CHP generation. This is because CHP facilities depend on fossil fuels as the primary source of energy. To maximize the benefits of CHP in a transition to low-emissions industry, CHP systems will need to be fueled with low-carbon fuels or geothermal energy.



Management systems

Overview and application

In addition to energy-reducing equipment, established best practices for managing energy efficiency at industrial facilities are underutilized. For example, strategic energy management (SEM) is a process that was developed more than 15 years ago to help industrial facilities more efficiently use energy resources through continuous improvement.³³ Although SEM programs have proven cost-effectiveness among facilities, these programs are not widely adopted within American industries. In addition to SEM programs, ISO 50001 is a voluntary international standard that provides a framework for implementing an energy management system (EnMS). Industrial facilities can use an EnMS to better manage energy consumption and achieve savings by establishing policies and procedures to track, analyze, and improve energy efficiency.³⁴ However, not all industrial facilities leverage EnMS to improve efficiency.

Deployment considerations

Alliances and federal programs also work to disseminate tools and resources for industrial facilities to improve energy efficiency. The DOE Better Plants program works with manufacturers to set ambitious energy, water, waste, and emissions reduction goals. To achieve this mission, the Better Plants program creates educational resources geared toward facilities.³⁵ On a regional level, the Midwest Energy Efficiency Alliance (MEEA) promotes energy efficiency to optimize energy generation, reduce consumption, create jobs, and decrease carbon emissions. Although not solely focused on the industrial sector, MEEA includes industrial facilities in its building efficiency work and provides broader information and resources to help support facilities in improving energy efficiency.

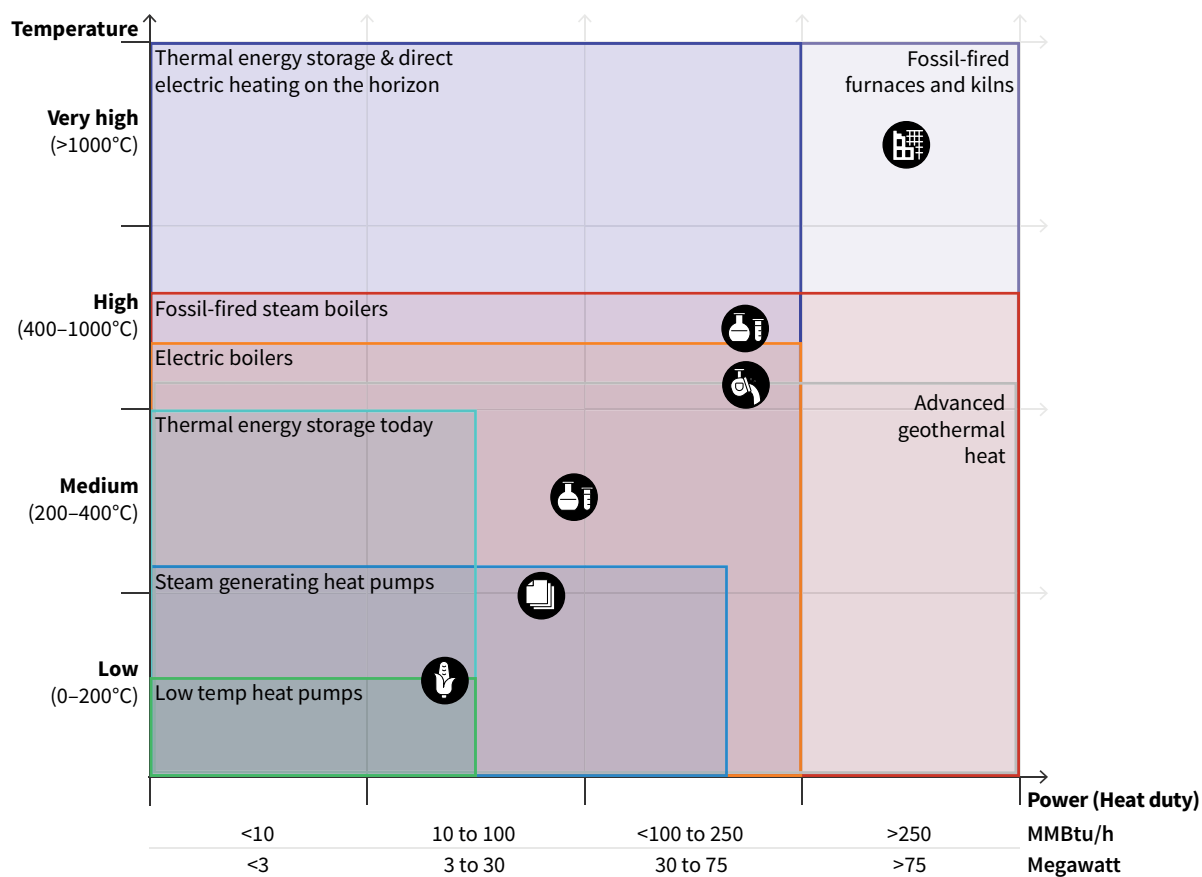
Electrification

Electrified heating technology options vary by heating temperature and power requirements. Exhibit 9 shows the heat and power capabilities of several fossil and electrified heating technologies that are commercially available today. The general heat and power requirements of industrial subsectors are overlaid on the matrix to represent where technologies are best applied. There are several electrified technologies that meet the heat requirements of the food and beverage, pulp and paper, and chemicals industries due to the processes' lower heating and power requirements.

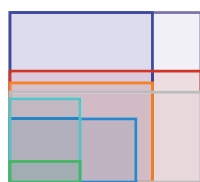
Exhibit 9

Temperature and power capabilities of heating technologies compared with the requirements of industrial sectors

This map is a simplified representation of a complex industry. Its purpose is to help a general audience understand the main factors shaping pathways to low-emission industrial heating.



Industrial heat technologies



The values represent the capability of a single unit of each technology. In practice, multiple units can be combined—for example, stacking several thermal energy storage units—to increase overall power delivery.

Note: Illustrative and non-exhaustive

RMI Graphic. Source: RMI analysis

Key industrial subsectors

- Food & beverage
- Pulp and paper
- Chemicals
- Refining
- Iron & steel, cement

The values represent the an approximate overlay of the average energy needs for typical heating applications in key industrial subsectors.

Most subsectors require heat across multiple temperature ranges, and equipment size varies depending on the application and facility scale.

Electric resistance heating

Overview

Electric resistance heating, also called joule heating or ohmic heating, uses an electric current to directly or indirectly produce heat at a target temperature. With indirect heating, the current runs through a resistor and heats surrounding materials through convection, conduction, or radiation.

Application

Resistance heating is a proven technology in industry with a TRL of 9 and is most commonly applied as indirect heating. Currently, resistance heating is mainly deployed in the food and beverage sector in drying, pasteurizing, cooking, and other processes. Resistance heating is applicable across all other industrial sectors to replace fossil-fired equipment like boilers, ovens, furnaces, and air heaters without major system changes.³⁶

Deployment considerations

Electrified equipment with resistance heating has several advantages. Uniform heating can be achieved by strategically positioning heating elements to ensure that heat is evenly controlled and consistently applied. Resistance heating also allows for precise temperature controls, making it a suitable alternative for any process heating that requires specific thermal conditions. The precise temperature controls also reduce the risk of overheating the equipment. Finally, resistance heating equipment can have much faster startup and shutdown times compared with fossil-fired equipment, allowing for more flexible production and implementation into facilities with batch productions.³⁷

Thermal energy storage

Overview

TES, or thermal batteries, is a storage solution that converts electricity into heat. The heat is stored for a duration of time depending on the material used and then released by the unit when heat is needed. Like other storage solutions, TES can heat its materials using low-cost, intermittent electricity from sources like wind or solar to minimize cost while still supplying manufacturing processes with heat on demand.

There are several types of TES, which can be divided into three categories: sensible, latent, and thermochemical. Latent and thermochemical TES technologies are lower than TRL 9 and still within their research and testing phases. Sensible TES technologies are the most technically proven at TRL 9 and store energy through heating either liquid or solid materials, like graphite, rocks, ceramics, molten salts, or water.³⁸

Application

TES can be used to replace fossil-fired equipment or be paired with other electrification technologies to improve efficiency and reliability when using intermittent renewable power sources. TES technologies can provide customized thermal energy needs depending on facility requirements, providing on-demand heat at a wide range of temperatures to provide steam, process air, and hot water for different industrial processes.

Deployment considerations

TES bridges the gap between renewable energy supply and regular baseload industrial requirements. Electrification of heating that still meets the reliability criteria industrials will likely require of TES, especially in the near and medium term while renewable capacity is still growing. In addition to reliability improvements, the ability to consume energy during off-peak hours and the use of low-cost storage mediums like rocks or bricks makes TES economically competitive compared with fossil-fired equipment.³⁹

Next-generation geothermal heating

Overview

According to The 2035 Initiative, geothermal energy is currently utilized in 40 countries for applications ranging from electricity generation to industrial heating, including a milk pasteurization facility in Klamath Falls, Oregon, and a pulp and paper processing facility in Kawerau, New Zealand.⁴⁰ While conventional geothermal systems have historically been limited by geographic constraints, next-generation geothermal technologies overcome this barrier by enabling access to subsurface heat nearly anywhere.

These advanced systems involve drilling deep boreholes to circulate fluid underground, where it absorbs geothermal heat before being pumped back to the surface for use. There are two primary types: enhanced geothermal systems, which use a single-pass fluid flow, and advanced geothermal systems, which operate in a closed-loop configuration.

Application

Next-generation geothermal heating can provide continuous, low-emissions heat, typically in the form of steam, suitable for all low- and medium-temperature industrial processes. It has low operating costs and can be used for CHP generation. Geothermal energy can also be coupled with heat pumps to boost the efficiency of energy use.

Deployment considerations

Capital costs are the main challenge for next-generation geothermal energy: each well costs approximately \$4.8 million, and a minimum of two wells are required per system. As a result, these systems may be most viable when colocated within industrial parks, where infrastructure costs and maintenance responsibilities can be shared across multiple facilities. The heat-as-a-service model, where a developer finances, constructs, and maintains the geothermal system and charges industrial customers for delivered heat and power, for example, via a monthly utility bill, may also be particularly suitable for this technology.⁴¹ Next-generation geothermal energy systems also come with some geothermal resource risk. Resource availability can be unpredictable, and wells require active oversight and specialized expertise for monitoring and maintenance.

For Michigan-specific planning, geothermal resource mapping is available through Project Innerspace.⁴²

Fuel switching and CCS

Other emissions-reduction strategies fall into two broad categories: fuel switching and CCS. Although these strategies are commercially available, they are less effective for decarbonizing low- and medium-temperature process heat. Fuel switching strategies are best reserved for applications such as high-temperature process heat or feedstock replacement in the chemicals industry where emissions cannot be easily abated with efficiency or today's low-carbon electrification technologies. Currently, CCS is most impactful and economic for process emissions where CO₂ streams are more concentrated compared with post-combustion streams with dilute concentrations.⁴³ Because these technical interventions are more strategically reserved for high-heat- and -process-related needs, they are out of scope for this roadmap. There are a few cases where individual facilities could consider fuel switching or CCS as an emissions-reduction lever for low- and medium-temperature heating applications; these are described briefly below.

Fuel switching

Fuel switching is the broad category of emissions-reduction strategies in which facilities transition to combustion fuels with lower emissions. This includes switching from fossil fuels to nonfossil sources like e-fuels or biofuels or to lower-emitting fossil fuels such as switching from coal to certified low-emissions natural gas. Cleaner fuels like low-emissions hydrogen and biofuel still offer very limited production capacities in the United States. Due to the limited availability and the complexities of transporting hydrogen over long distances, industrial applications should be reserved for hard-to-electrify applications such as high-temperature heating for steel production, heavy transportation, and some chemicals production routes.⁴⁴

However, there are a few cases where industrial facilities could consider switching to biofuels for low- and medium-temperature applications. The first is if waste biomass streams such as agricultural wastes, forest residues, or biogas from sources like landfills are readily available near a facility. The second is if there are natural synergies between the manufacturing process and its use of biomass, such as using the black liquor waste stream further in the pulp and paper manufacturing process.

In some cases, facilities with large volumes of coal combustion could consider fuel switching to natural gas if other technologies are not technically or economically feasible for the site. However, due to system inefficiencies upstream, methane leakage often reduces the emissions reduction impact of switching to natural gas.⁴⁵ To guarantee emissions reductions, it is critical to reduce fugitive and flaring emissions across gas transport, oil refining, and chemicals equipment through enhanced leak detection.

Carbon capture and storage

CCS technologies capture stationary process and combustion CO₂ emissions from industry and transport it for long-term storage. Two primary drivers for CCS viability are CO₂ concentration and distance to storage location. CCS is more efficient and cost-effective when capturing emissions streams with high CO₂ concentrations. Today, CCS is best implemented on process emissions streams because industrial combustion flue gas streams typically have lower concentrations of less than 10% CO₂.⁴⁶ The saline aquifers in Michigan and surrounding states could be potential local storage sites, making CCS in the state more viable for facilities with high process and combustion emissions. However, without any currently operational or planned CO₂ pipelines in Michigan, facilities would likely need to be colocated with storage sites for CCS to be feasible.⁴⁷

Barriers to Low-Emissions Industry

Though the emissions-reduction technologies and strategies referenced above are largely commercially available, industrial facility managers face a uniquely complex set of barriers preventing implementation. These challenges fall into three broad categories. First, **individual facility and technology constraints** reflect the site-specific challenges that make it difficult for plants to adopt new solutions. Second, **financial barriers** like high energy costs, capital requirements, and restrictive investment norms can limit the business case for cleaner technologies. Finally, **system-level barriers** such as grid capacity, long equipment lifespans, and slow permitting processes create broader structural obstacles that affect the entire industrial sector. Together, these factors shape the pace and feasibility of emissions reduction across Michigan industry, and understanding their role is essential to designing effective policy interventions to accelerate industrial emissions reductions.

Individual facility barriers and technology constraints

Unique facility needs and integration levels

Industrial facilities are highly customized environments, with equipment often tailored to specific process needs.⁴⁸ Even when technologies are designed to be cross-sector and “plug-and-play,” integrating them into existing systems requires detailed engineering and planning.

In addition to customized needs, many industrial facilities also have highly integrated heat and material flows, which can complicate efforts to electrify individual components without disrupting the entire system. Upgrades and retrofits must be considered at the facility level, which increases complexity and reduces scalability.

Dilemma of choice

Industrial facilities face a complex landscape of efficiency and electrification upgrade and retrofit options, ranging from more mature technologies like electric boilers and heat pumps to emerging solutions such as thermal batteries.⁴⁹ This abundance of options can create decision paralysis, especially when TRLs, policy incentives, and energy prices are in flux.⁵⁰ A lack of clear guidance on sequencing amid this uncertainty can stall progress, including for deployment of technologies like low- and medium-temperature electric heating that are especially valuable for their ability to be deployed across sectors.⁵¹ As a result, companies may benefit from structured technical assistance and planning support to navigate this complexity.

Capacity constraints

Some industrial facilities, especially smaller ones, may lack the internal capacity or technical expertise to evaluate emissions reduction opportunities and to determine what options might be best suited to their unique needs. These restrictions include limited awareness of available technologies, insufficient site-specific data, and a shortage of qualified assessors or consultants.⁵² Workforce development and technical assistance efforts can help support adoption of emissions reduction technologies and build internal capacity.⁵³

Financial barriers

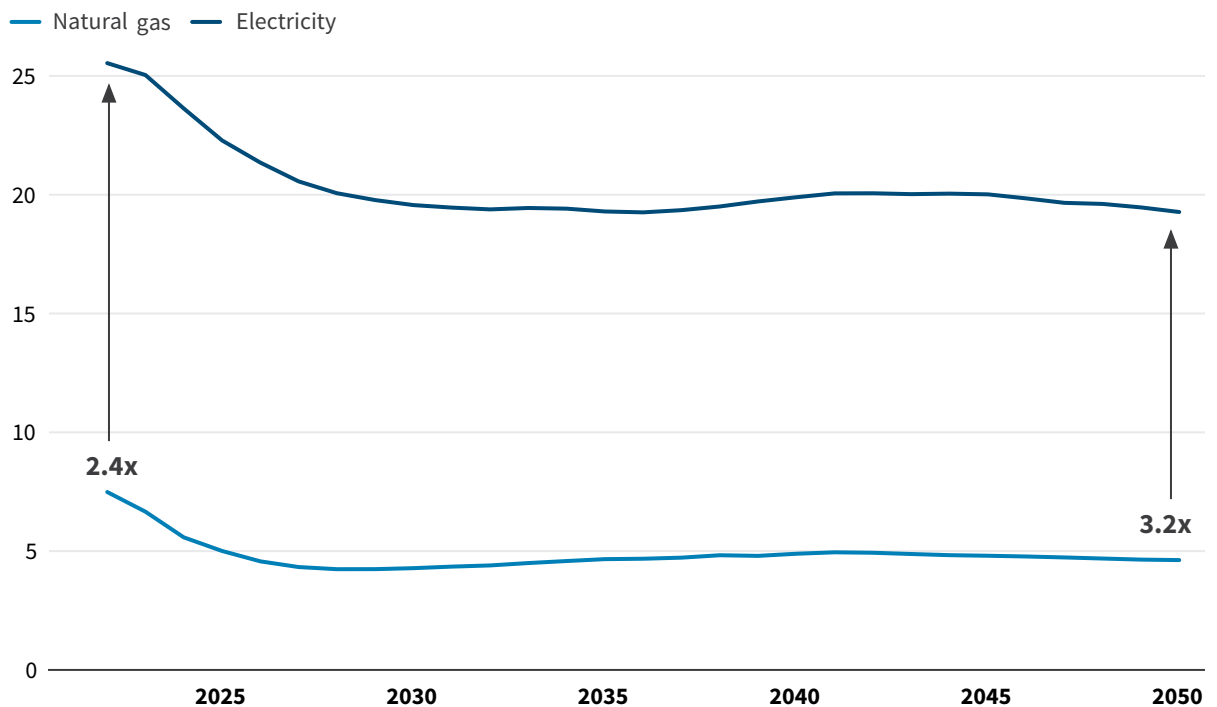
Electricity vs. gas costs and operational expenditures

The rate and scale of industrial heat electrification will depend on energy prices. Under current conditions, industrial electricity prices in the East North central region as defined by the US Energy Information Administration, which includes Michigan, are forecast to remain above industrial natural gas prices, with cost parity between the two not expected by 2050 (see Exhibit 10).⁵⁴

Exhibit 10

Industrial energy prices in the East North Central region (2022 \$ /MMBtu)

Industrial electricity prices (2022 \$ / MMBtu) in the East North Central region, which includes Michigan, were 2.4 times higher than natural gas prices in 2022 and are forecast to be 3.2 times higher in 2050.

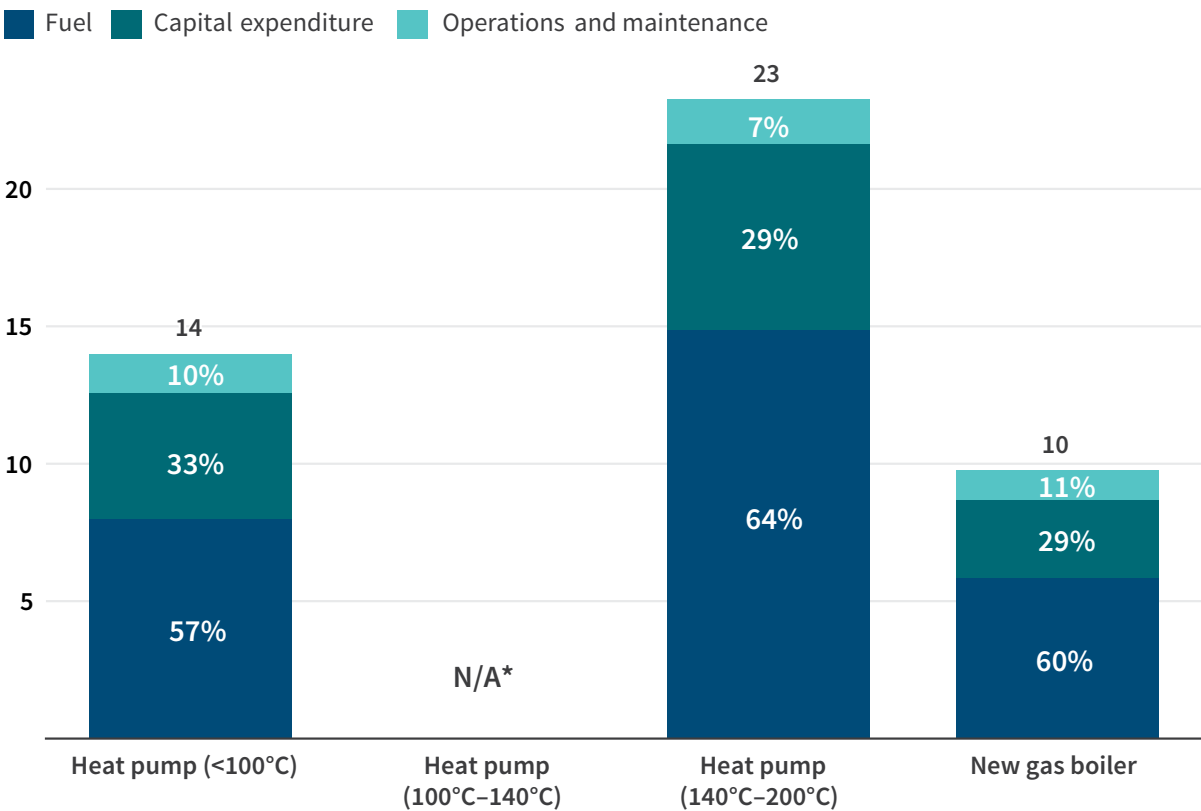


RMI Graphic. Source: US Energy Information Administration

Higher electricity costs will increase operational expenditures for facilities when switching to electrification technologies because the majority of the levelized cost of heat is due to fuel costs, rather than capital expenditure needs (see Exhibit 11).

Exhibit 11

Levelized cost of heat in industrial heating equipment (\$/MMBtu-thermal)



* Insufficient data for Heat Pump (100°C–140°C) levelized cost of heat in Michigan.

RMI Graphic. Source: Energy and Environmental Economics, Inc.

As a result of these operational expenditure considerations, the competitiveness of certain electrification technologies is sensitive to electricity prices. For example, heat pumps could theoretically competitively replace a portion of industrial natural gas demand in states with lower electricity costs, but this may require policy intervention in high-cost states to aid adoption.⁵⁵

High and fluctuating energy costs can complicate operational plans, including emissions reduction efforts. In 2022, for example, Century Aluminum Company announced it would temporarily idle its Hawesville, Kentucky aluminum smelter in response to high energy costs.⁵⁶

Efficiency gains from electric technologies can offset some operational expenditure needs. A 2023 analysis found, for example, that thermal batteries have a smaller efficiency loss as they charge and store heat than the loss associated with combusting natural gas to produce heat, contributing to the technology’s cost-competitiveness in certain regions.⁵⁷ The report also concluded this competitiveness is improved when paired with real-time pricing (RTP) or access to wholesale power markets.

Up-front capital costs

High up-front capital expenditure needs are a significant barrier to scaling industrial emissions reduction technologies. Facilities must carefully evaluate the highest-and-best use of capital by weighing emissions-

reduction investments against other priorities like production expansion, reliability and safety upgrades, or compliance needs.⁵⁸ Facilities can also consider the cost-benefit ratio of replacing equipment for emissions reductions earlier than replacement cycles would otherwise dictate. Policy interventions, particularly financial incentives, can help overcome any cost-benefit gaps related to this decision.

The DOE forecasts that, nationwide, industrial sectors could need between roughly \$700 billion and \$1.1 trillion in capital expenditure to deploy decarbonization technologies to reach net zero by 2050.⁵⁹

Short payback periods and financial model capital restrictions

Manufacturing companies often require short payback periods — frequently three years or less — for capital investments, which limits the adoption of lower-emissions technologies that may have longer-term returns.⁶⁰ This approach can be driven by factors like risk aversion, shareholder expectations, and the need to maintain competitiveness in low-margin markets.

The prioritization of short-term returns and internal rate of return found in these traditional financial models can also be shaped by limited access to or awareness of innovative financing mechanisms like carbon contracts for differences (CCfDs) or energy-as-a-service models.⁶¹

System-level barriers

Electricity demand

Large-scale electrification of industrial heat will drive increased industrial electricity demand and a need for new electricity supplies across Michigan, including in the service areas of the state's two largest electric utilities, DTE Electric and Consumers Energy. In some cases, however, holdups like grid congestion, limited interconnection capacity, and aging transmission infrastructure may constrain the grid's ability to meet that demand and delay the deployment of some electrification technologies.

If 100% of the fuel consumed for energy at industrial facilities in Michigan — excluding fuel used as a chemical feedstock, biomass, and purchased heat and absent any other changes — were shifted to electricity by 2050, annual industrial electricity demand in the state would increase 169% from 26.1 terawatt-hours (TWh) in 2024 to 70.1 TWh by 2050, according to the Energy Policy Simulator model.⁶² As of December 2024, the transmission system operator Midcontinent Independent System Operator (MISO) had approximately 56 GW — most of which is solar and battery storage capacity — in interconnection agreements projected to come online in the near term.⁶³ In the Pennsylvania–New Jersey–Maryland Interconnection's (PJM) service area at the same time, generator retirements were outpacing new generation.⁶⁴ Just within Michigan as of August 2025, there was approximately 58 GW of electricity generation capacity active in state interconnection queues.⁶⁵

These needs are not insurmountable, but they require proactive planning and investment in grid technologies and capacities. While this report is not focused on electricity sector interventions to increase grid capacity, measures taken by state decisionmakers to that effect can be an important enabler of industrial electrification. In particular, integrating flexible industrial loads into the grid can help manage load growth while enhancing the value proposition of clean energy investments by aligning demand with variable supply.

Asset lives and capital improvement cycles

Boilers and other traditional industrial heating equipment typically have long asset lives — for some, up to and beyond 40 years — and therefore long depreciation periods, which can discourage early replacement.⁶⁶ This makes timing critical because policies must align with capital improvement cycles to be effective.

High bar for proof of concept

Manufacturers can be hesitant to adopt new technologies without proven performance in similar settings. This risk aversion is especially strong in sectors with tight margins or high reliability requirements, like the cement sector, where end products must meet performance standards that may limit room for deployment of emissions-reducing supplementary cementitious materials.⁶⁷

Pilot projects and first commercial deployments are essential to build confidence. State support for demonstration grants and research, development, and demonstration (RD&D) can help de-risk these technologies and accelerate deployment.

Long deployment cycles

Deploying low-emissions upgrades and retrofits can involve lengthy planning, permitting, and execution cycles. These extended timelines are driven by several factors: the complexity of integrating new technologies into existing industrial systems, the need for detailed engineering and feasibility studies, and the time required for state and federal permitting procedures where necessary.⁶⁸ An analysis from consulting firm McKinsey & Company, for example, found that the average proposed manufacturing project takes two to three years to proceed through the federal permitting process.⁶⁹

State Interventions

Targeted state policy interventions are essential to overcoming economic, regulatory, and infrastructure barriers to industrial emissions reductions in Michigan. These interventions can help lower costs, reduce uncertainty, and accelerate deployment of clean technologies across the state's industrial sectors. State action can manifest in a variety of policy strategies that Michigan can adopt or expand on, including those presented in the *Policy interventions menu* section of this report.

Although state policy plays a pivotal role in enabling the deployment of energy efficiency and electrification technologies, these efforts must also align with Michigan's and the federal government's existing air quality and emissions regulations, which shape the compliance landscape for industrial decarbonization, and should consider Michigan's unique characteristics, like the composition of its electricity generation sources. Michigan decision makers can also consider how best to incorporate industrial emissions reduction goals into planning efforts like state implementation plans, which are developed by state and local governments and outline strategies for local actors to limit climate pollution and meet National Ambient Air Quality Standards (NAAQS) set by the EPA.

Current landscape

Michigan has several existing and upcoming policies and programs to address industrial emissions, though very few that directly address the industrial sector. The state is currently drafting its Comprehensive Climate Action Plan, which follows the release of the MI Healthy Climate Plan in 2022, which proposed measures for industrial decarbonization ranging from spurring clean industrial innovation to improving facility efficiency. Although none of these measures received a federal climate pollution reduction grant, ongoing state planning efforts remain an opportunity to address industrial emissions and secure alternative funding.

Michigan also has a small manufacturing retooling program with funds to promote energy efficiency upgrades in small facilities across the state.⁷⁰ This funding represents an opportunity for smaller businesses with less capital availability to implement energy- and cost-saving measures. However, the program currently supports efficiency measures only and does not cover the bigger facilities that we focus on in this roadmap, which have a larger emissions profile. The state also announced a \$31.8 million funding opportunity for a Supplier Conversion Grant Program, which provides funding for small and medium automotive manufacturers to shift production towards making electric vehicle components.⁷¹ While this program highlights efforts within state government to support a clean manufacturing transition, the grants do not support emissions reductions in the actual production process.

Michigan's Retired Engineers, Scientists, Technicians, Administrators, Researchers, and Teachers, or RESTART, program also offers businesses of up to 500 employees and schools and municipalities with technical assistance on energy auditing and identifying energy and cost savings opportunities.⁷² Though the program is open to businesses, it has prioritized school and municipal buildings in the last few years.

Overall, the state has some of the key ingredients to encourage low-emissions industry: appropriate regulatory authority and various state financing tools for efficiency and clean energy projects. However, to directly encourage industrial emissions reductions, the state can consider expanding programs in some places, increasing public funding availability in others, and creating new incentives to enable industrial

emissions reductions across the state. Michigan decision makers can also consider how best to incorporate industrial emissions reductions goals into planning efforts like state implementation plans, which are developed by state and local governments and outline strategies for local actors to limit climate pollution and meet National Ambient Air Quality Standards (NAAQS) set by the EPA.

Policy intervention mechanisms and authorities

To effectively support industrial emissions reductions in Michigan, state policymakers must consider not only what interventions to pursue, but also how and when those interventions can be implemented, and by whom. The mechanisms through which policies are deployed vary widely, from setting long-term standards to offering direct financial support or improving planning and permitting processes. These mechanisms fall into three broad categories:

- **Management**, which includes data collection and planning;
- **Certainty**, which involves mandates, standards, and long-term goals; and
- **Support**, which encompasses programs and policies that provide funding, incentives, workforce development, and technical assistance.

Each intervention can also involve action from one or more state decision-making bodies, including the Michigan legislature, governor's office, climate office, energy office, economic development office, public utility commission (PUC), utilities, and other agencies such as the Department of Transportation or relevant building code councils. Understanding which entities hold authority and what level of funding or regulatory change may be needed can help prioritize near-term opportunities and guide long-term planning.

Interventions can also be stacked and sequenced. Near-term interventions are those that would likely (1) be relatively easy to implement, including those that can build on existing programs, and/or (2) relate to feasible infrastructure deployment that would have the greatest potential for long-term impact if implemented today. Midterm interventions are those that might (1) face more hurdles to pass or authorize, and/or (2) have complex design features that require time to develop. Long-term interventions are those that (1) might have the greatest impact as TRLs of various low-emissions technologies improve, and/or (2) could be implemented in the near term but strengthened over time, like efficiency requirements.

The interventions in the following sections are included to show a variety of options but do not constitute specific recommendations.

Mapping policy solutions to barriers

To accelerate industrial emissions reductions in Michigan, it is critical to align policy interventions with the specific barriers they are designed to address. This helps identify high-impact opportunities, supports strategic planning, and ensures that state action is both responsive and effective.

Exhibit 12 maps potential policy strategies to the barriers they help confront. Many interventions can address multiple barriers simultaneously, such as technical assistance programs that help facilities navigate both technology complexity and internal capacity gaps. Others can be more targeted, like interconnection reforms aimed at reducing grid bottlenecks.

Exhibit 12 Mapping policy interventions to industrial emissions reduction barriers

Barrier	Policy Strategy	Benefits
Unique facility needs and integration levels	Technical assistance for facility-level technology and electricity assessments	Provide site-specific guidance to help facilities integrate new technologies into unique, complex systems
	State-mandated facility-level assessments	Ensure tailored solutions by requiring facilities identify their own emissions-reduction opportunities
	Clean heat emissions standards	Encourage whole-facility planning and integration by setting performance expectations
Dilemma of choice	Technical assistance for facility-level technology and electricity assessments	Help facilities evaluate and prioritize among many technology options
	Grant programs for industrial electrification and/or efficiency projects	Reduce risk and complexity by supporting a range of technology choices, helping direct facilities toward certain available technology options
	Encouraged participation efforts for certification programs and alliances	Help facilities identify vetted technologies and best practices, reducing uncertainty
	Equipment requirements set through air quality regulations	Set clear standards for facilities to adhere to as they navigate equipment choices
Capacity constraints	Technical assistance for facility-level technology and electricity assessments	Address gaps in internal expertise and awareness of available solutions
	Workforce education and training programs	Build the skilled workforce needed to assess and implement new technologies
	Binding targets for sector-wide industrial energy efficiency	Create a clear mandate that drives investment in capacity building and efficiency upgrades
	Material efficiency standards	Reduce the need for complex retrofits by encouraging simpler, less resource-intensive production
Electricity vs. gas costs and operational expenditures	Alternative electricity pricing paths for industrial consumers	Allow facilities to optimize energy use and reduce costs
	Large-load electricity tariff reforms	Can make electricity pricing more favorable to incentivize electrification
	Utility exit fee reforms	Reduce or remove financial penalties for leaving gas service, lowering the effective cost of switching to electric heat and improving the economics of electrification
	Incentives and support for clean electricity generation	Support development of lower-cost clean electricity, improving affordability for industrial users
	Clean heat production tax credits	Provide financial incentives for early adoption of clean heat solutions
	Tax credits for clean manufacturing production	Reduce financial burden for facilities investing in clean production technologies
	Local or regional cap-and-invest or carbon pricing mechanism	Place a price on carbon emissions and improve the relative economics of low-carbon technologies

Exhibit 12 Mapping policy interventions to industrial emissions reduction barriers, continued

Barrier	Policy Strategy	Benefits
Up-front capital costs	Grant programs for industrial electrification and/or efficiency projects	Reduce the initial investment required for new equipment
	Incentives for emissions-reducing equipment	Lower capital costs for purchasing clean technologies
Short payback periods and financial model capital restrictions	Grant programs for industrial electrification and/or efficiency projects	Make projects more attractive by improving payback periods
	Incentives for emissions-reducing equipment	Enhance financial returns, helping projects meet internal investment criteria
	State “buy clean” initiatives	Create market demand for low-carbon products, improving investment returns
	Local or regional cap-and-invest or carbon pricing mechanism	Create a predictable carbon price and generate revenue that can be reinvested into clean technology deployment for long-term value
Electricity demand	Renewable portfolio standards that include renewable thermal power/waste heat	Reduce grid strain by promoting nonelectric clean heat sources
Asset lives and capital improvement cycles	Clean heat production tax credits	Incentivize early replacement of long-lived fossil equipment
	Incentives for emissions-reducing equipment	Make retrofits more financially attractive before end of life
	Grant programs for industrial electrification and/or efficiency projects	Support upgrades outside normal capital cycles
	Efficiency requirements for new-build facilities	Ensure new facilities adopt efficient technologies from the outset, avoiding long-lived fossil systems
	Energy efficiency standards for industrial equipment	Encourage replacement of outdated equipment with more efficient alternatives
	Equipment requirements set through air quality regulations	Encourage replacement of high-emissions equipment that does not meet minimum performance or emissions standards
High bar for proof of concept	RD&D grants or incentives	Fund demonstration projects to prove new technologies in real-world settings
Long deployment cycles	Alternate approval processes for emissions reduction projects at existing sites	Shorten permitting and implementation timelines and streamlines regulatory processes for faster project delivery

RMI Graphic

Policy interventions menu

Though adequately mapping policy interventions to major decarbonization barriers is essential to support industrial emissions reductions, so too is robust design of those interventions.

Generally, the best-practice design principles for state policy interventions ensure the policies are:

- Rooted in evidence and data,
- Clear and adaptable,
- Effective and efficient,
- Equitable and inclusive,
- Focused on the long term, and
- Transparent and enforceable.

Interventions can be sequenced to match time-based considerations like the TRLs of emissions reduction technologies and the feasibility of deployment in the near through long term. They can also be arranged so enabling policies, like financial supports for rapid deployment, and foundational policies, like those that advance grid-scale clean energy to support electrification, are implemented in the near to midterm, with other policies like emissions standards being implemented in the near term but made more stringent over time.

The interventions outlined in this section, also reflected in Exhibit 12, span a range of mechanisms and include some best practice guidance. An intervention's inclusion does not constitute a recommendation but is intended to show the variety of options available to state decision makers.

Notably, the emissions intensity of Michigan's grid — and therefore the electricity received by grid-connected facilities — differs by utility provider, making electricity-related interventions more pivotal for some facilities than others. Consumers Energy, for example, reported that in 2024, approximately 59.9% of its electric supply came from gas-based sources, 31.8% from coal, and 8.6% from wind, in addition to small contributions from other renewables.⁷³ Though Consumers Energy had planned to eliminate the use of coal in its owned generation by 2025, recent orders from the DOE have directed the utility to continue operating a coal plant that had been slated for retirement.⁷⁴ DTE Energy's fuel mix for electricity supply in 2024 was approximately 41% coal, 26% natural gas, 19% nuclear, and 12% wind and solar, among other resources.⁷⁵ Across the entire state's service area in 2023, approximately 46% of electricity generation came from natural gas and 11% from renewables.⁷⁶

STRATEGY 1

Support the adoption of emissions-reducing technologies financially

(1.1) Tax credits for clean manufacturing production

To help address cost barriers, Michigan can consider tax credits for clean manufacturing production that provide financial incentives to industrial facilities that produce low-carbon goods. These credits can be structured to reward manufacturers based on the carbon intensity of their products, with tiered benefits for commodities such as steel, cement, and chemicals. The policy could also be designed to make credits refundable and transferable to aid accessibility for firms without tax liability as well as incorporate robust emissions tracking systems to verify performance.⁷⁷

Exact emissions reductions from this policy depend on uptake and product mix, but targeting high-emissions materials could yield substantial benefits. Costs would primarily fall on the state budget through forgone tax revenue, with administrative costs for verification and compilation of accurate and updated emissions data, as well as reporting enforcement.

Michigan does not currently have a clean manufacturing production tax credit (PTC). State policy designers could draw from language of the federal Advanced Manufacturing Production Credit (known as 45X) established by the 2022 Inflation Reduction Act.⁷⁸ Some efforts to establish international standards for carbon intensity of heavy industry goods like steel also outline metrics and thresholds that could inform any standards set by the state for the credit.⁷⁹

(1.2) Clean heat production tax credits

A clean heat PTC incentivizes the generation of low-carbon heat from electricity for industrial processes and reduces operational costs for sectors otherwise reliant on fossil-fueled heat.⁸⁰ As with a clean manufacturing tax credit, the PTC should be refundable and transferable, allowing firms without tax liability to benefit directly without relying on tax equity investors, who typically capture a significant portion of the credit's value.⁸¹ The PTC should also be designed to decrease in value as TRLs improve, and can be calculated based on the temperature range and emissions profile of the heat source and the temperatures required for specific industrial processes. Emissions reduction potential is significant, particularly in sectors reliant on fossil-fueled heat. Costs would be borne by the state through tax expenditures, and enforcement would require emissions data collection and verification systems. Michigan does not currently have a clean heat PTC in effect.

STRATEGY 1, CONTINUED

Support the adoption of emissions- reducing technologies financially

(1.3) Grant programs for industrial electrification and/or efficiency projects

Grant programs for industrial electrification and/or efficiency projects provide direct financial support for facilities to adopt clean technologies, addressing financial barriers and the dilemma of choice by enabling facilities to act on emissions-reduction opportunities. Grants can apply to both new construction and retrofits and may include transparency stipulations or cost-sharing requirements. Programs should prioritize projects with high emissions reduction potential and be flexible enough to accommodate diverse facility needs.

Michigan has some basis for such a program in the matching grants for energy efficiency improvements for small manufacturers offered through its retooling program.⁸² The emissions reduction potential of grants depends on project scope, and long-term grant project success relies on electricity prices, with uptake potentially limited if significantly higher annual energy costs would make electrification financially infeasible despite deferred up-front costs. Costs are borne by the state or federal government, although there is potential for leveraging private capital. Grant programs can also be reauthorized to support long-term emissions reduction planning.

(1.4) Incentives for emissions-reducing equipment

Incentives for emissions-reducing equipment, such as utility rebates or tax credits, can support the purchase and installation of lower-emissions technologies by addressing up-front capital costs and short payback period barriers. These incentives can be scaled based on the margin by which equipment outperforms emissions intensity thresholds. Incentives can be tailored to different facility sizes and technology types and can be particularly impactful when paired with performance standards. These incentives should be designed to ensure real emissions benefits to avoid uptake by buyers who would have purchased emissions-reducing equipment even without the incentive. Emissions reductions will vary by equipment type. Costs are borne by utilities or the state, and continued funding and reauthorization of the incentives would be needed.

Utilities around the country have a variety of efficiency incentive programs.⁸³ Michigan does not have a direct incentive for deployment of specific industrial or commercial technologies like heat pumps, though the state does have a Michigan Home Energy Rebates (MiHER) program administered by the Department of Environment, Great Lakes, and Energy (EGLE) that supports some technology upgrades and could serve as a model to be extended to industrial facilities.⁸⁴

STRATEGY 2

Improve efficiency requirements

(2.1) Efficiency requirements for new-build facilities

Efficiency requirements for new-build industrial facilities mandate that newly constructed plants meet minimum energy performance standards. These requirements can be embedded in building codes or sector-specific regulations and are designed to lock in long-term energy savings and avoid future retrofit needs. Michigan's building codes are based in part on the 2015 International Energy Conservation Code, with state-specific amendments.⁸⁵

Because this policy has the potential to increase up-front investment costs, pairing it with financial supports will increase its efficacy. Although emissions reductions depend on facility type and energy use, early adoption of electric boilers or heat pumps in new facilities can significantly reduce long-term fossil fuel reliance. Costs are borne by developers, but can be mitigated through incentives, and assistance can be tailored to small and medium-sized manufacturers that may face the largest proportional up-front cost burden.

(2.2) Renewable portfolio standards that include renewable thermal power/waste heat

Expanding Michigan's Renewable Portfolio Standard (RPS) to include renewable thermal energy — like solar thermal, biomass, and geothermal technologies — and waste heat recovery would recognize nonelectric clean heat sources as eligible for renewable energy credits.⁸⁶ This policy would entail tracking thermal heat output across industrial facilities, setting a portfolio standard for the share coming from clean heat, creating a market for clean heat credits, and assessing compliance costs for facilities that fall short of the standard.

This policy supports emissions reduction in sectors where electrification is challenging and can be adjusted to match regional resource availability. Because most RPS structures are designed around electrical — not heat — output, this change would require careful design, including new tracking and crediting systems for thermal energy, legislative updates to the RPS framework, and clear definitions of eligible technologies.

This intervention would broaden the scope of Michigan's existing clean energy policy to align it with the new maturity of lower-emissions technology in the industrial space, and directly addresses system-level barriers related to electricity demand. It targets potentially underutilized heat sources and can be inclusive if designed to support smaller facilities and diverse technologies. Emissions reductions depend on uptake and technology mix. Costs would likely be primarily administrative and borne by the state, with potential for long-term savings through reduced grid strain.

Case Study: Massachusetts's Alternative Energy Portfolio Standard

Massachusetts's RPS and Alternative Energy Portfolio Standard (APS) provide an example of how renewable thermal energy can be integrated into state-level clean energy standards. Established under the Green Communities Act of 2008, the APS was designed to complement the state's RPS — itself established by the Massachusetts Electric Utility Restructuring Act of 1997 and amended by the 2008 law — by recognizing technologies that improve energy efficiency and reduce climate pollution outside of renewable energy systems.⁸⁷ In December 2017, the Massachusetts Department of Energy Resources concluded rulemaking to expand the APS to include renewable thermal technologies, fuel cells, and waste-to-energy thermal systems as eligible sources.⁸⁸

Under the APS, eligible renewable thermal technologies include CHP, air- and ground-source heat pumps, geothermal heat exchange, solar thermal, woody biomass, biogas, liquid biofuels, and compost heat exchange systems, all subject to specifications.⁸⁹ These systems must deliver useful thermal energy to facilities in Massachusetts and have an operational start date of January 1, 2015, or later. Facilities that qualify generate alternative energy certificates (AECs) per every megawatt-hour equivalent of thermal energy generated.⁹⁰ These AECs, like renewable energy credits under the RPS, can be bought by utilities to comply with state clean energy standards, creating a financial incentive for clean thermal energy deployment.⁹¹

Massachusetts's APS has design features that could be emulated in other states' policies. For example, the program uses multipliers to reward technologies based on their emissions reduction potential and application type. Ground-source heat pumps and solar hot water systems used for domestic purposes receive higher multipliers, increasing their financial attractiveness.⁹² The APS minimum standard indefinitely increases by 0.25% annually to promote steady growth in clean thermal energy adoption.⁹³ This incremental approach aims to help Massachusetts build a diverse portfolio of clean thermal technologies while reducing reliance on fossil fuels for heating.



STRATEGY 2, CONTINUED

Improve efficiency requirements

(2.3) Energy efficiency standards for industrial equipment

Energy efficiency standards for industrial equipment set minimum performance thresholds for technologies such as motors and boilers. These standards can be phased in over time and be designed to become more stringent, encouraging continuous improvement.⁹⁴

Though Michigan does not have a binding industrial energy efficiency standard, the state does promote energy efficiency efforts through its energy waste reduction targets, which require utilities to help customers, including industrial customers, reduce energy use.⁹⁵ Air permitting processes overseen by EGLE (e.g., permits to install and renewable operating permits) may also include energy-related conditions for equipment or processes.⁹⁶

This policy, which addresses barriers related to outdated equipment and long asset lives, is most impactful when paired with state incentives and utility programs that support efficiency upgrades. This is in part to encourage manufacturers to outperform the standard's cutoffs where possible. It can also be paired with "no-regrets" policies for end-of-life boiler replacement along with financial supports to cover the cost differential between a traditional replacement boiler and an electric boiler or heat pump for small and medium-sized manufacturers. Michigan already has administrative laws governing boiler repairs and installation.⁹⁷ Costs are borne by manufacturers and facility owners, with enforcement costs borne by the state.

(2.4) Binding targets for sector-wide industrial energy efficiency

Binding energy efficiency targets establish mandatory goals for energy savings across the industrial sector. These targets can be aligned with utility programs and state climate goals and may be implemented through legislation or regulatory mandates. Although Michigan does not currently have sector-specific efficiency targets, it does have energy savings targets for utilities.⁹⁸

This policy can address capacity constraints by setting clear goals for facilities to follow and encourages long-term planning. Emissions reductions depend on the ambition of the targets and compliance rates. Costs include enforcement and program administration, typically borne by the state, with potential for cost savings through reduced energy use. Equity among facilities can be supported by tailoring targets to facility size and sector characteristics.

(2.5) Encouraged participation efforts for certification programs and alliances

Encouraging industrial facilities to participate in voluntary certification programs and alliances — such as ISO 50001 or sector-specific energy management initiatives — can build awareness of best practices and promote recognition for facilities adopting efficiency improvements.⁹⁹ This policy is low cost and easy to implement but has limited impact without mandates or incentives. Michigan could also consider creating something akin to California's Heat Pump Partnership, a public-private initiative that aims to rapidly scale the adoption of residential heat pumps across the state through consumer and contractor education and targeted policies.¹⁰⁰ Michigan does not have a direct certification program policy in effect. Emissions reductions are indirect and depend on voluntary uptake. Costs are minimal and are borne by participating firms.

(2.6) Material efficiency standards

Material efficiency standards require manufacturers to reduce the amount of raw material used in production or increase the use of recycled content. By reducing emissions via materials changes and without necessitating complex retrofits, this policy aids efficiency without requiring the specialized knowledge or capacity needed for equipment changes, which some facilities may lack. These standards support circular economy efforts and can drive innovation in product and process design. Implementation would require sector-specific tailoring and robust enforcement mechanisms.¹⁰¹

Emissions reductions depend on material type and production volume, though an analysis for the Energy Transitions Commission suggested material efficiency measures could curb global heavy industry emissions by 40% by 2050.¹⁰² Costs include compliance and enforcement, typically borne by manufacturers and the state. Michigan does not have a dedicated material efficiency standard in effect.

(2.7) Equipment requirements set through air quality regulations

Under the federal Clean Air Act, states must develop regulations and documents—collectively referred to as state implementation plans (SIPs)—to implement, maintain, and enforce the NAAQS set by the law for six criteria air pollutants.¹⁰³ Michigan EGLE's Air Quality Division is the agency responsible for developing the state's SIP and other state air quality rules.¹⁰⁴

Michigan can leverage air quality regulations to drive industrial decarbonization by setting equipment standards that require the adoption of lower-emissions technologies more stringent than federal rules. This approach has precedent in California's South Coast Air Quality Management District (SCAQMD), which in 2024 passed zero-emission boiler rules designed to limit nitrogen oxide (NOx) emissions from residential and commercial boilers in line with SCAQMD's air quality management plan.¹⁰⁵ The rules set NOx emission limits and a compliance schedule for covered facilities, providing clear compliance pathways for manufacturers.¹⁰⁶

Adopting similar equipment requirements in Michigan through the SIP process or other rulemaking has the potential to lock in long-term emissions reductions, improve local air quality, and create market certainty for manufacturers investing in clean technologies. These standards can be phased in over time, updated to reflect advances in emission control technologies and changes in federal and state air quality regulation, and paired with other supportive policies like technical assistance and financial supports.



STRATEGY 3

Incentivize flexible industrial electricity demand

(3.1) Alternative electricity pricing paths for industrial consumers

Granting industrial consumers access to real-time or wholesale electricity pricing allows facilities to purchase electricity at rates that reflect actual market conditions, rather than fixed tariffs. This can incentivize load shifting to off-peak hours where possible, and support deployment of electrification technologies in concert with thermal batteries.¹⁰⁷ RTP is especially valuable for sophisticated industrial users with predictable energy use or flexible operations.

The MPSC has previously directed DTE Energy and Consumers Energy to implement time-of-use and on-peak rates as part of electric rate cases, and has established the Michigan Power Grid Time-Based Pricing Workgroup to support the rollout of this pricing.¹⁰⁸ Some utilities may be able to offer custom pricing arrangements for large customers, but these are not standardized or required by Michigan policy. RTP is not broadly mandated but may be available to large customers through special contracts or pilot programs with utilities.

To maximize effectiveness, RTP programs should be opt-in and paired with advanced metering infrastructure. Policies should be rooted in data, using historical load profiles and price signals to guide design. They should be adaptable to evolving grid conditions and equitable by ensuring smaller facilities are not excluded due to complexity or infrastructure gaps. Emissions reductions are indirect but potentially significant if load shifting enables greater integration of electrification technology. Costs are borne by utilities and participating facilities, with potential savings from reduced peak demand and improved grid stability.

STRATEGY 3, CONTINUED

Incentivize flexible industrial electricity demand

(3.2) Large-load electricity tariff reforms

Large-load tariff reforms aim to restructure electricity pricing for industrial customers to better reflect their actual cost of service and incentivize flexible, low-carbon energy use. This can include changes like creating new rate classes for flexible loads or implementing critical peak pricing.¹⁰⁹ These reforms allow facilities to benefit from lower off-peak prices, especially when paired with on-site storage technologies. Tariff changes should be transparent and aligned with grid planning processes, and include clear metrics for participation and ratepayer protections, including ensuring industrial users continue to contribute an appropriate share of nonmarginal costs and customer-specific costs.¹¹⁰

A forthcoming report from Natural Resources Defense Council (NRDC) featuring analysis from Energy and Environmental Economics, Inc (E3) finds that, while electricity rate reform is foundational to narrowing the price gap between producing industrial heat with electricity versus gas boilers, marginal cost based rates are insufficient on their own to bring electrification to cost parity with gas in most subsectors. In Michigan, sectors with lower temperature boiler heat needs like paper facilities are closest to cost parity; whereas sectors with higher temperature heat needs like ethyl alcohol have lower heat pump efficiency and larger effective spark spread. The report identifies several ways to close this gap, including exploring the potential to use waste heat from non-combustion sources like refrigeration, which can significantly increase the performance of heat pumps and lower their operating costs. In addition, policies like a clean heat PTC can be designed to eliminate any remaining gap and unlock more cost-effective electrification opportunities.

Equity considerations are critical to ensure small and variable-load facilities are not disadvantaged by tariff changes. Although emissions reductions are indirect, they can be substantial if reforms enable broader electrification and load flexibility. Depending on the structure of the tariff changes and if other ratepayers are implicated, costs are primarily administrative and borne by utilities and regulators, with potential savings for participating facilities. Michigan does not currently have a direct policy or program in effect.

(3.3) Utility exit fee reforms

Exit fee reforms remove or reduce financial penalties for industrial customers who switch from fossil fuel systems (typically natural gas) to electricity. These fees, often imposed by utilities to recover infrastructure investments, can lock facilities into carbon-intensive systems and discourage electrification.¹¹¹ Michigan does not have a policy dedicated to statewide reform of exit fees for industrial customers.

This policy can be designed to limit exit fees to cases where recent infrastructure investments were made and to establish transparent criteria for fee applicability. Emissions reductions are indirect because removing exit fees can potentially unlock electrification for facilities otherwise deterred by cost. Costs may shift to utilities or be absorbed through rate adjustments, requiring careful stakeholder engagement.

Advancing grid clean capacity for industrial electrification

While this report focuses on ways to directly influence industrial clean energy use, measures to increase clean generation to meet this new industry-driven electricity demand on the grid will be important to emissions reduction efforts by making electricity cheaper, cleaner, and more reliable. State decisionmakers can confront barriers to clean generation like grid congestion, limited interconnection capacity, and aging transmission infrastructure through a variety of mechanisms, including:

- **Improved utility planning procedures:** By aligning long-term utility investment strategies with state decarbonization goals, this approach helps ensure clean grid power is available when facilities look to electrify their processes.
- **Improved utility interconnection procedures:** Slow interconnection procedures can delay new clean generation sources from connecting to the grid. Improving and streamlining these procedures reduces grid bottlenecks and is critical for ensuring that the grid is able to meet industrial electricity demand with clean generation.
- **Siting and permitting reforms for clean energy projects:** Siting and permitting reforms accelerate the development of clean energy infrastructure by reducing soft costs and increasing transparency, addressing system-level barriers to grid expansion.
- **Supported deployments of grid-enhancing technologies (GETs) and advanced conductors:** Supporting deployment of GETs, such as dynamic line ratings, advanced conductors, and topology optimization, can increase grid capacity and flexibility without major infrastructure expansion, mitigating electricity demand concerns.¹¹² These technologies improve transmission efficiency and resilience, enabling more clean energy to reach industrial loads.
- **Incentives and support for clean electricity generation:** A suite of complementary financial incentives, standards, and financing structures can be deployed to incentivize both grid-scale and on-site clean energy generation and to help industries reliably and affordably access clean electricity. These might include a tax credit for clean electricity generation, clean electricity rebates, incentives for on-site renewables installation, standards for clean generation colocation with new-build industrial facilities, and CCfDs for clean electricity.
- **Reduced or eliminated grid interconnection fees for low-carbon energy:** Reducing or eliminating grid interconnection fees for low-carbon energy projects lowers financial barriers for developers that otherwise act as a barrier to the deployment of clean electricity generation technologies.

STRATEGY 4
Streamline permitting processes for emissions reduction projects

(4.1) Alternate approval processes for emissions reduction projects at existing sites

To directly address long deployment cycles as a barrier, the state could consider streamlining permitting for emissions reduction projects at existing facilities. This could include fast-tracking approvals, standardizing documentation, and providing clear eligibility criteria for technologies like electric boilers or heat pumps. Although Michigan does not have a dedicated expedited permitting pathway for clean industrial upgrades, the state has proposed and implemented a variety of permitting changes since 2018.¹¹³

To be effective, these processes should prioritize high-impact projects, maintain environmental safeguards, and be accessible to small and medium-sized manufacturers. Emissions reductions depend on project scope, but faster permitting can shorten deployment timelines and thus accelerate emissions reductions. Costs are mainly administrative and would be borne by permitting agencies.

STRATEGY 5
Improve emissions standards

(5.1) Clean heat emissions standards

The state could also consider a clean heat emissions standard, which sets performance benchmarks for industrial thermal energy systems.¹¹⁴ The standard should be technology-neutral, allowing facilities to choose the most cost-effective compliance pathway, but also have guardrails to ensure only meaningful measures are supported.¹¹⁵ The standard should apply to both new and existing equipment and should be rooted in analysis that aligns the rule with broader state climate goals. Michigan does not currently have a clean heat emissions standard.

Best practices include using verified emissions data, setting clear thresholds that can be made more stringent in the long term, and ensuring enforcement through transparent reporting.¹¹⁶ Emissions reductions depend on coverage and stringency, but the policy is foundational for driving long-term electrification and clean heat adoption. Costs include compliance and verification, typically borne by facilities and the state.

(5.2) Local or regional cap-and-invest or carbon pricing mechanism

A cap-and-invest or carbon pricing mechanism sets a price on industrial emissions, creating financial incentives for facilities to reduce their carbon footprint. Revenue from the program can be reinvested in clean technology deployment, workforce training, or community resilience. Michigan does not have a carbon pricing program, and while politically challenging, this policy could offer a powerful market signal and long-term funding source.

Carbon pricing should reflect emissions intensity and be phased in gradually. Equitable outcomes can be supported through specifically allocated revenue investment in disadvantaged communities. Emissions reductions from the program depend on the price level and coverage, and costs are borne predominantly by emitters, with potential economic benefits from reinvestment and innovation.

Case Study: Colorado’s Clean Heat Standard

In 2021, Colorado became the first state in the United States to adopt a clean heat standard through Senate Bill 21-264, which mandates climate pollution reductions from gas utilities. The law requires gas distribution utilities with more than 90,000 retail customers to submit clean heat plans to the state’s PUC demonstrating how they will reduce emissions 4% by 2025 and 22% by 2030, relative to 2015 levels.¹¹⁷ These plans can include a mix of clean heat resources, including beneficial electrification, energy efficiency, recovered methane, and green hydrogen, and must be implemented at the lowest reasonable cost to customers, with a cost cap of 2.5% of annual gas bills for all full-service customers.¹¹⁸

Colorado’s largest utility, Xcel Energy, submitted its first clean heat plan in 2023, committing \$176 million annually to reduce emissions by 2.2 Mt by 2030 through six emissions reduction strategies.¹¹⁹ The Colorado PUC approved the plan in June 2024 with modifications, after opposition from some nonprofits over the utility’s proposed inclusion of certified natural gas and carbon offsets in its first clean heat portfolio proposal initiated a discussion process.¹²⁰

Colorado’s approach also includes data-gathering and transparency elements in clean heat plan requirements, like an annual report requirement and a directive for utilities to describe their monitoring and verification methodology.¹²¹

STRATEGY 6

Leverage state buying power

(6.1) State “buy clean” initiatives

A state or regional “buy clean” initiative uses public procurement to support low-carbon industrial products — especially construction materials like steel, cement, and asphalt — by prioritizing procuring materials with verified lower emissions for state-backed projects. This creates stable demand for cleaner goods and helps manufacturers economically justify investments in emissions-reducing technologies. Michigan has no dedicated buy clean policy in place but was part of the federal–state Buy Clean Partnership under the Biden administration.¹²²

Best practices include setting clear emissions thresholds, using standardized product-level carbon intensity metrics, and ensuring verification systems are transparent and enforceable.¹²³ Costs to the state may be higher for acquisition of low-carbon materials compared with traditional materials.

STRATEGY 7

Understand the opportunity and build information bases to support modernizing industrial technology deployment

(7.1) RD&D grants or incentives

RD&D grants support innovation in industrial decarbonization by funding pilot projects, material development, and process improvements. These programs help de-risk and demonstrate proof of concept for emerging technologies. Michigan has a foundation for this type of support in a set of laws signed in January 2025 that establish both the Michigan Innovation Fund — initially allocated \$60 million in funding — and a state Research and Development Tax Credit.¹²⁴

This policy can be targeted toward especially carbon-intense industrial process needs and sectors where TRLs are low. Transparent reporting and qualification requirements should be included in the program, which should also be adaptable to evolving TRLs. Emissions reductions are long term and depend on successful commercialization. Costs are borne by the state, which would likely need to continuously reauthorize funding for the program, with potential for private co-investment.

(7.2) Workforce education and training

Workforce education and training programs help build the skilled labor needed to deploy and maintain clean industrial technologies. These can include direct job training, curriculum development, and support for access to electrification-related careers. The Michigan Department of Labor and Economic Opportunity, Workforce Development already has a system to award funds to employers for training efforts through Michigan Works! agencies, including programs like the Going PRO Talent Fund.¹²⁵ EGLE also identified workforce development and training as a key strategy in the MI Healthy Climate Plan.¹²⁶

Programs should be designed with industry input, prioritize underserved communities, and be flexible to meet changing technology needs. Although emissions reductions are indirect, workforce readiness is essential for long-term decarbonization. Costs are borne by the state and participating institutions, with benefits including job creation and economic resilience.

STRATEGY 7, CONTINUED

Understand the opportunity and build information bases to support modernizing industrial technology deployment

(7.3) Technical assistance programs for facility-level technology and electricity assessments

Technical assistance programs help industrial facilities evaluate technology options and site-specific opportunities for emissions reductions, addressing the dilemma of choice, unique facility needs, and capacity constraints barriers. Support can include engineering assessments, energy audits, and guidance on electricity pricing models or financing options. Emissions reductions of this policy are indirect and depend on uptake and implementation of projects indirectly enabled by the assistance. Costs are borne by the state, with potential for federal support.

Michigan has several existing programs that can be leveraged for this policy. For example, EGLE has the RESTART program aimed at providing technical assistance and on-site assessments for small- and medium-sized commercial businesses.¹²⁷ The Michigan Infrastructure Office, established by Governor Gretchen Whitmer, also has a Technical Assistance Center, though the first window for funding opportunities through the center closed in February 2025.¹²⁸

(7.4) State-mandated facility-level assessments

Mandating facility-level assessments would require industrial sites to evaluate their emissions reduction potential, helping identify opportunities and inform planning. Although Michigan does not currently require these assessments, similar reporting requirements exist for air quality permitting and compliance.¹²⁹

To be effective, mandates should include clear guidelines, allow flexibility in methodology, and be paired with technical assistance. They should be enforceable and designed to minimize burden on small manufacturers. Emissions reductions depend on follow-through, but the policy is foundational for building a statewide low-emissions roadmap for industry. Costs are borne by facilities and the state.

Building the Foundation for a Low-Carbon Industrial Future

There is both a climate and material benefit for Michigan to pursue low-emissions, low- and medium-temperature industrial heat. To meet statewide decarbonization goals set forth in the MI Healthy Climate Plan, deliver clean air benefits to burdened communities, and prepare Michigan's industry to compete in the low-carbon markets of the future, industrial emissions need to be abated. Due to barriers like project economics, technical assistance needs, and grid capacity concerns, companies are not pursuing ways to improve their production methods independently. The interventions outlined in this roadmap can ease the switch for facilities adopting more efficient and electrified technologies.

While one intervention will not sufficiently address the problem, the state can consider sequencing a number of priority policies to begin to address industrial emissions with technology that is already commercially viable.



Appendix: Glossary of Technical Terms

Advanced geothermal systems: Geothermal systems that operate in a closed-loop configuration to extract heat from the earth.

Carbon border adjustment mechanism: A policy tool that imposes a carbon price on imports to equalize the cost of domestic and foreign goods.

Carbon capture and storage (CCS): A technology that captures carbon dioxide emissions from sources like power plants and stores it underground.

Carbon contracts for differences (CCfDs): Financial instruments that provide price certainty for low-carbon technologies by covering cost gaps.

Clean heat standard: A policy that sets emissions performance benchmarks for heating technologies.

Coefficient of performance (COP): A ratio that measures the efficiency of heating technologies, comparing heat output to energy input.

Combined heat and power (CHP): A system that simultaneously generates electricity and useful heat from the same energy source.

Electric boiler: A boiler that uses electricity to generate heat, often used as a cleaner alternative to fossil-fueled boilers.

Electrification: The process of replacing fossil fuel-based systems with electric-powered alternatives.

Energy management system (EnMS): A framework for managing energy use and improving efficiency in organizations.

Enhanced geothermal systems: Geothermal systems that use fluid injection to enhance heat extraction from underground reservoirs.

Geothermal energy: Energy derived from the heat stored beneath the earth's surface.

Greenhouse Gas Reporting Program (GHGRP): A US EPA initiative for tracking industrial emissions.

Heat pump: A device that transfers heat energy from a source to a destination, often used for heating or cooling.

High-temperature heat: Heat delivered to an industrial process above 400°C.

Industrial assessment centers (IACs): Programs that provide energy assessments to industrial facilities to identify efficiency improvements.

ISO 50001: An international standard for energy management systems to improve energy performance.

Levelized cost of heat: A measure of cost for delivering thermal energy, measured in dollars per MMBtu delivered to an industrial process.

Low-carbon fuels: Fuels that produce fewer carbon emissions compared with traditional fossil fuels.

Low-temperature heat: Heat delivered to an industrial process between 0 and 200°C.

Material efficiency standards: Strategies to reduce the amount of raw materials used in manufacturing or increase recycled content.

Medium-temperature heat: Heat delivered to an industrial process between 200°C and 400°C.

Renewable portfolio standard (RPS): A regulation that requires increased production of energy from renewable sources.

Technology readiness level (TRL): A measure used to assess the maturity of a particular technology.

Thermal energy storage (TES): A technology that stores thermal energy for later use, improving energy efficiency and flexibility.

Waste heat recovery: The process of capturing and reusing heat that would otherwise be lost in industrial processes.

Endnotes

- 1 *HEATSET: US Industrial Sector Heat Emissions and Temperature Dataset*, October 2024, Center for Applied Environmental Law & Policy, <https://www.caelp.org/heatset>.
- 2 *Case Study: MVR Heat Pumps & Thermal Efficiency at Chivas Brothers Distillery*, Renewable Thermal Collaborative, June 6, 2024, <https://www.renewablethermal.org/piller-chivas-case-study/>; *Case Study: Diageo Distillery*, Renewable Thermal Collaborative, June 7, 2022, <https://www.renewablethermal.org/case-study-diageo-distillery/>; *Case Study: Thermal Energy Storage at Herkkumaa Food Manufacturing Facility*, Renewable Thermal Collaborative, June 13, 2024, <https://www.renewablethermal.org/elstor-herkkumaa-case-study/>.
- 3 “Michigan,” US Bureau of Labor Statistics Midwest Information Office, July 2025, <https://www.bls.gov/regions/midwest/michigan.htm>.
- 4 “Michigan,” United States Trade Representative, accessed September 5, 2025, <https://ustr.gov/map/state-benefits/mi>.
- 5 Michigan Energy Policy Simulator (online tool), Energy Innovation LLC and RMI, accessed September 5, 2025, <https://energypolicy.solutions/simulator/michigan/en>.
- 6 *MI Healthy Climate Plan*, Michigan Department of Environment, Great Lakes, and Energy (EGLE), April 2022, accessed September 5, 2025, <https://www.michigan.gov/egle/-/media/Project/Websites/egle/Documents/Offices/OCE/MI-Healthy-Climate-Plan.pdf>.
- 7 *Technology Readiness Assessment Guide*, DOE G 413.3-4A, Amendment Change 1, 9–11, US Department of Energy, September 15, 2011, <https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04a-admchg1>.
- 8 Ernst Worrell and Gale Boyd, “Bottom-Up Estimates of Deep Decarbonization of US Manufacturing in 2050.” *Journal of Cleaner Production* 330 (January 2022): 129758, <https://doi.org/10.1016/j.jclepro.2021.129758>.
- 9 Nathan Mariano, et al., *Unlocking Next-Generation Geothermal Heat for Industry*, The 2035 Initiative, July 2025, <https://www.2035initiative.com/unlocking-next-generation-geothermal-heat-for-industry>.
- 10 Short-Term Energy Outlook, US Energy Information Administration (EIA), National Energy Modeling System, November 2022, <https://www.eia.gov/outlooks/aeo/data/browser/>.
- 11 *Evaluation of Low- and Mid-Temperature Industrial Boiler Health Impacts*, American Lung Association (ALA) and ICF, August 2025, <https://www.lung.org/getmedia/28132557-8108-480a-b23e-f0a80834e49c/ICF-Boiler-Impacts.pdf>.
- 12 *Evaluation of Low- and Mid-Temperature Industrial Boiler Health Impacts*, 2025.

- 13 “Michigan,” United States Trade Representative, accessed September 5, 2025, <https://ustr.gov/map/state-benefits/mi>.
- 14 *Carbon Border Adjustment Mechanism*, European Commission Taxation and Customs Union, accessed September 5, 2025, https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en.
- 15 *HEATSET*, 2024.
- 16 “National Map of Industrial Boilers,” Evergreen Action, accessed September 3, 2025, <https://clausa.app.carto.com/map/07d7be74-69f7-4a7f-9cd7-bb92a84b5db3>.
- 17 “Table 3.2 Fuel Consumption, 2022,” in *Manufacturing Energy Consumption Survey (MECS): Consumption, End-Use, and Fuel-Switching Tables*, US Energy Information Administration, August 2025, https://www.eia.gov/consumption/manufacturing/data/2022/pdf/Table3_2.pdf.
- 18 “Industrial Decarbonization,” The 2035 Initiative, UC Santa Barbara, accessed September 5, 2025, <https://www.2035initiative.com/industrial-decarbonization>.
- 19 Joe Cresko et al., *Industrial Decarbonization Roadmap*, US Department of Energy, 2022, <https://doi.org/10.2172/1961393>.
- 20 “Home – Koloma,” Koloma, accessed September 3, 2025, <https://koloma.com/>; “Hyterra – Natural Hydrogen Exploration & Production,” Hyterra, accessed September 3, 2025, <https://hyterra.com/>.
- 21 *Global Hydrogen Review 2024*, International Energy Agency, October 2024, <https://www.iea.org/reports/global-hydrogen-review-2024>.
- 22 “Industrial Training and Assessment Centers,” DOE Office of Manufacturing and Energy Supply Chains, accessed September 5, 2025, <https://www.energy.gov/mesc/industrial-assessment-centers-iacs>; “Better Plants,” US Department of Energy Better Buildings Solutions Center, accessed September 5, 2025, <https://betterbuildingssolutioncenter.energy.gov/better-plants>.
- 23 https://data.bls.gov/cew/apps/table_maker/v4/table_maker.htm#type=18&from=2023&to=2024&qtr=1&own=5&ind=1013&area=26000&supp=1; “Industrial Training and Assessment Center – About Us,” ITAC Michigan State University, accessed August 25, 2025, <https://itac.msu.edu/about-us>.
- 24 Cresko, *Industrial Decarbonization Roadmap*, 2022.
- 25 Worrel, “Bottom-Up Estimates of Deep Decarbonization of US Manufacturing in 2050,” 2022.
- 26 *Industrial Electrification Technologies Booklet*, US Department of Energy Better Plants, 2025, <https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/FINAL%20Industrial%20Electrification%20Booklet.pdf>.

- 27 Cordin Arpagaus et al., “Industrial Heat Pumps: Technology Readiness, Economic Conditions, and Sustainable Refrigerants.” ACEEE, July 11, 2023. https://www.aceee.org/sites/default/files/pdfs/IHP_Workshops_2023/Cordin_Arpagaus_-_OST.pdf.
- 28 *RTC Vision Report*, Renewable Thermal Collaborative (RTC), September 2, 2023, <https://www.renewablethermal.org/vision/>.
- 29 Amandine Denis-Ryan and Cameron Buter, *Industrial Heat Pumps Key to Addressing Excess Gas Demand*, Institute for Energy Economics and Financial Analysis, October 2024, https://ieefa.org/sites/default/files/2024-10/Industrial%20heat%20pumps%20key%20to%20addressing%20excess%20gas%20demand_Oct24.pdf.
- 30 “From Stealth to Steam,” AtmosZero, June 26, 2025, <https://atmoszero.energy/stealth-to-steam/>; “Industrial Steam Heat Pump Boiler,” AtmosZero, accessed August 26, 2025, <https://atmoszero.energy/>.
- 31 “Combined Heat and Power: Frequently Asked Questions,” EPA Combined Heat and Power Partnership, last modified April 2022, https://www.epa.gov/sites/default/files/2015-07/documents/combined_heat_and_power_frequently_asked_questions.pdf.
- 32 *Combined Heat and Power (CHP) Technical Potential in the United States*, US Department of Energy, March 31 2016, <https://www.energy.gov/sites/default/files/2016/04/f30/CHP%20Technical%20Potential%20Study%203-31-2016%20Final.pdf>.
- 33 Peter Therkelsen et al., *Strategic Energy Management Program Persistence and Cost Effectiveness An Analysis of the SEM Program Landscape*, North American Strategic Energy Management Collaborative, 2021, <https://doi.org/10.2172/1878740>.
- 34 “50001 Energy Management Systems,” US Department of Energy Better Plants, accessed August 20, 2025, <https://betterbuildingssolutioncenter.energy.gov/iso-50001/what-iso-50001>.
- 35 “Better Plants Resource Library,” DOE Better Plants, accessed August 20, 2025, <https://betterbuildingssolutioncenter.energy.gov/better-plants/better-plants-resource-library>.
- 36 *RTC Vision Report*, 2023.
- 37 “What Are the Advantages of Resistance Heating? Achieve Precision and Efficiency in Your Processes,” Kintek, last modified February 2025, <https://kindle-tech.com/faqs/what-are-the-advantages-of-resistance-heating>; *Industrial Electrification Technologies Booklet*, 2025.
- 38 *Thermal Energy Storage*, European Association for Storage of Energy, September 26 2023, https://ease-storage.eu/wp-content/uploads/2023/09/2023.09.26-Thermal-Energy-Storage_for-distribution.pdf.
- 39 Felix Hennebert, “Thermal Storage Solutions to Decarbonize Industrial Heat,” UC Berkeley Energy & Resources Collaborative, January 15, 2024, <https://berc.berkeley.edu/news/thermal-storage-solutions-decarbonize-industrial-heat>.

- 40 Mariano, *Unlocking Next-Generation Geothermal Heat for Industry*, 2025.
- 41 “Heat as a Service: How Companies Can Use This Innovative Solution on Their Decarbonization Journey,” WBCSD, September 15, 2022, <https://www.wbcd.org/news/heat-as-a-service/>.
- 42 “The Geothermal Exploration Opportunities Map Beta (GeoMap),” Project Innerspace, accessed September 5, 2025, <https://geomap.projectinnerspace.org/map-selection/>.
- 43 “Pre-Combustion Carbon Capture Research,” US Department of Energy Office of Fossil Energy and Carbon Management, accessed September 3, 2025, <https://www.energy.gov/fecm/pre-combustion-carbon-capture-research>.
- 44 Michael Liebreich, “Hydrogen Ladder Version 5.0,” last modified October 23, 2023, <https://www.linkedin.com/pulse/hydrogen-ladder-version-50-michael-liebreich/>.
- 45 Deborah Gordon and Shannon Hughes, “Reality Check: Natural Gas’s True Climate Risk,” RMI, July 13, 2023, <https://rmi.org/reality-check-natural-gas-true-climate-risk/>.
- 46 *RTC Vision Report*, 2023.
- 47 “Map of Carbon Pipelines,” American Carbon Alliance, accessed September 3, 2025, <https://americancarbonalliance.org/map-of-us-pipelines/>.
- 48 Elena Verdolini et al., *Industrial Deep Decarbonization: Modeling Approaches and Data Challenges*, Resources for the Future, August 16, 2023, <https://www.rff.org/publications/reports/industrial-deep-decarbonization-modeling-approaches-and-data-challenges/>.
- 49 Ali Hasanbeigi et al., *Electrifying US Industry: A Technology and Process-Based Approach to Industrial Decarbonization*, Renewable Thermal Collaborative, January 2021, 75, <https://static1.squarespace.com/static/5877e86f9de4bb8bce72105c/t/6018bf7254023d49ce67648d/1612234656572/Electrifying+U.S.+Industry+2.1.21.pdf>; Kathleen Spees, J. Michael Hagerty, and Jadon Grove, *Thermal Batteries: Opportunities to Accelerate Decarbonization of Industrial Heat*, The Brattle Group, October 2023, <https://www.brattle.com/wp-content/uploads/2023/10/Thermal-Batteries-Opportunities-to-Accelerate-Decarbonization-of-Industrial-Heat.pdf>.
- 50 David L. Goldwyn and Andrea Clabough, *Reducing US Industrial Emissions Under Budgetary Uncertainty*, Atlantic Council, November 4, 2024, <https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/reducing-us-industrial-emissions-under-budgetary-uncertainty/>.
- 51 Ed Rightor, Andrew Whitlock, and Neal Elliott, *Beneficial Electrification in Industry*, ACEEE, July 9, 2020, <https://www.aceee.org/research-report/ie2002>.
- 52 *Beneficial Electrification in Industry*, 2020.
- 53 Meegan Kelly, *IEDO – Technical Assistance and Workforce Development Subprogram*, US Department of Energy, March 21, 2024, https://www.energy.gov/sites/default/files/2024-05/itiac-march2024-kelly-iedo-technical-assistance-and-workforce_1.pdf.

- 54 “Annual Energy Outlook 2023, Table: Table 3. Energy Prices by Sector and Source, Case: Reference case | Region: East North Central,” US Energy Information Administration, accessed August 2025, <https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2023®ion=1-3&cases=ref2023&start=2021&end=2050&f=A&linechart=ref2023-d020623a.19-3-AEO2023.1-3~ref2023-d020623a.23-3-AEO2023.1-3&map=ref2023-d020623a.3-3-AEO2023.1-3&ctype=linechart&sourcekey=0>.
- 55 Sean Smillie et al., *Decarbonizing Industrial Heat: Measuring Economic Potential and Policy Mechanisms*, Energy and Environmental Economics, October 2024, <https://www.ethree.com/wp-content/uploads/2024/10/CAELP-E3-Industrial-Electrification-Report.pdf>.
- 56 “Century Aluminum to Temporarily Idle Its Hawesville Smelter Due to Soaring Energy Prices; Issues WARN Notice to Employees,” Century Aluminum, last modified June 22, 2022, <https://centuryaluminum.com/investors/press-releases/press-release-details/2022/Century-Aluminum-to-Temporarily-Idle-Its-Hawesville-Smelter-Due-to-Soaring-Energy-Prices-Issues-WARN-Notice-to-Employees/default.aspx>.
- 57 Spees, *Thermal Batteries*, 2023.
- 58 *Beneficial Electrification in Industry*, 2020.
- 59 Katheryn Scott et al., *Pathways to Commercial Liftoff: Industrial Decarbonization*, US Department of Energy, September 2023, https://climateprogramportal.org/wp-content/uploads/2025/02/LIFTOFF_DOE_Industrial-Decarbonization_v8.pdf.
- 60 R. Neal Elliott, “Energy Investment Decisions in the Industrial Sector,” ACEEE, December 9, 2007, https://www.eia.gov/outlooks/documentation/workshops/pdf/energy_investments.pdf; PwC’s *Second Annual State of Decarbonization Report*, PwC, 2025, <https://www.pwc.nl/nl/themas/sustainability/documents/annual-state-of-decarbonization-2025.pdf>.
- 61 *Energy as a Service*, ACEEE, accessed August 2025, <https://www.aceee.org/sites/default/files/eo-energy-as-service.pdf>.
- 62 “Energy Policy Simulator,” Energy Innovation and RMI, accessed August 2025, <https://energypolicy.solutions/simulator/michigan/en>.
- 63 *2024 Long-Term Reliability Assessment*, North American Electric Reliability Corporation, July 15, 2025, https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_Long%20Term%20Reliability%20Assessment_2024.pdf.
- 64 *2024 Long-Term Reliability Assessment*, 2025.
- 65 “US County Map of Active Michigan Generation Interconnection Requests,” Interconnection. fyi, accessed August 2025, <https://www.interconnection.fyi/?transmission-owner=ComEd&state=MI&year=>.

- 66 *Characterization of the US Industrial/Commercial Boiler Population*, Energy and Environmental Analysis, Inc., May 2005, <https://invenoeng.com/wp-content/uploads/2017/08/Characterization-of-the-US-Industrial-Commercial-Boiler-Population.pdf>.
- 67 *Making Net-Zero Concrete and Cement Possible*, Mission Possible Partnership, 2023, <https://www.missionpossiblepartnership.org/making-net-zero-concrete-and-cement-possible-report/>.
- 68 *Decarbonizing Industry by 2050: A Federal and State Policy Blueprint*, Industrial Innovation Initiative, November 2021, <https://industrialinnovation.org/wp-content/uploads/2023/12/i3-Federal-and-State-Policy-Blueprint2021.pdf>.
- 69 “Unlocking US Federal Permitting: A Sustainable Growth Imperative,” McKinsey & Company, last modified July 28, 2025, <https://www.mckinsey.com/industries/public-sector/our-insights/unlocking-us-federal-permitting-a-sustainable-growth-imperative>.
- 70 “Small Manufacturers Retooling,” Michigan Department of Environment, Great Lakes, and Energy, accessed September 6, 2025, <https://www.michigan.gov/egle/about/organization/materials-management/energy/rfps-loans/small-manufacturers-retooling>.
- 71 Michigan Department of Labor & Economic Opportunity. “Michigan Supplier Conversion Grant Program.” Accessed October 6, 2025, <https://www.michigan.gov/leo/bureaus-agencies/economic-transition/michigan-supplier-conversion-grant-program>.
- 72 *RESTART 2023 Report: A Year of Impact*, RESTART@LTU partnership, Michigan Department of Environment, Great Lakes, and Energy, accessed September 6, 2025, <https://www.michigan.gov/egle/-/media/Project/Websites/egle/Documents/Programs/MMD/Energy/RESTART-Report-2023.pdf>.
- 73 *Annual Report*, CMS Energy and Consumers Energy, 2024, https://s26.q4cdn.com/888045447/files/doc_financials/2024/ar/AnnualReport2024_Full_WEB-ready.pdf.
- 74 *Annual Report*, 2024; Ethan Howland, “DOE Extends Order to Delay Retiring Consumers’ Michigan Coal Plant,” Utility Dive, last modified August 21, 2025, <https://www.utilitydive.com/news/doe-consumers-energy-emergency-order-miso/758265/>; Order No. 202-25-7, US Department of Energy, August 2025, <https://www.energy.gov/sites/default/files/2025-08/MISO%20Order%20No.%20202-25-7.pdf>.
- 75 “Fuel Mix,” DTE Energy, accessed August 2025, <https://www.dteenergy.com/us/en/residential/community-and-news/environment/fuel-mix.html>.
- 76 “Michigan State Energy Profile,” US Energy Information Administration, last modified October 17, 2024, <https://www.eia.gov/state/print.php?sid=mi>.
- 77 Sara Baldwin et al., *Overcoming All Barriers to Industrial Electrification*, Energy Innovation, June 2025, <https://energyinnovation.org/wp-content/uploads/Overcoming-All-Barriers-to-Industrial-Electrification.pdf>.
- 78 “Advanced Manufacturing Production Credit,” US Internal Revenue Service, last modified May 29, 2025, <https://www.irs.gov/credits-deductions/advanced-manufacturing-production-credit>.

- 79 *Towards More Accurate, Timely, and Granular Product-Level Carbon Intensity Metrics*, OECD, 2024, https://www.oecd.org/en/publications/towards-more-accurate-timely-and-granular-product-level-carbon-intensity-metrics_4de3422f-en.html.
- 80 Baldwin, *Overcoming All Barriers to Industrial Electrification*, 2025.
- 81 Jeffrey Rissman, *A Production Tax Credit for Clean Industrial Heat*, Energy Innovation, July 2024, <https://energyinnovation.org/wp-content/uploads/2024/07/A-Production-Tax-Credit-for-Clean-Industrial-Heat.pdf>.
- 82 “Small Manufacturers Retooling,” accessed August 2025.
- 83 Pavitra Srinivasan, Andrew Hoffmeister, and Kristin Campbell, *State Industrial Decarbonization Policy Handbook for Utilities*, ACEEE, June 2023, 19, <https://www.aceee.org/sites/default/files/pdfs/I2301.pdf>.
- 84 “Home Energy Rebates,” Michigan Department of Environment, Great Lakes, and Energy, accessed August 2025, <https://www.michigan.gov/egle/about/organization/materials-management/energy/rfps-loans/home-energy-rebate-programs>.
- 85 *Building Energy Codes and Michigan Communities*, Michigan Department of Environment, Great Lakes, and Energy, accessed August 2025, <https://www.michigan.gov/egle/-/media/Project/Websites/egle/Documents/Programs/MMD/Energy/resources/codes-community.pdf>.
- 86 Samantha Donald, *Renewable Thermal in State Renewable Portfolio Standards*, Clean Energy States Alliance, July 2018, <https://www.cesa.org/wp-content/uploads/Renewable-Thermal-RPS.pdf>; *Quadrennial Technology Review 2015 Chapter 6: Innovating Clean Energy Technologies in Advanced Manufacturing*, US Department of Energy, 2016, <https://www.energy.gov/sites/prod/files/2016/06/f32/QTR2015-6I-Process-Heating.pdf>.
- 87 “Summaries of All the Renewable and Alternative Energy Portfolio Standard Programs,” Commonwealth of Massachusetts, accessed August 2025, <https://www.mass.gov/info-details/program-summaries>; “Relevant Statutes, Regulations, and Guidelines for the Programs Administered by DOER’s Renewable Energy Division,” Commonwealth of Massachusetts, accessed August 2025, <https://www.mass.gov/info-details/statutes-regulations-and-guidelines>.
- 88 “Historical Development of the Alternative Energy Portfolio Standard,” Commonwealth of Massachusetts, accessed August 2025, <https://www.mass.gov/info-details/historical-development-of-the-alternative-energy-portfolio-standard>.
- 89 Alternative Energy Portfolio Standard, 225 CMR 16.00, Commonwealth of Massachusetts, accessed August 2025, 8-11, <https://www.mass.gov/doc/225-cmr-1600-alternative-energy-portfolio-standard/download>.
- 90 “Alternative Energy Portfolio Standard (APS) & Renewable Thermal (RT) Technologies,” Massachusetts Clean Energy Center, accessed August 2025, <https://www.masscec.com/alternative-energy-portfolio-standard-aps-renewable-thermal-rt-technologies>; “Alternative Energy Credits,” SRECTrade, accessed August 2025, <https://www.srectrade.com/markets/aec/introduction>.

- 91 “Renewable Energy Certificates (RECs) Factsheet,” Massachusetts Climate Action Network, accessed August 2025, <https://www.massclimateaction.org/recs>.
- 92 *Alternative Energy Portfolio Standard Guideline on Multipliers for Renewable Thermal Generation Units*, Commonwealth of Massachusetts Department of Energy Resources, December 29, 2017, <https://www.mass.gov/doc/guideline-on-multipliers-for-renewable-thermal-generation-units-121517-final/download>.
- 93 “Summaries of All the Renewable and Alternative Energy Portfolio Standard Programs,” accessed August 2025.
- 94 Baldwin, *Overcoming All Barriers to Industrial Electrification*, 2025.
- 95 “Energy Waste Reduction Standards and Plans,” Michigan Department of Environment, Great Lakes, and Energy, accessed August 2025, <https://www.michigan.gov/mpsc/commission/workgroups/2023-energy-legislation/energy-waste-reduction-standards-and-plans>.
- 96 “EGLE Permits,” Michigan Department of Environment, Great Lakes, and Energy, accessed August 2025, <https://www.michigan.gov/egle/Regulatory-Assistance/permits>; *Michigan Guide to Air Use Permits to Install*, Michigan Department of Environment, Great Lakes, and Energy, January 1998, <https://www.egle.state.mi.us/aps/downloads/permits/MIGUIDE.PDF>.
- 97 “Boiler Permit Information,” Michigan Licensing and Regulatory Affairs, accessed August 2025, <https://www.michigan.gov/lara/bureau-list/bcc/sections/permit-section/permits/boiler-permit-information>.
- 98 *2023 Utility Energy Waste Reduction Programs: Annual Report on the Implementation of PA 295*, Michigan Public Service Commission, October 25, 2024, <https://www.michigan.gov/mpsc/-/media/Project/Web/sites/mpsc/regulatory/reports/pa295-ewr/2023-EWR-Report-to-the-Legislature.pdf>.
- 99 “ISO 50001: Energy Management,” International Organization for Standardization, accessed August 2025, <https://www.iso.org/iso-50001-energy-management.html>.
- 100 “Scaling California’s Heat Pump Market: The Path to Six Million,” California Heat Pump Partnership, accessed September 3, 2025, <https://heatpumppartnership.org/blueprint/>.
- 101 Antonella Pasetto et al., *Policy Toolbox for Industrial Decarbonisation*, International Energy Agency, March 2025, <https://www.iea.org/reports/policy-toolbox-for-industrial-decarbonisation>.
- 102 *Making Mission Possible: Delivering a Net-Zero Economy*, Energy Transitions Commission, September 2020, <https://www.energy-transitions.org/wp-content/uploads/2020/09/Making-Mission-Possible-Full-Report.pdf>.
- 103 “Basic Information about Air Quality SIPs,” U.S. Environmental Protection Agency, last modified January 6, 2025, <https://www.epa.gov/air-quality-implementation-plans/basic-information-about-air-quality-sips>.

- 104** “State Implementation Plan (SIP) and Attainment,” Michigan Department of Environment, Great Lakes, and Energy, accessed October 2025, <https://www.michigan.gov/egle/about/organization/Air-Quality/state-implementation-plan>; and “Air Laws and Rules,” Michigan Department of Environment, Great Lakes, and Energy, accessed October 2025, <https://www.michigan.gov/egle/about/organization/Air-Quality/laws-and-rules>.
- 105** “South Coast AQMD Approves Rule to Accelerate the Transition to Zero-Emission for Building Water Heaters,” South Coast Air Quality Management District, June 7, 2024, <https://www.aqmd.gov/docs/default-source/news-archive/2024/1146-2-June-7-2024.pdf>.
- 106** Rule 1146.2. Emissions Of Oxides of Nitrogen from Large Water Heaters and Small Boilers and Process Heaters, South Coast Air Quality Management District, June 7, 2024, <https://www.aqmd.gov/home/rules-compliance/rules/scaqmd-rule-book/proposed-rules/rule-1146-2>.
- 107** Spees, *Thermal Batteries*, 2023.
- 108** “Michigan PSC Directs Utilities to Offer Time of Use Rates,” Utility Dive, last modified July 10, 2015, <https://www.utilitydive.com/news/michigan-psc-directs-utilities-to-offer-time-of-use-rates/402069/>; “Time-Based Pricing,” Michigan Public Service Commission, accessed August 2025, <https://www.michigan.gov/mpsc/commission/workgroups/mi-power-grid/time-based-pricing>.
- 109** Andrew Satchwell et al., *Electricity Rate Designs for Large Loads: Evolving Practices and Opportunities*, Berkeley Lab, January 2025, https://eta-publications.lbl.gov/sites/default/files/2025-01/electricity_rate_designs_for_large_loads_evolving_practices_and_opportunities_final.pdf.
- 110** *Large Load Tariff Principles*, RMI, 2025, <https://rmi.org/insight/large-load-tariff-principles/>; Stacy Sherwood, *Review of Large Load Tariffs to Identify Safeguards and Protections for Existing Ratepayers*, Energy Futures Group, January 28, 2025, <https://energyfuturesgroup.com/wp-content/uploads/2025/01/Review-of-Large-Load-Tariffs-to-Identify-Safeguards-and-Protections-for-Existing-Ratepayers-Report-Final.pdf>.
- 111** Baldwin, *Overcoming All Barriers to Industrial Electrification*, 2025.
- 112** RMI Study Reveals Large Opportunity for Clean Energy and Customer Savings in PJM by Deploying GETs, RMI, 2024, <https://rmi.org/press-release/rmi-study-reveals-large-opportunity-for-clean-energy-and-customer-savings-in-pjm-by-deploying-gets/>.
- 113** James Broughel, *Pumping the Brakes on Reform: Michigan’s Permitting Engine Stalls Out*, Competitive Enterprise Institute, April 2025, https://cei.org/wp-content/uploads/2025/04/Fast_Track_-_Michigan_Permitting_Report_FINAL.pdf.
- 114** Gabrielle Stebbins and Chris Neme, *A Comparison of Clean Heat Standards: Current Progress and Key Elements*, Energy Futures Group, February 2024, 14. https://www.edf.org/sites/default/files/2024-03/Clean%20Heat%20Standards%20Report_FINAL%2002-2024.pdf.
- 115** Stebbins, *A Comparison of Clean Heat Standards*, 2024.

- 116 Jeffrey Rissman, *A Technology-Neutral Emissions Standard for Clean Industrial Heat*, Energy Innovation, July 2024, <https://energyinnovation.org/wp-content/uploads/A-Technology-Neutral-Emissions-Standard-for-Clean-Industrial-Heat.pdf>.
- 117 “Adopt Programs Reduce Greenhouse Gas Emissions Utilities,” SB21-264, Colorado General Assembly, accessed August 2025, <https://leg.colorado.gov/bills/sb21-264>.
- 118 “What Is a Clean Heat Plan?,” Colorado Public Utilities Commission, accessed August 2025, <https://puc.colorado.gov/cleanheatplans>.
- 119 “What is a Clean Heat Plan?,” accessed August 2025.
- 120 “Details of Decision C24-0397,” Colorado Public Utilities Commission, last modified June 10, 2024, https://www.dora.state.co.us/pls/efi/EFI_Search_UI.Show_Decision?p_dec=30982&p_session_id=; Stebbins, *A Comparison of Clean Heat Standards*, 2024.
- 121 “Adopt Programs Reduce Greenhouse Gas Emissions Utilities,” accessed August 2025.
- 122 “State Buy Clean Partnership,” US Climate Alliance, accessed August 2025, <https://usclimatealliance.org/member-support/federal-state-buy-clean-partnership>.
- 123 Rebecca Esau et al., *Buy Clean and Beyond: A Guide to Reaching Net-Zero Embodied Carbon in State-Owned Building Projects*, RMI, November 2023, <https://rmi.org/insight/guide-to-road-mapping-state-owned-building-projects-to-reach-net-zero-embodied-carbon/>.
- 124 “Governor Whitmer Signs Bipartisan Bills Establishing Innovation Fund, R&D Tax Credit to Unleash Entrepreneurship, Lower Costs for Businesses, Create Jobs,” Michigan Economic Development Corporation, last modified January 13, 2025, <https://www.michiganbusiness.org/press-releases/2025/01/whitmer-signs-bipartisan-bills-establishing-innovation-fund-r-and-d-tax-credit/>.
- 125 *Going PRO Talent Fund*, Michigan Department of Labor and Economic Opportunity, accessed August 2025, <https://www.michigan.gov/leo/-/media/Project/Websites/leo/Documents/WD/Program-Overviews/Going-PRO-Talent-Fund.pdf>; “Going PRO Talent Fund,” Michigan Department of Labor and Economic Opportunity, accessed August 2025, <https://www.michigan.gov/leo/bureaus-agencies/wd/programs-services/going-pro-talent-fund>.
- 126 *MI Healthy Climate Plan*, April 2022.
- 127 “RESTART Program,” Michigan Department of Environment, Great Lakes, and Energy, accessed August 2025, <https://www.michigan.gov/egle/about/organization/materials-management/energy/restart>.
- 128 “Michigan Infrastructure Office,” State of Michigan Office of the Governor, accessed August 2025, <https://www.michigan.gov/whitmer/issues/michigan-infrastructure-office>; “Michigan Infrastructure Office Technical Assistance Center,” Clean Fuels Michigan, last modified February 4, 2025, <https://www.cleanfuelsmichigan.org/our-resources/michigan-infrastructure-office-technical-assistance-center-tac/>.
- 129 “Air Quality Division Permits,” Michigan Department of Environment, Great Lakes, and Energy, accessed August 2025, <https://www.michigan.gov/egle/about/organization/air-quality/air-permits>.

Molly Freed, Camellia Moors, Ankur Dass, Emily Albergo, Allie Jobe, Hannah Thonet, Brianne Cangelose, and Jacob Corvidae, *Michigan Clean Manufacturing Roadmap*, RMI, 2025, <https://rmi.org/insight/michigan-clean-manufacturing-roadmap>.

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