NET-ZERO INDUSTRY IN MINNESOTA

FOUNDATION FOR A STATE ROADMAP BUILT ON STAKEHOLDER PERSPECTIVES

Fresh Energy
GREAT PLAINS INSTITUTE
NRRI
5lakes energy

February 2026

About This Project

Minnesota's industrial sector is entering a critical inflection point. Over the next decade, manufacturers, utilities, regulators, and communities will face simultaneous and sometimes competing demands, including but not limited to: the need for deep emissions reductions at the same time as grid modernization, pressure from rising electricity and fuel needs due to data centers and other factors, the realities of a workforce in transition, the desire for improved supply chain resilience and reduced environmental impacts, and increasing pressure for many of Minnesota's manufacturers to remain globally competitive.

These converging demands make it essential for Minnesota to approach industrial decarbonization in a coordinated fashion – with a foundation on which to make deliberate choices about where to focus limited resources, which industrial segments to prioritize, which technologies and pathways warrant near-term investment, and how to sequence actions over time. Choices made without coordination risk directing limited resources toward lower-impact or poorly sequenced investments, leaving higher-value opportunities unaddressed.

This preliminary report, led by 5 Lakes Energy with support from the Great Plains Institute, Fresh Energy, and the Natural Resources Research Institute (NRRI), was designed to lay the foundations and stakeholder-based framing needed to support a forthcoming, comprehensive industrial decarbonization roadmap. This state-level roadmap, which will be led by NRRI in collaboration with the same project partners, will build on the work presented herein to more fully assess technical options, sectoral analysis, sequencing, and investment priorities in light of limited public and private resources.

The key objective of this report is to provide the foundation for a detailed project plan to develop and maintain an industrial decarbonization roadmap for the state of Minnesota. The report meets this objective by:

- Identifying and profiling specific industrial subsectors,
- Outlining cross-sector coordination and vertical integration opportunities,
- Highlighting key tactics and key barriers to industrial transformation,
- Characterizing relevant stakeholder perspectives,
- Profiling the relevant state resources and activities and the opportunities for greater coordination, and
- Presenting a summary of key take-aways and next steps for Minnesota.

Ultimately, the broader effort aims to build a durable, actionable state-level roadmap that can guide coordinated policy, infrastructure, and investment decisions over time and across industrial and energy systems.

Project Contributors

Fresh Energy's mission is to shape and drive bold policy solutions to achieve equitable carbon-neutral economies. Fresh Energy is speeding Minnesota's transition to a clean energy economy, which will ensure that our region enjoys good health, a vibrant economy, and thriving communities today and for generations to come.

The Great Plains Institute (GPI) is a nonpartisan, nonprofit organization working to accelerate the transition to net-zero carbon emissions for the benefit of people, the economy, and the environment. Working across the United States, GPI combines a unique consensus-building approach, expert knowledge, research and analysis, and local action to find and implement lasting solutions.

NRRI is a state-chartered, applied research institute within the Research and Innovation Office of the University of Minnesota with a dual mission of economic development and responsible stewardship of natural resources. With three sites in northern Minnesota, NRRI has the capacity and expertise to demonstrate technologies from the bench to pilot scale, maintain strong partnerships with industry, government, academia, and communities and deliver integrated research solutions.

5 Lakes Energy is a Michigan-based consultancy supporting nonprofits, businesses, and government agencies in their pursuit of clean energy goals, design and implementation of climate solutions, and delivery of economic, public health, and other benefits to the people they serve.

Acknowledgements

The findings presented in this report represent the perspectives of and contributions from an array of stakeholders affiliated with Minnesota's industrial sector, communities, Tribal Nations, nonprofit organizations, academic researchers, national laboratories, and state agencies. We extend our appreciation for their time and willingness to participate.

Portions of this report drafted by 5 Lakes Energy also appear in contemporary reports that their industrial decarbonization team produced for Michigan and Wisconsin.

Executive Summary

Minnesota's Climate Action Framework both lays out a 'climate vision' for the state and recognizes the immediacy of climate change and its impacts. That vision also establishes goals for the state's energy-intensive manufacturing sector — as well as the power sector that serves it and the state's closely tied agricultural and forestry industries.

Boasting more than 8,500 manufacturers and 323,000 jobs, Minnesota's manufacturing sector is a cornerstone of the state's economy. But even as manufacturing jobs have declined in recent years, emissions from the sector have continued to increase. In fact, just 59 manufacturing facilities contribute the lion's share of the sector's emissions — with seven subsectors, constituted by just 37 facilities, emitting an estimated 87% of all CO_2e produced by the state's manufacturing sector.

MINNESOTA'S MANUFACTURING SECTOR BEARS A UNIQUE PROFILE:

- Manufacturing emissions arise from chemical processes, on-site landfill and wastewater treatment, and fluorinated gases, in addition to fuel combustion for process heat and sometimes electrical power.
- Manufacturing facilities burn a much broader range of fuels, including coal products and industrial byproducts, and they use a greater array of fuel-combusting units, like kilns and specialty furnaces, for those activities.
- While many of Minnesota's thousands of small and medium manufacturers can chart relatively straightforward paths to net-zero, the same isn't true for the state's 59 high-emitting facilities — instead, each will require its own complex, customized plan.

NEXT STEPS FOR MINNESOTA IN ITS EFFORT TO SUPPORT INDUSTRIAL DECARBONIZATION

To help Minnesota's elected officials, state agencies, and other decision-makers support the state's manufacturing sector through the incredible inflection point that stands before it, this report presents a diverse set of findings and perspectives. While this report is intended to serve as the foundation for a second, deeper technical study, the insights developed also point to several near-term next steps that Minnesota could pursue now to support progress toward a competitive, net-zero manufacturing sector:

- Reflect these findings in the implementation of the 'industrial innovation' thread of the state's new Climate-Smart Food Systems grant program.
- Explore policy options to encourage grid-focused strategies (like load-shifting and use of curtailed generation) and reduce the spark gap, as well as other stackable incentive options (like tax credits) — all to help reduce the additional operating costs (OPEX) currently associated with industrial electrification.
- Seek opportunities to better align incentive programs with infrastructure readiness and regional economic development efforts, with a particular emphasis on stronger coordination at the regional level.
- Continue to clarify the roles of state agencies and pathways for engaging industry in industrial decarbonization efforts, while striving for greater coordination across program areas — especially programs related to utilities, transportation infrastructure, site

development, incentives, and workforce development, all of which impact the health and vitality of Minnesota's communities.
- Develop and implement a comprehensive, cross-sector education and outreach strategy related to market-ready industrial electrification technologies, to more rapidly advance clean technology adoption.
- Explore the creation of CO_2 utilization industrial hubs to spur developments related to carbon capture, utilization, and sequestration.
- Articulate related areas where additional, deeper insights may be needed to support the state in progress toward its goals, especially where significant interdependencies across economic sectors may exist.

PRIORITY STRATEGIES FOR INDUSTRIAL DECARBONIZATION

In addition to surfacing these next steps, this report finds that the priority strategies for decarbonizing Minnesota's manufacturing sector include:

- Improvements in energy efficiency,
- Electrification of low- and medium-temperature process heat, and
- Fuel-switching to alternative, low-carbon-intensity fuels.

Presently, Minnesota's manufacturing sector consumes nearly 40 TWh of low- and medium-temperature heat energy each year — which tallies to about 4.3 GW of heat power consumption at any given moment. These are large numbers for a sector expected to progress toward net-zero via electrification, underscoring the need for extensive energy efficiency investments up front.

TECHNICAL APPROACHES TO INDUSTRIAL DECARBONIZATION

The technical approaches that Minnesota's manufacturers could pursue through this transition to net-zero include:

- Electrification through the adoption of industrial heat pumps, electric boilers, and thermal batteries;
- Switching to alternative, low-carbon fuels like biomass or renewable natural gas;
- Tactics such as nature-based solutions and carbon capture and sequestration, for managing residual emissions;
- Cross-sector coupling to enable targeted use of biomass residuals and CO_2 emissions as feedstocks for emerging biofuel and e-fuel markets; and
- Vertical integration — importing key upstream and downstream value-add manufacturing steps that rely on new, low-carbon technologies into Minnesota's manufacturing ecosystem to boost the state's economy while displacing dirtier production methods in other parts of the country.

MANUFACTURERS FACE SYSTEMIC BARRIERS IN THEIR PURSUIT OF MODERNIZATION

Clearly, for Minnesota's manufacturers this will be a complex path to navigate. A range of systemic barriers face the state's manufacturers, both small and large. These include:

- The high capital costs of upgrading facilities and equipment, the resulting impacts on operating costs that could arise from electrifying or fuel-switching, and the practical reality of when these changes should be made, based in part on multi-decadal asset lives, and
- The need to carefully weigh decisions tied to the market-readiness and site suitability of emerging technologies, as manufacturers consider whether to be early adopters or laggards in a rapidly globalizing economy.

These choices also won't be made in a vacuum: the ripple effects of their impact will be felt across the state's workforce, power sector, infrastructure, and communities. Effective permitting structures could serve as accelerators — while continuing uncertainty in the state and federal policy landscape in relation to renewable energy deployment, clean technology accelerators, levers to support early off-take, and more could hold back any meaningful transition for years to come.

BROAD — AND SOMETIMES COMPETING — STAKEHOLDER PERSPECTIVES

Compounding these challenges, Minnesota's manufacturers recognize the increasing need for their high-impact decisions to be made with broad input — perspectives from different stakeholder groups that can be challenging to navigate and are often at odds with each other. For example:

- Minnesota communities desire stable jobs, reduced pollution, and infrastructure improvements.
- Tribal Nations prioritize community wellbeing, workforce development, and economic opportunity — in addition to sovereignty and long-term environmental stewardship.
- Unions and labor seek opportunities to strengthen existing industries, protect workers, and support clear pathways for long-term employment in quality, family-sustaining jobs.
- Minnesota's environmental groups emphasize the need to focus on broader environmental impacts, like air and water pollution, while aligning messaging and initiatives related to climate change and climate quality, which includes prioritizing community wellbeing.

The complexity of this evolving landscape of stakeholder perspectives grows when considering that Minnesota's manufacturers will need to navigate it as the guidelines crafted by well-intended state legislators and state agencies continue to evolve, too.

Again, the insights and perspectives presented here are intended to serve as a level-setting foundation for Minnesota's policymakers, state agencies, and the other decision-makers who will need to be engaged in the effort to secure a competitive future for the state's manufacturing sector. Ultimately, the goal is for this report to be situated in a broader effort led by the Natural Resources Research Institute, intended to build a durable, actionable state-level roadmap that can guide coordinated policy, infrastructure, and investment decisions over time and across industrial and energy systems.

Table of Contents

Introduction and Background

A VISION FOR MINNESOTA'S MANUFACTURING FUTURE

Minnesota's Climate Action Framework (CAF) lays out a 'climate vision' for the state that includes three core tenets: carbon neutrality by 2050, climate resiliency across all economic sectors and the natural environment, and an equitable future for all. The CAF also recognizes the immediacy of climate change and its impacts, which Minnesotans are increasingly bearing as intense weather events grow more frequent and widespread. Along with 23 other states, Minnesota has joined the U.S. Climate Alliance, a bipartisan climate action coalition committed to upholding the goals of the 2015 Paris Agreement.[1]

The state's vision for its manufacturing sector is largely recorded under a series of sub-initiatives tied to two of the CAF's six goals: clean energy and efficient buildings, and a clean economy. The related sub-initiatives are further detailed as:

- Reducing wasted industrial heat by adopting broader strategies to utilize expelled heat,
- Increasing the energy efficiency of industrial buildings and processes,
- Becoming a national leader in clean innovation, with a focus on improving worker health, productivity, and sustainability in the industrial sector, and
- Supporting companies and the workforce through transition as the state's industries evolve.

Importantly, that vision also includes prioritizing community health by recognizing the burdens of industrial pollution, especially those that disproportionately impact some communities, and the role that the state can play in the siting and permitting of future industrial facilities.

This vision aligns well with the more generally recognized three pillars of sustainability: social, economic, and environmental. In this framework, the social pillar prioritizes the well-being of all people, the economic pillar stresses financial responsibility and long-term economic strength, and the environmental pillar calls for protecting the planet and natural resources — including mitigating the effects of climate change and reducing air pollution.

Thus, a sustainable vision for the future of Minnesota's industrial sector must prioritize and consider these three pillars equally. This philosophy, coupled to the state's vision as expressed in its CAF, serves as the basis for the structure and framing of the research, analysis, and recommendations related to industrial decarbonization presented in the remainder of this report.

STATE GOALS FOR INDUSTRIAL DECARBONIZATION

The ultimate goal for Minnesota's industrial sector is to achieve net-zero by 2050, in alignment with the goals of the 2015 Paris Agreement. Because industrial electrification is one tactic needed for the state to meet this goal, the state must also achieve the adjacent goal of delivering 100% carbon-free electricity through its utilities, munis, and co-ops to all electric customers in the state, including manufacturing facilities. The 100% carbon-free electricity

[1] "The Paris Agreement," United Nations Climate Change, accessed January 2026.

standard, a goal mandated by state law according to 2023 Senate File 4 and House File 7, has three sub-goals:[2,3]

- Increase the state's Renewable Energy Standard to 40% by 2025,
- Further increase the state's Renewable Energy Standard to 55% by 2035, and
- Finally, establish a standard to achieve 100% carbon-free electricity by 2040.

In parallel, the state also plans to explore new options for reducing thermal emissions by at least 20% by 2030 through, for example, implementing a clean heat standard and incentivizing clean heat through effective implementation of the state's Energy Conservation Optimization[4] Act and Natural Gas Innovation Act.[5]

Within the Climate Action Framework developed by Minnesota, the six overarching goals are expanded into sub-initiatives (listed in the preceding section), and those sub-initiatives are further expanded into state action steps which specify the state's role as either leading, enacting, or encouraging the associated work. The following relevant state action step has a quantified target:

- Reducing waste heat in the industrial sector by 10% by 2030.

Lastly, more than many other states, Minnesota's manufacturing sector is closely tied to its natural resources, including agriculture and forestry. The state's CAF captures both sectors in its second goal: climate-smart natural and working lands. Several of the initiatives and sub-initiatives tied to this goal will likely have implications for Minnesota's manufacturing sector, which is highly tied to natural and agricultural resources:

- Maintain, expand, and actively manage forestlands;
- Accelerate soil health and nitrogen and manure management practices, and promote fertilizer and manure application practices that minimize nitrogen loss;
- Encourage water recycling; and
- Support emerging agricultural and forest technologies and products.

For example, how Minnesota approaches agricultural nitrogen management has implications for how farmers engage in the fertilizer and renewable natural gas markets; many industries could adopt better water management practices including ultrafiltration and stronger water recycling initiatives; new winter cover crops and changes to timber management practices could further support the state's entry into the broadening biofuels market, with potential to support industrial fuel-switching; and active land management programs will likely play a central role in any future carbon offset markets structured around nature-based solutions, which hard-to-abate industries may need to access to achieve net-zero.

---

2 "Governor Walz Signs Bill Moving Minnesota to 100 Percent Clean Energy by 2040," Minnesota Department of Commerce, February 7, 2023.

3 J. Olson, "Minnesota's 100% clean electricity law explained," Fresh Energy, February 20, 2023.

4 "Energy Conservation and Optimization," Minnesota Department of Commerce, accessed January 2026.

5 "Natural Gas Innovation Act (NGIA)," Minnesota Public Utilities Commission, accessed January 2026.

MINNESOTA'S MANUFACTURING EMISSIONS

As of 2022, Minnesota was home to more than 8,500 manufacturers staffing more than 323,000 manufacturing jobs within the state. Although manufacturing is now the state's second largest industry after being surpassed by healthcare two decades ago, the manufacturing sector still boasts one of the highest average annual wages, at $77,000. Distributions of jobs, average annual salaries, and facility numbers are given in Figures 1 and 2. These wages are boosted by the state's high number of jobs in lucrative manufacturing subsectors like petroleum refining and chemicals production. Some of the largest manufacturing subsectors in Minnesota include food, fabricated metal products, computer and electronic products, machinery, plastics and rubber products, printing and related activities, chemicals, wood products, and transportation equipment — each home to more than 10,000 jobs. The manufacturing subsectors experiencing the highest levels of growth in recent years have included food, machinery and transportation

MINNESOTA IS HOME TO

- 8,500 manufacturers
- 323,000 manufacturing jobs
- Avg. annual salary of $77,000

NUMBER OF MANUFACTURING JOBS AND CORRESPONDING AVERAGE ANNUAL SALARY BY SUBSECTOR

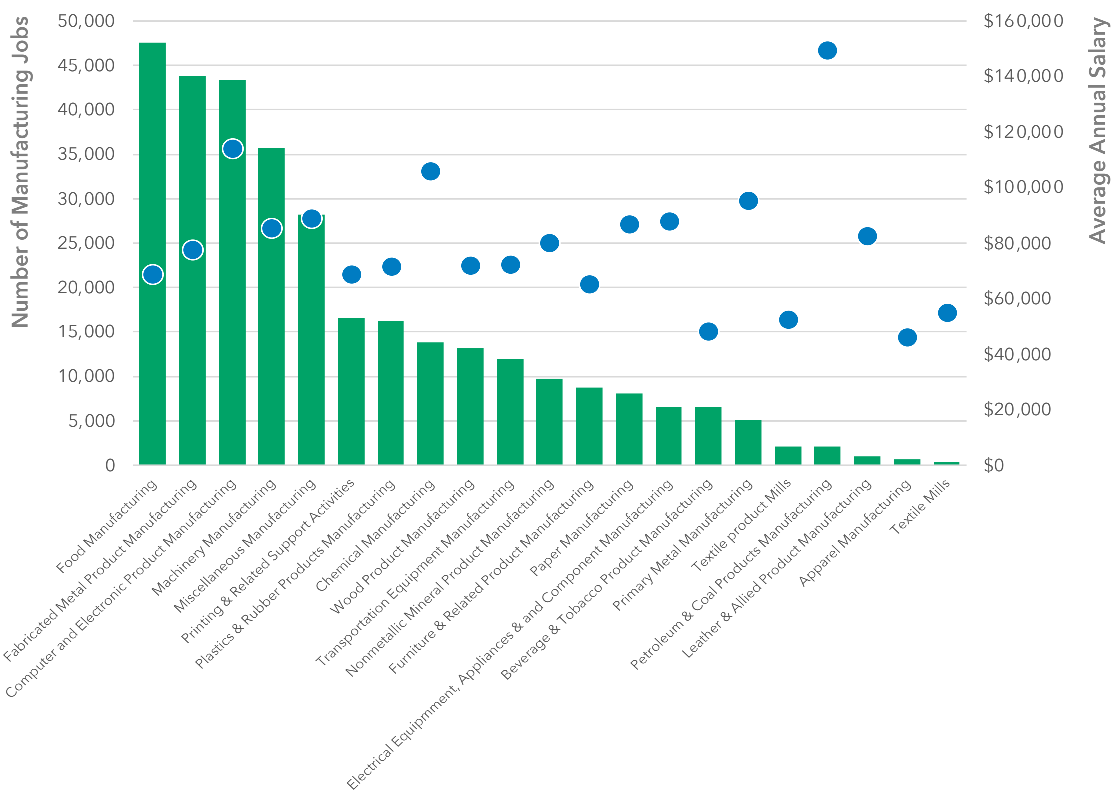


Figure 1 *Based on data from Minnesota's Department of Employment and Economic Development, the distribution of manufacturing jobs across subsectors and corresponding average annual salary. Most jobs are concentrated in food manufacturing, fabricated metal products manufacturing, computer and electronic products manufacturing, and machinery manufacturing, while jobs with the highest average annual salaries are associated with the computer and electronic products manufacturing, chemical manufacturing, and petroleum products manufacturing sectors.*

equipment, plastics and rubber products, wood products, chemicals, beverage and tobacco products, and textile mills. Despite this, jobs in Minnesota's manufacturing sector have overall trended downward since the early 2000s.[6]

In contrast, emissions from Minnesota's industrial sector, which is largely constituted by manufacturing, increased 23% from 2010 to 2020, as reported in the state's January 2025 greenhouse gas emissions inventory report to the legislature.[7] Some of this increase can be attributed to the recent addition of new manufacturing facilities, as well as increases in production in existing subsectors, like petroleum refining. While the sector's overall GHG emissions must be tackled for the state to achieve its net-zero 2050 goal, it is important to recognize that the vast majority of the state's industrial emissions originate from just 59 high-emitting facilities (each, >25,000 MT CO_2e annually), according to records of U.S. EPA's GreenHouse Gas Reporting Program (GHGRP; see Figure 3).

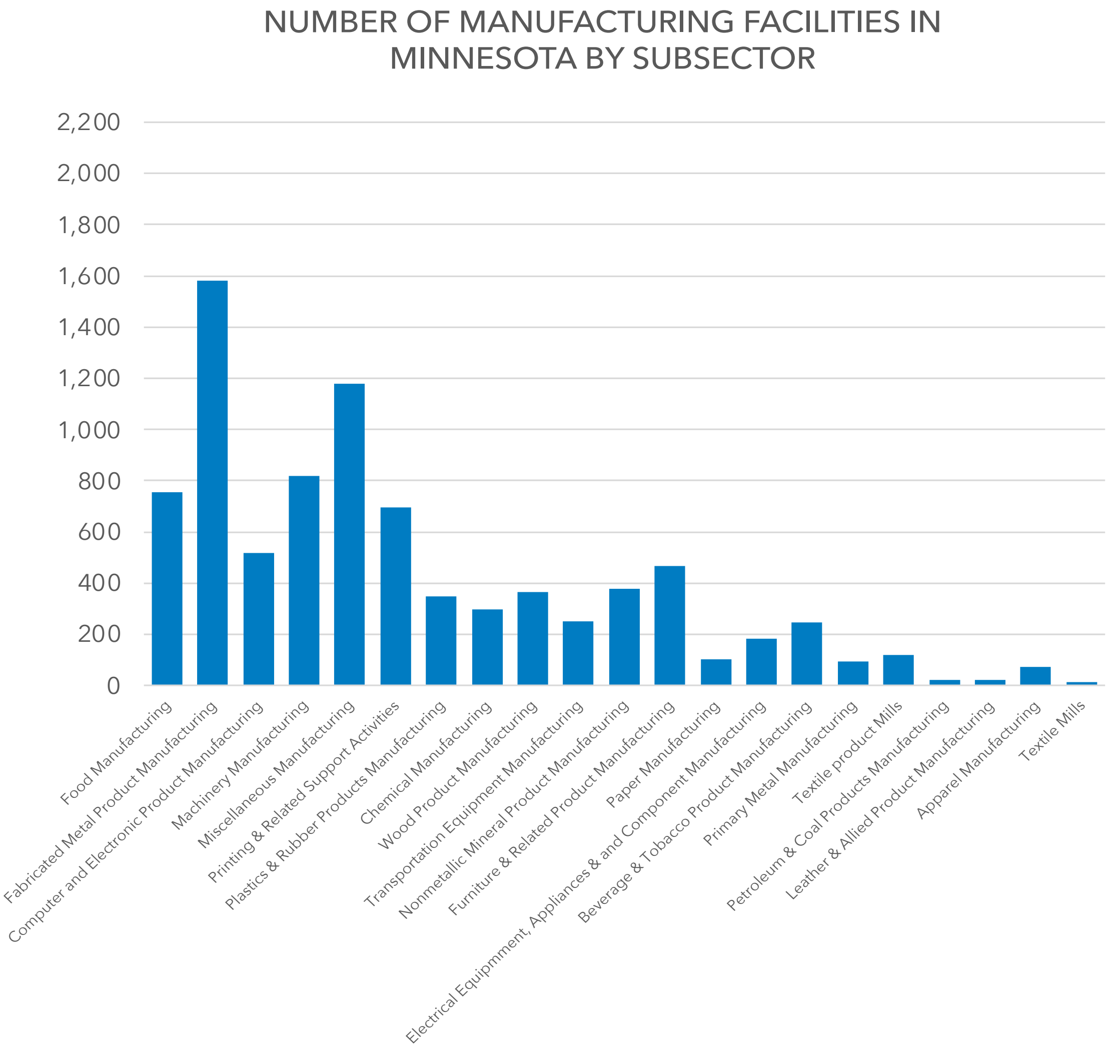


Figure 2 Compared against Figure 1, the number of manufacturing facilities in Minnesota by subsector presented in this figure indicates differences in job concentration by subsector. For example, food manufacturing employs more workers in half as many facilities as the state's fabricated metal products manufacturing industry, and similarly for computer and electronic products manufacturing.

6 "Manufacturing Industry Profile," Minnesota Department of Employment and Economic Development.

7 "Greenhouse gas emissions in Minnesota 2005-2022," Minnesota Pollution Control Agency and Department of Commerce, January 2025.

ANNUAL TOTAL EMISSIONS (MMT CO_2e) OF MINNESOTA'S HIGH-EMITTING MANUFACTURING AND INDUSTRIAL FACILITIES

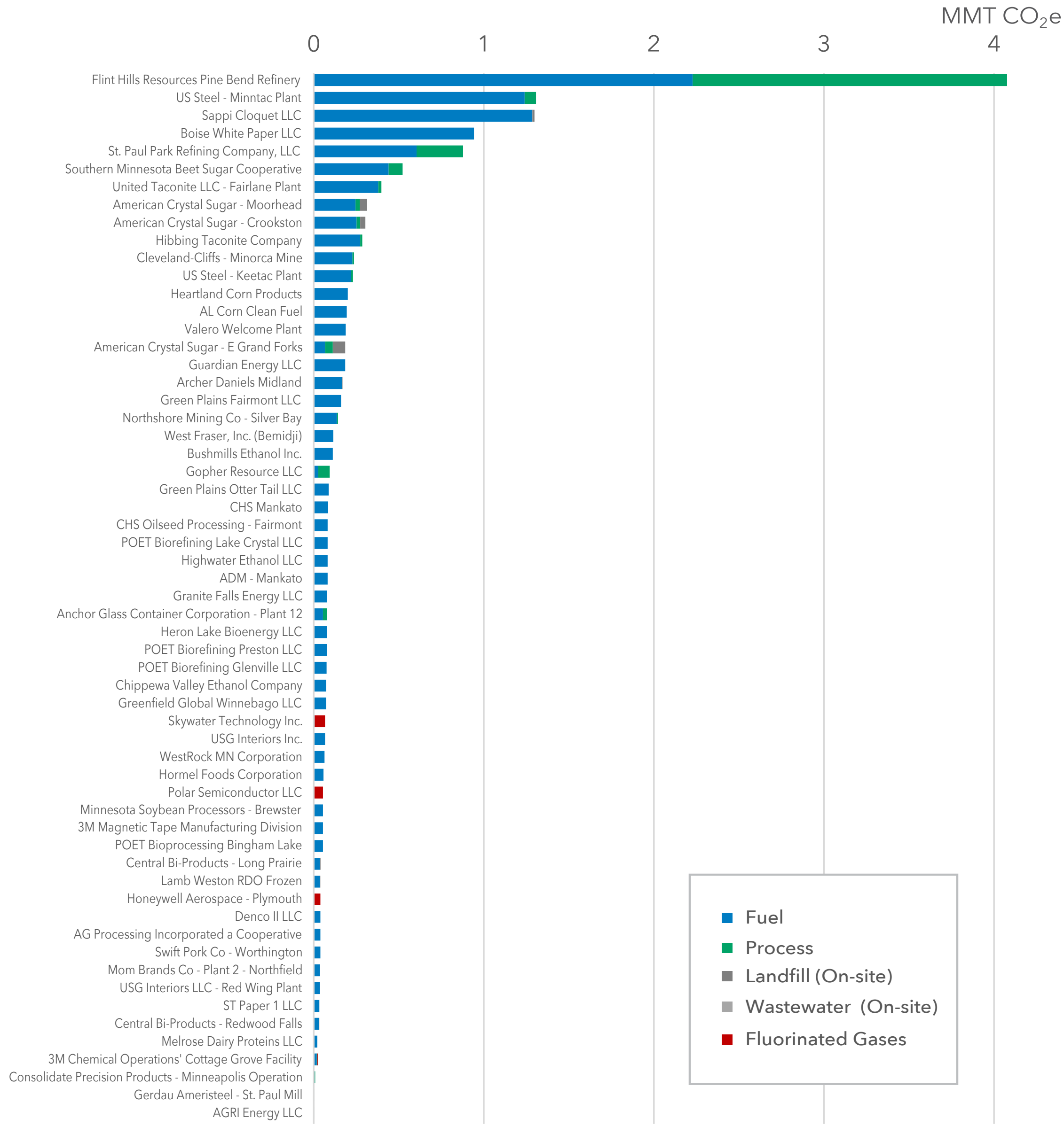


Figure 3 *Annual total emissions of Minnesota's high-emitting (large) manufacturing and industrial facilities, in million metric tons (MMT) of carbon dioxide equivalent (CO_2e). The figure tallies five categories of emissions (fuel-based, process, on-site landfill, on-site wastewater treatment, and production/use of fluorinated gases) originating from 59 facilities mandated to report to the U.S. EPA's GreenHouse Gas Reporting Program during 2023. The majority of emissions are associated with fuel combustion (blue), although petroleum refining also produces a range of process emissions, beet sugar manufacturers manage three on-site landfills that emit significant quantities of methane, and semiconductors and electronics manufacturing either produces or uses large quantities of fluorinated gases. On-site wastewater treatment is a minimal contributor to the sector's overall CO_2e, although significant for some facilities. White several of the facilities toward the bottom did not explicitly meet the reporting threshold for 2023, they are still included here because production levels can vary by year. Finally, it is important to note that even the 'low-emitting' facilities represented in this figure emit significantly more CO_2e per year than the average small or medium manufacturer in the state.*

This finding draws from U.S. EIA data on fuel sales to industrial end uses by facility size, which reveals that of 2,041 tabulated industrial consumers of natural gas in Minnesota consuming a total of 25.3 billion cubic feet of sales volume in 2023, just 17% of that sales volume was purchased by industrial users (including manufacturers) directly from Minnesota's state-

ANNUAL TOTAL EMISSIONS (MMT CO_2e) OF MINNESOTA'S HIGH-EMITTING MANUFACTURING AND INDUSTRIAL SUBSECTORS

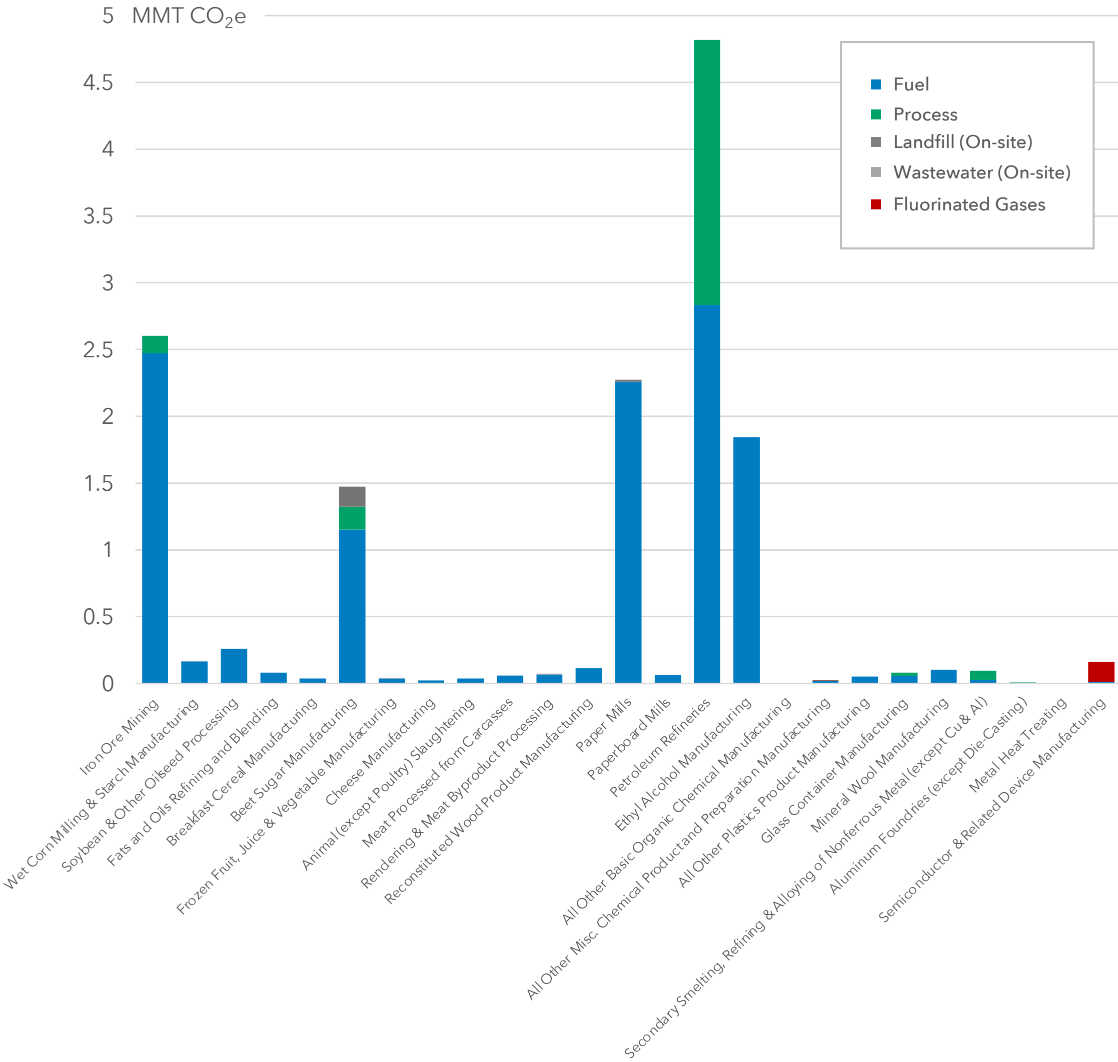


Figure 4 *Annual total emissions of Minnesota's high-emitting industrial and manufacturing subsectors, in million metric tons (MMT) of carbon dioxide equivalent (CO_2e). Five subsectors clearly contribute an outsized fraction of industrial and manufacturing emissions. Seven subsectors (iron ore mining, wet corn milling and starch manufacturing, soybean and other oilseed processing, paper mills, petroleum refineries, and ethyl alcohol manufacturing), constituted by just 37 facilities, contribute an estimated 93% of CO_2e from all high-emitting facilities, and 87% of CO_2e emitted by the state's entire manufacturing sector. Of note, all process emissions produced by beet sugar manufacturers are associated with lime production and use, and are entirely used on-site. 2023 GHGRP reporting year values for some subsectors are too small to appear in the figure. Subsectors correspond to 6-digit NAICS categories and are presented in what would be ascending numeric order of those codes.*

regulated gas utilities.[8] The remainder was purchased by some subset of the state's 59 high-emitting/largest manufacturers[9] from third-party suppliers or natural gas producers; in most cases, these manufacturers then contracted with Minnesota-regulated gas utilities for delivery ('transport') service through utility-owned infrastructure. According to recent research by the Great Plains Institute, 16% of recent gas sales to industrial end uses, however, fell entirely outside

[8] "Natural Gas Annual" report, U.S. Energy Information Administration, November 28, 2025.

[9] And perhaps a small number of facilities with emissions thresholds just below GHGRP's minimum cutoff for mandatory reporting.

of Minnesota's gas regulatory jurisdiction, in a category known as 'bypass,' which is instead regulated by the U.S. Federal Energy Regulatory Commission (FERC). GPI's study, "Industrial Clean Heat in Minnesota: An Overview of the Regulatory Landscape for Decarbonization," provides additional insights into the complexity of relevant jurisdictional considerations.[10]

Just 7 subsectors – constituted by 37 facilities – are responsible for 87% of all CO_2e emitted from Minnesota's manufacturing sector.

While Minnesota's manufacturing sector is diverse overall, the state's high-emitting manufacturers are concentrated in just 25 subsectors, when grouped at the 6-digit NAICS level (see Figure 4). Of these 25, just seven – constituted by 37 facilities – are responsible for nearly 93% of CO_2e emissions from all high-emitting facilities, and an estimated 87% of CO_2e from the state's entire manufacturing sector.[11] These seven subsectors of prominence include iron ore mining (largely due to taconite indurating furnaces), wet corn milling and starch manufacturing, soybean and oilseed processing, beet sugar manufacturing, paper mills, petroleum refineries, and ethyl alcohol manufacturing. When excluding petroleum refining, most of the associated emissions are due to fuel combustion, including the biogenic CO_2 associated with pulping liquor combustion via chemical recovery furnaces in the paper subsector (often categorized somewhat inaccurately as 'process' emissions). Other direct emissions arising from Minnesota's high-emitting subsectors include process emissions from petroleum refining, lime production and on-site industrial landfill (as methane) in the beet sugar industry, glass container manufacturing, and lead battery recycling in the secondary smelting industry.

Natural gas combustion contributes 60% of fuel-based CO_2e emissions from Minnesota's large (high-emitting) manufacturing facilities.

All high-emitting facilities in these 25 industrial subsectors consume natural gas (Figure 5), with combustion byproducts of that one fuel constituting 60% of all fuel-based CO_2e emissions from high-emitting manufacturers in Minnesota, based on GHGRP records. Some facilities with more complex processes or facility layouts also consume other fuels like propane, distillate fuel oil no. 2, anthracite coal, sub-bituminous coal, coal coke, wood and wood residuals, pulping liquor, and fuel gas, plus small amounts of yet other fossil fuel types. Following the same trend as total emissions, the industrial subsectors that contribute the majority of fuel-based CO_2e emissions include iron ore mining, wet corn milling and starch manufacturing, soybean and other oilseed processing, beet sugar manufacturing, paper mills, petroleum refineries, and ethyl alcohol manufacturing. Consumption of coal products is confined to certain high-temperature needs in a handful of subsectors, including stoker/power boilers, lime kilns at the state's four sugar beet manufacturers, and a smelting furnace.

As mentioned, two paper mills also possess chemical recovery furnaces, which burn dissolved lignin in spent pulping liquor, producing electricity for on-site consumption and allowing for crucial chemical recycling and reuse. This process minimizes waste and promotes energy

---

[10] H. Dobie and H. Turner, "Industrial Clean Heat in Minnesota: An Overview of the Regulatory Landscape for Decarbonization," Great Plains Institute, December 2025.

[11] Based on a combination of GHGRP records, U.S. EIA natural gas sales data, and the assumption that small and medium manufacturers largely rely on natural gas for heat needs.

ANNUAL FUEL EMISSIONS (MMT CO_2e) OF MINNESOTA'S HIGH-EMITTING MANUFACTURING AND INDUSTRIAL SUBSECTORS

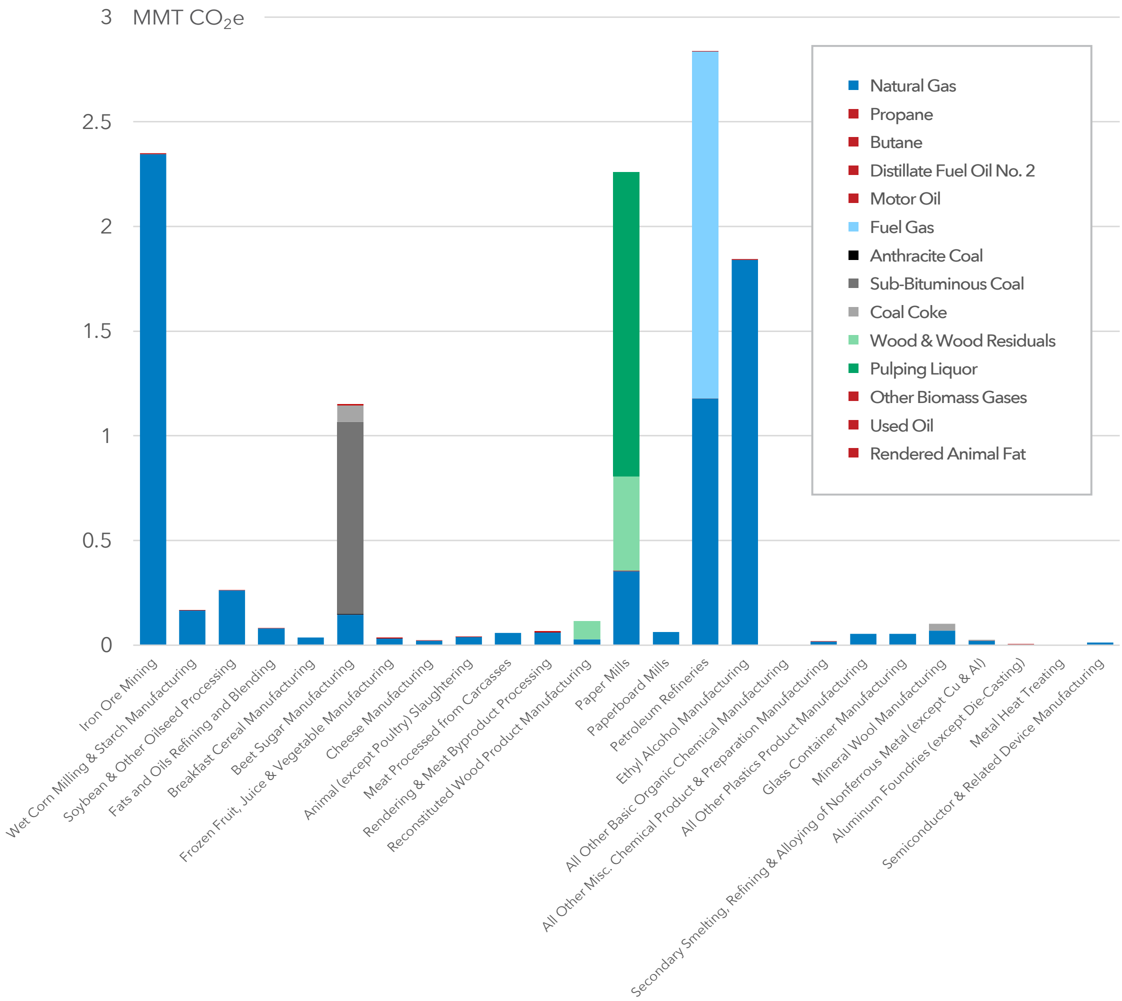


Figure 5 *Annual fuel-based emissions of Minnesota's high-emitting industrial and manufacturing subsectors, in million metric tons (MMT) of carbon dioxide equivalent (CO_2e). All subsectors consume fossil fuels, including natural gas which contributes about 60% of total fuel-based emissions from the sector. Some facilities with more complex facility layouts or processes consume a broader range of fuels. Nearly all coal products-based emissions are associated with lime production in the beet sugar manufacturing subsector (four facilities), although mineral wool production (one facility) and secondary smelting of nonferrous metals (one facility) also combust some coal products. Most biogenic emissions, typically considered net-zero, are associated with wood and wood residuals and pulping liquor combustion in the reconstituted wood product manufacturing and paper mills industries. Pulping liquor, in particular, is combusted during the chemical recovery process at two pulp and paper mills, in a process that the mills further rely on for on-site electricity generation. Minnesota's two petroleum refineries both produce and combust large quantities of fuel gas to support their refining operations. All other fuel types specified in the legend are burned in limited quantities and are thus represented in the same color (red). Like pulping liquor, some of these fuels (used oil, biomass gases, rendered animal fat) are also byproducts. 2023 GHGRP reporting year values for some subsectors are too small to appear in the figure. Subsectors correspond to 6-digit NAICS categories and are presented in what would be ascending numeric order of those codes.*

independence at the mills, reducing their net emissions footprint by sourcing power from a net-zero (biomass-derived) fuel. Several other facilities burn small amounts of biomass-derived fuels produced as byproducts, including used oil, biomass gases, and rendered animal fat.

Aside from the paper sector, Minnesota's high-emitting facilities largely burn fuels for heat energy to drive their thermal-based manufacturing processes. Because the process needs vary by industrial subsector, so too do their relative needs for heat energy in the low (<200°C), medium (200-500°C), and high (>500°C) temperature ranges, as shown in Figure 6. For example, most of the subsectors that fall under food manufacturing, paper (excluding kilns and chemical recovery furnaces) production, and ethyl alcohol manufacturing all have a

ANNUAL HEAT ENERGY CONSUMPTION (TWh) OF MINNESOTA'S HIGH-EMITTING MANUFACTURING AND INDUSTRIAL SUBSECTORS

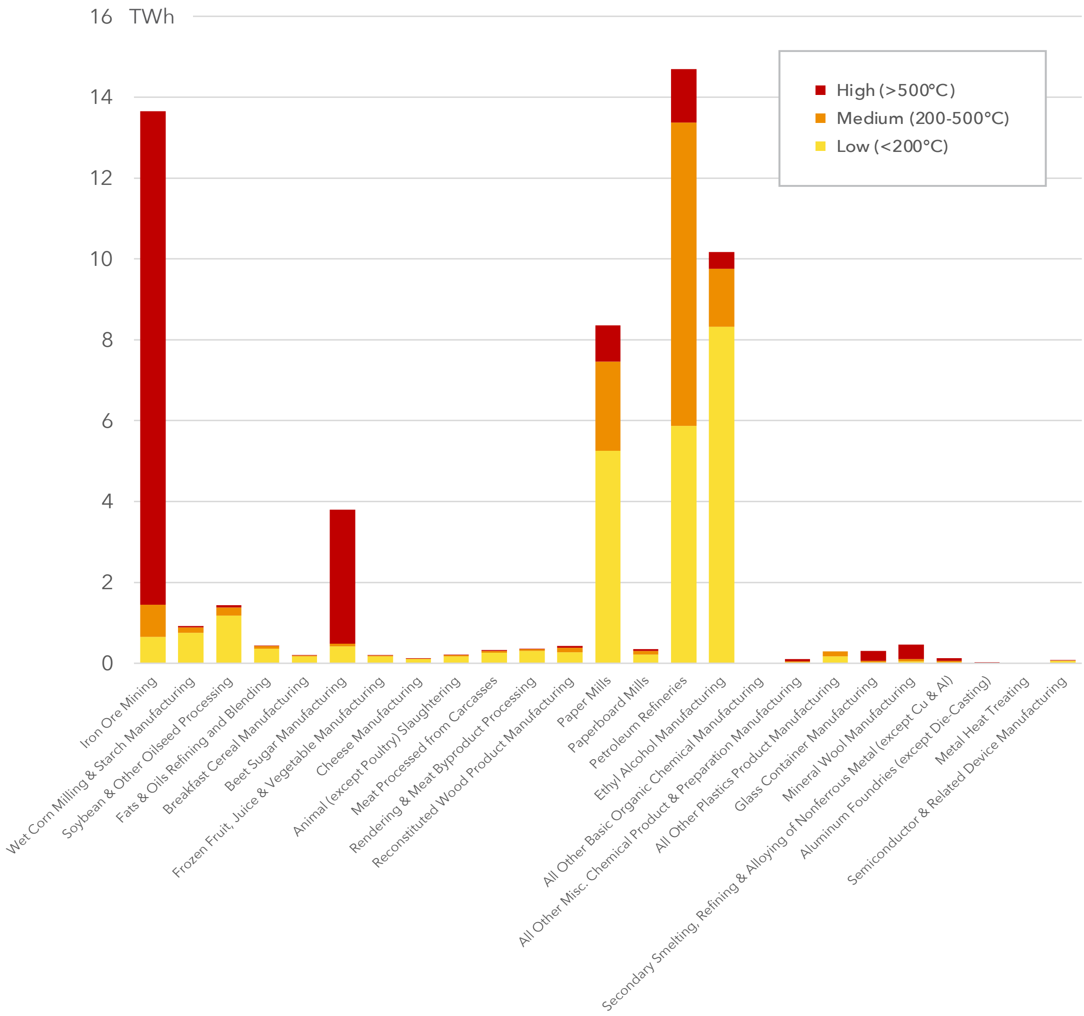


Figure 6 *Estimated annual heat energy consumption of Minnesota's high-emitting industrial and manufacturing subsectors, in terawatt hours (TWh). Estimating heat energy needs in TWh offers an opportunity to further estimate the clean electricity needs that subsectors would require if electrifying. In most cases, low-temperature industrial heat is considered readily electrifiable with existing technologies, and similarly for many medium-temperature heat applications. As shown in the figure, some subsectors (e.g., most food manufacturing, ethyl alcohol manufacturing) predominantly consume low- or low- and medium-temperature heat, meaning that electrification of the constituting facilities could eliminate nearly all direct emissions from these subsectors. In contrast, subsectors that rely more heavily on high-temperature heat will require alternative means for decarbonizing, such as fuel-switching or changes to processes. In all cases, it is important to recognize that the 59 high-emitting facilities represented in this figure will require tailored solutions to achieve facility- or subsector-level net-zero. 2023 GHGRP reporting year values for some subsectors are too small to appear in the figure. Subsectors correspond to 6-digit NAICS categories and are presented in what would be ascending numeric order of those codes.*

predominant need for low-temperature process heat. In contrast, iron ore pellet production in the iron ore mining industry, lime manufacturing in the beet sugar industry, glass container manufacturing, and mineral wool manufacturing have a predominant need for high-temperature process heat. Regardless of process heat temperature, creating decarbonization plans for each of these subsectors and their associated high-emitting facilities will require custom approaches with a suite of solutions, ranging from electrification to fuel-switching.

ELECTRIFICATION POTENTIAL OF MINNESOTA'S MANUFACTURERS

The distinct heat needs of Minnesota's 25 manufacturing subsectors and their 59 high-emitting constituent facilities are met by different types of combustion units, with boilers commonly supplying low- and medium-temperature (<500°C) process heat and various types of specialty furnaces and kilns typically supplying high-temperature (>500°C) heat. Records show that facilities that rely on boilers commonly have more than one boiler on-site. For example, back-up boilers allow a facility to maintain production during servicing of the primary boiler. In some cases, Minnesota's high-emitting facilities may rely on 10 or more separate heat-supplying units, reflecting a facility complexity far more extensive than that found in most commercial buildings or single-family residential units.

To support industrial decarbonization interests, electrification of low- and medium-temperature industrial process heat is one priority strategy, tied to certain types of heat-supplying units, process needs, and temperature ranges, such as low- (<200°C) and medium-temperature (200-500°C) heat. Tallying all low- and medium-temperature heat from Minnesota's 59 high-emitters yields an estimated 37.9 TWh of annual heat energy needs. Most large industrial facilities operate continuously nearly every hour of the day and every day of the year, with highly infrequent (and typically planned) downtimes for maintenance and upgrades. Thus, assuming a levelized heat demand across all 8,760 hours of a single year, Minnesota's high-emitting facilities currently consume about 4.3 GW of low- and medium-temperature heat on-site in any given moment (i.e., thermal power).[12] The state's >8,500 small and medium manufacturers consume an additional several hundred megawatts of thermal power. Finally, in contrast, Minnesota's paper mills, through pulping liquor combustion in chemical recovery furnaces, are also producers of a large fraction of the electricity they consume (estimated at 4-5 TWh), and any industrial electrification transition should seek to preserve their current processes and electricity generation means.

At any given moment, Minnesota's high-emitting facilities consume roughly

4.3 GW

of low- and medium-temperature heat on-site.

Combined, these findings give a starting point for assessing future clean power needs to support industrial electrification of priority manufacturing subsectors in Minnesota. Two additional factors are worth noting in this context. One, many electrified technologies are more efficient than their fuel-burning counterparts, as described in greater detail in *Electrification*. Depending on the temperature lift,[13] for example, an industrial heat pump can supply process heat at efficiencies several times greater than unity, which would correspondingly reduce the energy consumption of the facility.[14,15] Two, power generation and distribution systems face efficiency losses from the point of power generation to the point of consumption (often

[12] Energy values were calculated from fuel and emission records in GHGRP, and corresponding emission factors published by U.S. EPA, overlain by published models of energy consumption by low-, medium-, and high-temperature heat fractions, by subsector.

[13] The 'temperature lift' is the difference between the starting 'cold' temperature and the necessary 'hot' temperature needed to drive a process.

[14] N. Mariano, O. Quinn, A. Merlo, et al., "The Clean Heat Climate Opportunity: A Roadmap for Electrifying Low- and Medium-Temperature Industrial Heat," The 2035 Initiative, UC Santa Barbara, December 2025.

[15] E. Rightor, P. Scheihing, A. Hoffmeister, and R. Papar, "Industrial Heat Pumps: Electrifying Industry's Process Heat Supply," ACEEE, March 2022.

estimated as 7%), and renewable installations operate at just a fraction of their nameplate capacity due to the intermittency of sunlight and wind (on average, 20% for solar and 33% for wind in Minnesota, based on 2023 EIA data[16]).

Effectively, these factors compete with each other when assessing the potential impact on the power grid that industrial electrification would induce: improved efficiencies mean less energy would be consumed on-site during manufacturing activities, but even so, the inherent inefficiencies of the power grid could necessitate that the state's utilities would need to supply a 'nameplate' generation capacity several times the estimated heat power consumption of 4.3 GW. This fact will be true even if Minnesota's industrial sector widely adopts thermal energy storage as a tactic to reduce the cost of procuring thermal power while helping to stabilize clean power demand and response across the state's power grid (see *Electrification: Thermal Batteries*, below). All these points combined suggest that for Minnesota and its utilities to effectively plan for the future, deeper, more nuanced analysis of industrial electrification scenarios will be necessary.

It is also important to bring a degree of focus to Minnesota's food and beverage manufacturers, in part because the state was the recipient of a U.S. EPA Climate Pollution Reduction Grant focused on Climate-Smart Food Systems. A sizable portion of this award ($60 million) will form the basis of a new 'industrial innovation' grant program with a dual emphasis on facility-level technical assistance and planning, and project implementation. Figure 7 provides a closer look at the estimated heat energy needs for high-emitting manufacturers that fall into the relevant food and beverage NAICS categories in Minnesota. The energy needs represented

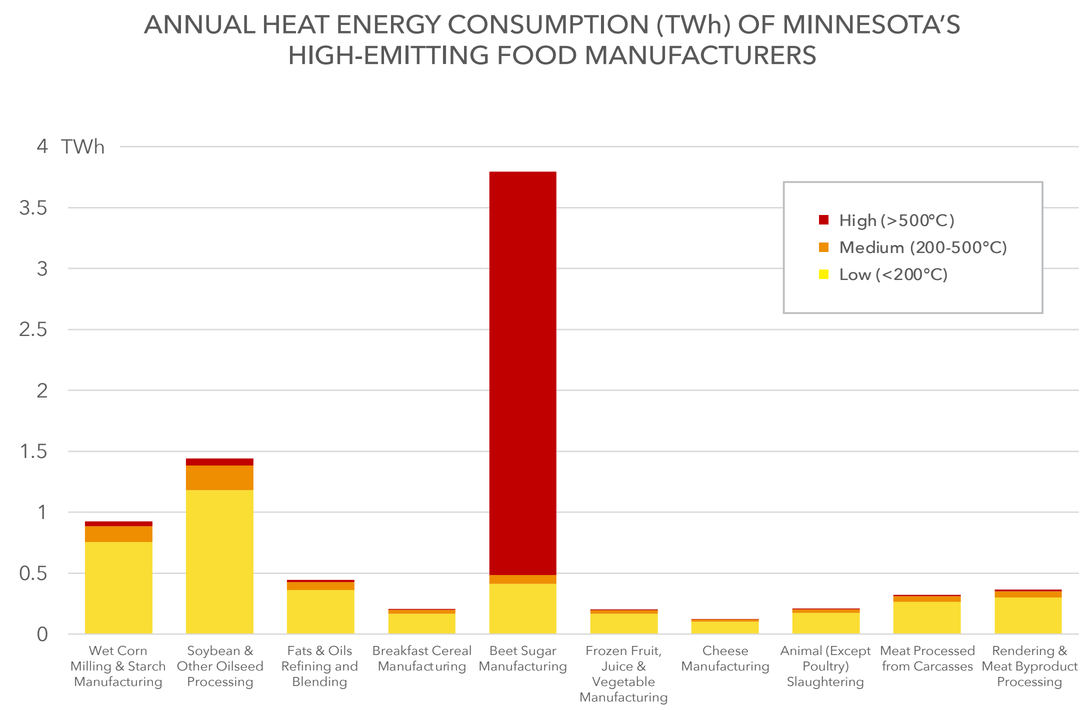


Figure 7 *Estimated annual heat energy consumption of Minnesota's high-emitting food manufacturing subsectors, in terawatt hours (TWh). Estimating heat energy needs in TWh offers an opportunity to further estimate the clean electricity needs that these subsectors would require if electrifying. In most cases, low-temperature industrial heat is considered readily electrifiable with existing technologies, and similarly for many medium-temperature heat applications. As shown in the figure, food manufacturing activities in Minnesota (except beet sugar manufacturing) predominantly consume low-temperature heat, meaning that electrification of the 17 facilities represented in this figure could eliminate nearly all direct emissions from seven of eight food manufacturing subsectors. Subsectors correspond to 6-digit NAICS categories and are presented in what would be ascending numeric order of those codes.*

---

[16] "Minnesota: State Profile and Energy Estimates," U.S. Energy Information Administration, accessed January 2026.

in this figure are associated with 17 high-emitting facilities, although it should be noted that recent records indicate the state is home to another 999 small and medium manufacturers in qualifying NAICS categories. Of the facilities represented in the figure, low-temperature processes currently consume an estimated 3.9 TWh of heat energy per year, while medium-temperature processes consume roughly 0.7 TWh. Levelized, these values equate to the consumption of about 500 MW of low- and medium-temperature heat by Minnesota's high-emitting food manufacturers at any given moment.

A recent study by The 2035 Initiative took a more nuanced approach to analyzing the electrification potential of facilities that fall into the NAICS categories represented in Figure 5 (with the exception of the 'Meat Processed from Carcasses' subsector). For each NAICS category, they developed a process model archetype to model mass and energy flows at the unit level. This fine-grained approach captures how plants operate in practice and how electrification would change fuel use, electricity demand, costs, and emissions. Applying this framework, the researchers estimated the reduction in health-harming criteria air pollutants (CAPs) achievable if 16 high-emitting Minnesota facilities could be electrified with industrial heat pumps. See *GET THE FACTS: Industrial Electrification Can Benefit Community Health, Too*. Their complete findings are reported in "The Clean Heat Climate Opportunity: A Roadmap for Electrifying Low- and Medium-Temperature Industrial Heat."

TECHNICAL APPROACHES TO DECARBONIZING INDUSTRY

The primary tactics for reducing scope 1 industrial emissions are minimizing on-site fuel combustion by increasing energy and materials efficiency (i.e., reducing input requirements and waste generation) and electrifying heat production where possible.[17] For processes that are especially difficult to electrify, the use of alternative fuels with a low carbon intensity is another option. Finally, for residual carbon emissions that cannot be abated with existing approaches, carbon capture and/or carbon offsets may be needed. The tools for, and the challenges associated with, implementing these strategies are described in the following.

The primary tactics for reducing scope 1 industrial emissions are minimizing on-site fuel combustion by increasing energy and materials efficiency and electrifying heat production.

Efficiency improvements

Measures to increase mechanical and thermal efficiency and reduce heat waste are typically the most cost-effective options for facilities striving to lower their carbon intensity.[18] In support of this idea, the efficiency measures implemented by the growing number of industrial partners in the U.S. Department of Energy's Better Plants Program — currently more than 3,700 industrial plants — have delivered a 1.8% average annual energy intensity improvement rate, leading to two impressive savings totals since 2009: 2.8 quadrillion BTU of industrial heat and $14.1 billion in facility operating costs.[19] The most impactful areas for efficiency enhancements at energy-intensive industrial facilities include the adoption of energy-efficient technology alternatives, systems optimization (via the use of sensors, analytics, smart manufacturing tools, and strategic energy management),

[17] J. Millot, "Scope 1 emissions explained: How to track, report, and reduce operational carbon," Carbon Direct, accessed January 2026.

[18] J. Cresko, E. Rightor, A. Carpenter, et al., "Industrial Decarbonization Roadmap," U.S. Department of Energy, September 2022.

[19] U.S. DOE's Better Plants infographic 2024, accessed December 2025.

GET THE FACTS

Industrial Electrification Can Benefit Community Health, Too

Fossil fuel combustion releases harmful air pollutants that directly affect human health. Many fuels, including coal, woody biomass, and distillate oils, emit **fine particulate matter ($PM_{2.5}$)**, a pollutant linked to asthma, cardiovascular disease, and premature death.[1] **Natural-gas-fired boilers and heaters** release **nitrogen oxides (NO_x)**, which have direct respiratory impacts and contribute to the formation of **ground-level ozone (O_3)** and **secondary $PM_{2.5}$**. Burning sulfur-containing fuels emits **sulfur dioxide (SO_2)**, which also reacts in the atmosphere to form secondary $PM_{2.5}$.

These pollutants place the greatest burden on communities located near industrial facilities. Across the U.S., industrial sites are more likely to be located near Black, Hispanic, and other communities of color, reflecting decades of racial segregation and inequitable siting practices. As a result, people of color and low-income households are still consistently exposed to higher levels of $PM_{2.5}$, NO_x, and ozone, even after decades of air-quality improvements.[2] Layered on top of existing socioeconomic challenges, these unequal pollution burdens leave marginalized communities facing more illness and greater health risks.

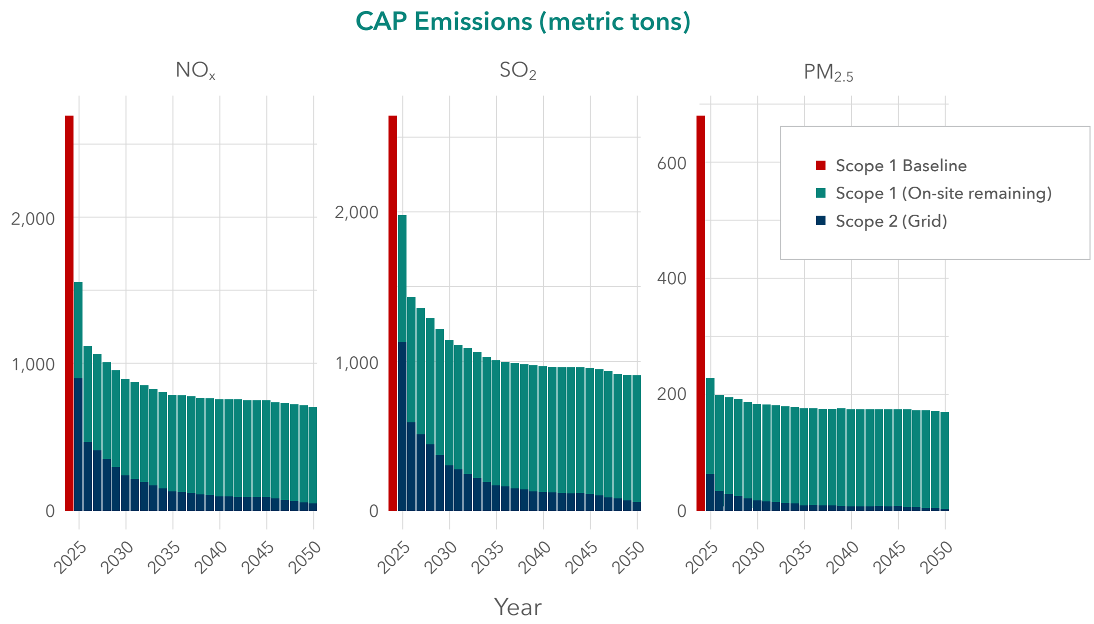
To better understand how these dynamics apply in Minnesota, researchers at the University of California, Santa Barbara's The 2035 Initiative conducted a rigorous engineering analysis to assess the techno-economic feasibility of electrifying industrial process heat and to estimate the resulting pollution impacts. Their study, "The Clean Heat Climate Opportunity: A Roadmap for Electrifying Low- and Medium-Temperature Industrial Heat," focuses on **low- and medium-temperature heat**, which accounts for a large share of energy use in food and beverage manufacturing and is well suited for electrification using commercially available technologies such as **industrial heat pumps and electric boilers**.

The study finds that full electrification of Minnesota's 16 high-emitting food and beverage manufacturing plants would reduce pollution by **47,000 metric tons of NO_x, 40,000 metric tons of SO_2, and 13,000 metric tons of $PM_{2.5}$** from 2025 through 2050. It is estimated that such reductions would help Minnesota communities avoid **250 thousand asthma attacks, 460 emergency room visits, and 400-800 premature deaths**, along with **35,000 lost workdays and 70,000 lost school days**, delivering **$8.3–$14 billion in cumulative health and economic benefits** over that same time period.

---

1 "Inhalable Particulate Matter and Health ($PM_{2.5}$ and PM10)," California Air Resources Board, accessed January 2026.

2 J. Liu, L. P. Clark, M. J. Bechle, et al., "Disparities in Air Pollution Exposure in the United States by Race/Ethnicity and Income, 1990–2010," Environmental Health Perspectives, December 2021.



Annual CAP emissions comparing baseline technology (red bars using NEI 2020 data) to electrification with air-source heat pumps and efficiency improvements (stacked bars). Under electrification, Scope 2 (grid) emissions reflect increased electricity demand, while Scope 1 (on-site) emissions represent remaining pollution from non-electrified processes (byproduct fuels, CHP, and high-temperature processes were out of scope; see report for details). Year 2025 uses current grid conditions (eGRID 2023 emissions factors) and years 2026-2050 use NREL's Cambium "Mid-case 95% Decarbonization by 2050" grid projection.

UC SANTA BARBARA
The 2035 Initiative

The 2035 Initiative at UC Santa Barbara is a cutting-edge "think-and-do" tank that brings together world-leading environmental policy research labs to develop politically viable roadmaps for a low-carbon, equitable, and climate-resilient energy system. We use empirical research, policy development, and media engagement to support transformational policy change in the United States and across the planet. Learn more about who we are and what we do.

and waste heat recovery.[20] Specific solutions vary by subsector, facility, and process, and a high level of customization is required to implement some of the most impactful measures, especially those related to systems optimization and waste heat utilization.

Industrial heat pumps can play a key role in waste heat recovery and reuse. Heat pumps, typically powered by electricity, transfer heat from one location to another – an approach that is significantly more energy efficient than technologies like resistance heating units that convert electricity to heat directly. The efficiency of a given heat pump system is related to its

[20] J. Cresko, E. Rightor, A. Carpenter, et al., "Industrial Decarbonization Roadmap," U.S. Department of Energy, September 2022.

required temperature 'lift,' that is, the difference between the temperature of the source heat and the higher temperature needed for the manufacturing process. Therefore, the recovery of waste heat using a heat pump has a double advantage in that it drastically reduces energy losses from the system while simultaneously enabling greater efficiency (or higher output temperature) per unit of electrical energy supplied to power the pump.

The use of waste heat recovery to generate electricity, in a process known as 'waste heat to power' or WHP,[21] is another key approach for system-level efficiency in manufacturing. In WHP systems, thermal energy from waste heat is used to drive a turbine, which generates electrical power. Optimizing the use of WHP technology depends on the specific system and waste heat characteristics, such as temperature and consistency. The generated electricity can be used onsite or sold to the grid.

As stated above, although enhanced efficiency measures are often highly cost effective, a variety of barriers can either prevent or slow down their implementation.[22] Major barriers include internal competition for capital and short return on investment requirements, insufficient incentives from the government or utilities, and a lack of familiarity and technical expertise in available solutions or at many facilities.

Electrification

In 2023, fuel combustion for process heating accounted for more than 12 MMT of CO_2e emissions in Minnesota, constituting more than half of the CO_2e emissions attributed to the state's industrial sector in its biennial GHG report to the state legislature.[23] Electrification of process heating — especially when paired with continued grid decarbonization — presents a major opportunity to lower the carbon footprint of Minnesota's manufacturing sector. Electrified heat generation is typically more efficient than combustion because no energy is lost to the production of hot exhaust gases or water vapor — both inefficiencies that are inherent to combustion systems. In addition, the replacement of fossil fuel-powered equipment with electric heat generation at industrial facilities would eliminate point sources of air pollution at thousands of locations across the state, thus providing significant co-benefits in the form of higher quality of life and healthcare cost savings for the communities in which these facilities reside (for example, see *GET THE FACTS: Industrial Electrification Can Benefit Community Health, Too* and *GET THE FACTS: New Cumulative Impacts Legislation Will Help Reduce the Health Harms of Industrial Air Pollution*). This is an especially impactful point for communities in environmental justice census tracts.[24]

In 2023, fuel combustion for process heating accounted for more than

12 MMT of CO_2e

emissions in Minnesota.

A variety of electricity-powered, industrial heat-generating technologies are available in the market today, with some ready for mass deployment (high technology readiness level or TRL)[25] and others at earlier stages of development (lower TRL). In general, electrification options for

[21] "Waste Heat to Power," U.S. DOE's Combined Heat and Power Technology Fact Sheet Series, accessed December 2025.

[22] "Barriers to Industrial Energy Efficiency: Report to Congress," U.S. Department of Energy, June 2015.

[23] "Greenhouse gas emissions in Minnesota 2005-2022," Minnesota Pollution Control Agency and Department of Commerce, January 2025.

[24] "MPCA Environmental Justice," Minnesota Pollution Control Agency, accessed January 2026.

[25] "Technology-to-Market," U.S. Department of Energy, accessed January 2026.

heat generation are more advanced for lower-temperature applications, with some technology types ready to be deployed at scale. Among the most mature clean heat technologies that could supply a large fraction of industrial process heat are heat pumps and electric boilers,[26] which can provide heat up to approximately 200°C and 350°C, respectively. These options have been highlighted in recent reports as critical for decarbonizing low- and medium-temperature processes.[27,28,29] Another electrified technology that will be critical for supporting industrial electrification is thermal batteries. These systems aim to electrify a wide temperature range of industrial process heat while enabling demand flexibility — an approach that could help balance the supply and demand sides of the electric grid and, thereby, has the potential to help reduce energy costs across customer classes.

Heat pumps. A major feature of heat pumps is their high efficiency. Because heat pumps move rather than directly generate heat, they can deliver more thermal energy than the electric energy that they consume. According to one estimate, widescale deployment of industrial heat pumps could save up to one-third (32%) of energy used in manufacturing process heating.[30] Commercially available heat pumps can provide heat up to 160°C,[31] with newer models being developed to reach 200°C.[32] Heat pumps are particularly suitable for industries that have significant requirements for lower temperature process heat, such as food and beverage, pulp and paper, and chemicals manufacturing. In subsectors that rely on higher temperatures, heat pumps can play a valuable role by recovering waste heat for preheating feedstocks or gases, thereby reducing overall energy demand, as discussed in *Efficiency improvements*, above.

Heat pumps are particularly suitable for industries that have significant requirements for lower temperature process heat, such as food and beverage, pulp and paper, and chemicals manufacturing.

The main challenges related to heat pump adoption include high upfront costs (capital expenses or CAPEX) and the degree of facility engineering/design (which impacts site suitability) typically required to incorporate them into existing facilities. In contrast, electric boilers require minimal facility engineering changes to replace legacy gas boilers, allowing them to serve as a 'drop-in replacement' technology, albeit with lower energy efficiency than a heat pump.

Electric resistance heating. Electric resistance heating converts electrical energy into thermal energy by running an electric current through a resistor. Resistance heating can be direct or indirect and is already used for a variety of industrial applications. Equipment that commonly employs resistance heating today includes dryers, ovens, air heaters, and boilers. Electric boilers have a particularly high impact potential because they constitute a commercially ready, mature technology that can serve as a drop-in replacement for the ubiquitous fossil fuel-

---

[26] For example: Skyven Technologies, AtmosZero, and Thermon Precision Boilers.

[27] E. Rightor, P. Scheihing, A. Hoffmeister, and R. Papar, "Industrial Heat Pumps: Electrifying Industry's Process Heat Supply," ACEEE, March 2022.

[28] S. Smillie, D. Alberga, R. Locken, et al., "Decarbonizing Industrial Heat: Measuring Economic Potential and Policy Mechanisms," Energy and Environmental Economics, Inc., October 2024.

[29] "The Renewable Thermal Vision," Renewable Thermal Collaborative, accessed January 2026.

[30] E. Rightor, P. Scheihing, A. Hoffmeister, and R. Papar, "Industrial Heat Pumps: Electrifying Industry's Process Heat Supply," ACEEE, March 2022.

[31] Notably, this is above the temperature at which water turns to steam, which is commonly used in industrial processes as the mechanism of heat supply (through pipe networks).

[32] For example, Ecop Technologies' 700 kW heat pump. V. Thompson, "Ecop Technologies launches 700 kW industrial heat pump with output temperatures of up to 200 C," PV Magazine, August 1, 2024.

powered boilers that Minnesota's manufacturing sector currently relies on.[33] Electric boilers can generate steam up to 350°C, and with energy efficiencies of 95-99%, they are substantially more efficient than combustion-powered boilers (only 70-80% efficient).[34]

The electrification of industrial boilers in Minnesota could annually save

2.9 TWh

of energy and reduce emissions by up to

4.6 million tons of CO_2.

According to a recent estimate from the Lawrence Berkeley National Laboratory, the electrification of industrial boilers in Minnesota could annually save 10.6 petajoules (2.9 TWh, or nearly 8% of current heat energy consumption) of energy and reduce CO_2 emissions by up to 4.6 million tons, depending on the extent of grid decarbonization.[35]

Although electric boilers can be readily integrated into existing facilities in place of legacy equipment and have lower upfront costs compared to heat pumps, a major barrier to deployment is the high cost of electricity relative to natural gas and the resulting higher operating costs of electric versus natural gas-powered boilers, as reflected in a recent study by The 2035 Initiative.[36]

Thermal batteries. Thermal batteries are another promising technology for meeting a wide range of industrial heating needs, capable of providing heat up to 1,800°C.[37] Two primary characteristics of thermal batteries are their ability to convert electricity to heat and their capacity to store heat for long periods of time — hours to days — with minimal losses (Figure 8). The coupling of both capabilities is the central feature of thermal batteries that Minnesota's manufacturing sector could tap to meaningfully address the electricity cost barrier and promote increased reliance on solar and wind power (often criticized as 'too intermittent' to support manufacturing electrification), at both the facility and grid levels.

Thermal batteries typically use inexpensive materials (e.g., graphite, clay bricks, molten salts, crushed rocks, slag byproduct[38]) capable of storing large quantities of high-temperature heat, which is generated by running an electric current through either a resistor or the storage material itself. A flow of air or liquid through the chamber storing the hot materials is then used to deliver the battery's stored heat to the industrial process. Thermal batteries can achieve efficiencies (as thermal energy output versus electrical energy input) of 90-98% and can operate without efficiency degradation over many cycles and years.[39] Existing thermal batteries are most advanced for lower-temperature applications, but several companies[40] are working on systems capable of reaching 1,500–1,800°C to serve sectors such as lime manufacturing, taconite processing, and ferrous metals production.

---

[33] "Industrial Boiler Pollution in Minnesota," Evergreen Collaborative and Sierra Club, accessed January 2026.

[34] M. Jibran, S. Zuberi, A. Hasanbeigi, W. R. Morrow, "Electrification of Boilers in U.S. Manufacturing," Lawrence Berkeley National Laboratory, November 2021.

[35] M. Jibran, S. Zuberi, A. Hasanbeigi, W. R. Morrow, "Electrification of Boilers in U.S. Manufacturing," Lawrence Berkeley National Laboratory, November 2021.

[36] N. Mariano, O. Quinn, A. Merlo, et al., "The Clean Heat Climate Opportunity: A Roadmap for Electrifying Low- and Medium-Temperature Industrial Heat," The 2035 Initiative, UC Santa Barbara, December 2025.

[37] For example: Antora Energy, Electrified Thermal Solutions, and Rondo Energy.

[38] See example industrial applications from thermal energy storage system manufacturer Kraftblock.

[39] K. Spees, J.M. Hagerty, J. Grove, "Thermal Batteries: Opportunities to Accelerate Decarbonization of Industrial Heat," The Brattle Group, Center for Climate and Energy Solutions, and Renewable Thermal Collaborative, October 2023.

[40] For example: Antora Energy.

GET THE FACTS

New Cumulative Impacts Legislation Will Help Reduce the Health Harms of Industrial Air Pollution

Criteria air pollutants (CAPs) are a set of pollutants that are particularly prevalent and harmful to human health. The U.S. Environmental Protection Agency has designated six pollutants as CAPs: **carbon monoxide (CO)**, **lead**, **nitrogen oxides (NO_x)**, **ground-level ozone (O_3)**, **particulate matter (PM)**, and **sulfur dioxide (SO_2)**. Each of these pollutants can be produced by a variety of industrial activities, harming nearby communities as they disperse into the air from exhaust systems.

Due to historical racially motivated policies, many industrial facilities are located in or nearby environmental justice communities – communities that are majority Black, Indigenous, and People of Color (BIPOC) and/or low-income. These communities often experience exposure to other forms of pollution, as well as a range of social, economic, and environmental disadvantages. This leads to an effect known as **cumulative impacts**.

Cumulative impacts is an increasingly prominent concept in the environmental justice movement as it effectively outlines why BIPOC and low-income communities experience significantly worse health outcomes and a lower quality of life compared to wealthier, whiter communities. A combination of racially motivated policies, prejudiced decision-making, and a lack of community involvement in permitting has led to the close or overlapping proximity of many industrial facilities with Minnesota's environmental justice communities. Additionally, our current regulatory system largely fails to properly account for cumulative impacts, because the system mostly looks at whether an individual facility stays under its permitted limits for specific pollutants like CAPs. This means that although racially motivated policies like redlining and racial covenants are no longer in effect, we continue to see a disproportionate burden of pollution in environmental justice communities.

A **cumulative impacts analysis** looks at a variety of environmental, social, economic, and health factors to determine how overburdened a community is. Fundamentally, a cumulative impacts framework recognizes that we need to examine and understand the combined effects of exposure to a multitude of stressors over a prolonged period of time when making environmental decisions. Examples of communities suffering the burden of cumulative impacts are South Minneapolis and West St. Paul (see inset figure), which have experienced a combination of industrial pollution from multiple facilities, a lack of green cover, low access to health care, proximity to multiple highways, food insecurity, exposure to lead pipes and paint, and much more.

In 2023, as a result of strong grassroots advocacy by environmental justice communities, Minnesota joined a handful of other states, including New Jersey and New York, in passing a comprehensive cumulative impacts law.[1,2] This law defines environmental justice communities as any census tract with either 40% or more BIPOC, 35% or more low-income, or 40% or more low English proficiency residents, or federally recognized as 'Indian Country' (i.e., a Tribal reservation). The law requires increased analysis of cumulative impacts for industrial facilities in the seven-county Twin Cities metro area, Rochester, and Duluth, with an opt-in option for Tribes. At the time of the release of this report, the law is currently undergoing rulemaking to determine exactly how it will be implemented, in a process that will wrap up in the summer of 2026.[3] Once finished, the law will go

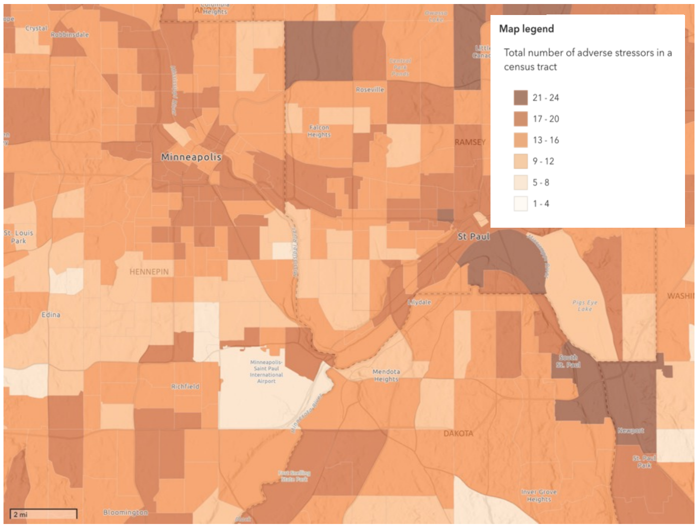
[1] "116.065 Cumulative Impacts Analysis; Permit Decisions in Environmental Justice Areas," 2025 Minnesota Statutes, accessed February 2026.

[2] "The Cumulative Impacts Law," Frontline Communities Protection Coalition, accessed February 2026.

[3] "Cumulative impacts: A tool to address pollution in a community," Minnesota Pollution Control Agency, accessed February 2026.

into effect and begin regulating industrial facilities applying for air permits through the Minnesota Pollution Control Agency (MPCA).

In its final form, this law will require a cumulative impacts analysis for any industrial facility likely to emit harmful air pollutants that is applying for a new, expanded, or renewed air permit and is located either inside of or within one mile of an environmental justice area in the Twin Cities metro area, Rochester, or Duluth. The analysis will look at a variety of stressors and determine whether the facility will have a "**substantial adverse impact**" on the nearby environmental justice community. If so, the facility will either have its permit denied or will be required to enter into a community benefit agreement with the MPCA. While details are still being finalized through the rulemaking process, the goal of this law is to better understand cumulative impacts in Minnesota, require increased analysis for potentially harmful facilities, increase community involvement in the permitting process, and allow historically marginalized and overburdened communities a much stronger say over the presence and certain practices of harmful facilities in their neighborhoods.



MPCA's draft Cumulative Impacts Mapping & Analysis Tool reveals the high burdens faced by the residents of South Minneapolis (census tracts shown in darker colors), and some surrounding areas. The tool uses a combined 24 environmental, social, economic, and health stressors to quantify the cumulative impacts faced by select Minnesota communities in the Twin Cities metro area, Rochester, and Duluth. According to the legend, darker colors indicate that an increasing fraction of the 24 measured stressors are above a statewide or county average, meaning that the community is particularly overburdened and vulnerable.

Once the draft rules are finalized and a notice of intent to adopt has been published (likely around May of this year, 2026), there will be an official public comment period. This will offer a final opportunity for interested parties and individuals to react to the draft rules posed by the MPCA before an administrative law judge decides whether the rules can go into effect. For this law to be fully realized, it is essential that the rules embody the goals of transparency, accountability, and community empowerment.

COPAL

COPAL, Comunidades Organizando el Poder y la Acción Latina, *is a member-based organization established in 2018 to improve the quality of life of Latine families in Minnesota by creating opportunities, building collective power, and transforming systems.*

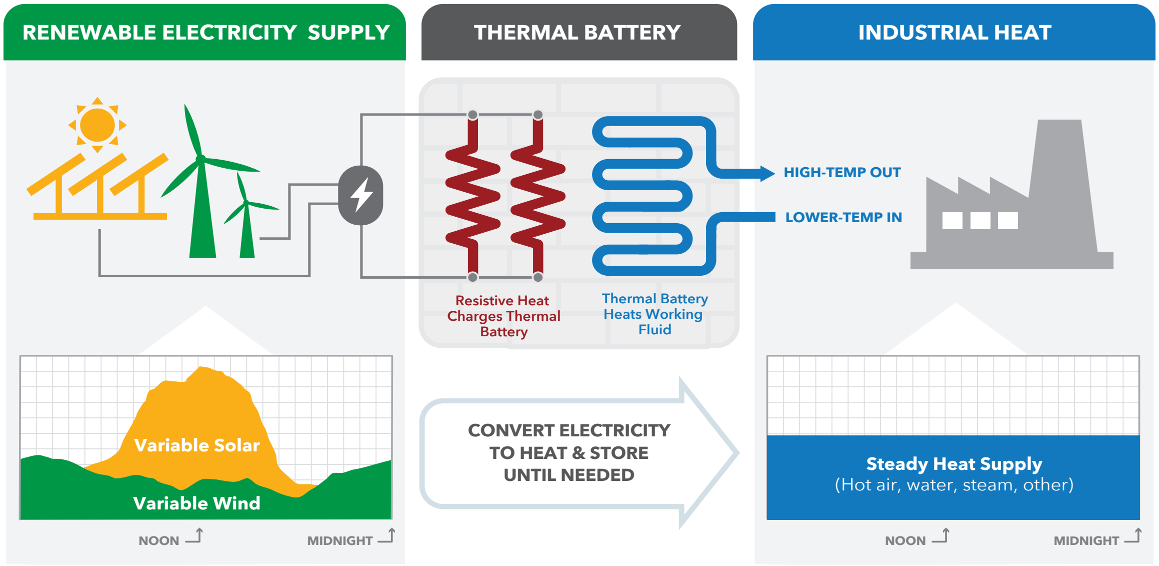


Figure 8 *Thermal batteries can support balancing of supply and demand with greater penetration of renewables into the power grid by drawing on clean electricity when there is excess to resistively heat (charge) the battery's material. This heat can then be stored with minimal losses over long periods of time (hours to days) until the manufacturing process needs it, then transferring heat to the process through a working fluid (air or liquid). This approach can help reduce curtailment of excess renewable generation, while meeting the steady heat needs of large manufacturing processes. The adoption of thermal batteries, paired with modern electric rate structures, can therefore serve two purposes: meaningful facility-level decarbonization and balancing of supply and demand in the power grid, which further serves utilities' interests. Adapted from K. Spees, J. M. Hagerty, and J. Grove, "Thermal Batteries: Opportunities to Accelerate Decarbonization of Industrial Heat," The Brattle Group, Center for Climate and Energy Solutions, and Renewable Thermal Collaborative, with permission from the authors.*

Beyond heat delivery, thermal batteries can function as an energy storage mechanism similar to electrochemical batteries (e.g., lithium ion). This means thermal batteries are an alternative technology with the potential to help balance the supply and demand constraints on power grids as they are increasingly constituted by renewable generators. In this context, the thermal battery can be charged during times of excess electricity supply, when generation from renewables exceeds the load (demand) from customers. This is advantageous because it reduces the need for curtailment.[41] On the output side, thermal batteries can supply constant, uninterrupted heat to meet the specific requirements of industrial users – or they can be configured to generate power. Thermal batteries can be powered by the grid or dedicated renewable generation assets, positioned either in front of or behind the meter.

Thermal batteries can also function as an energy storage mechanism, with the potential to help balance the supply and demand constraints on power grids.

While thermal batteries have a clear potential to support balancing the power grid, thereby enabling greater penetration of intermittent renewable power generation into Minnesota's grid and ensuring more efficient use of existing grid resources, outdated electric pricing schemes threaten their adoption. As shown in Figure 9, the levelized cost of heat (LCOH, or cost to produce a unit of heat) from thermal batteries is highly sensitive to electricity rate structures. According to analysis presented in a recent report,[42] access to wholesale electricity pricing could already make thermal battery heat cheaper than natural gas-powered heat in Minnesota and neighboring states because of the region's abundance of renewable electricity and the

[41] 'Curtailment' occurs when power output exceeds demand and the grid managers intentionally shut down certain power generators to reduce output.

[42] K. Spees, J.M. Hagerty, J. Grove, "Thermal Batteries: Opportunities to Accelerate Decarbonization of Industrial Heat," The Brattle Group, Center for Climate and Energy Solutions, and Renewable Thermal Collaborative, October 2023.

regular need for resource curtailment. Therefore, key to supporting wide-scale thermal battery adoption in the state will be the implementation of supportive policies, alternative electricity rate structures (beyond a simple switch to time-of-use rates[43]), and increased availability of renewable energy.

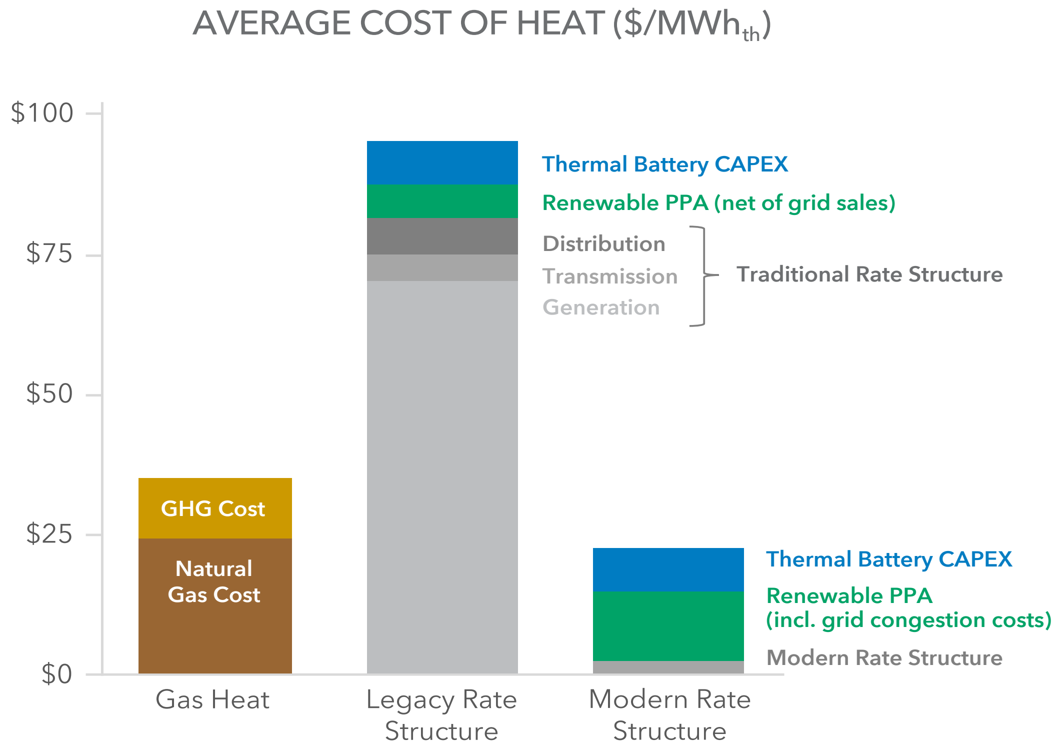


Figure 9 *Under legacy electric utility rate structures, most manufacturers today would face higher costs to operate with electrified process heat than traditional natural gas-powered heat, as shown by the cumulative costs (given in MWh per therm, as a levelized cost of heat or LCOH). However, a modern rate structure with a time-of-use pricing scheme that offers access to market-based electricity prices can reduce these levelized costs and enable the adoption of thermal batteries, potentially delivering process heat for less than a traditional natural gas-powered boiler could supply it. Reprinted from K. Spees, J. M. Hagerty, and J. Grove, "Thermal Batteries: Opportunities to Accelerate Decarbonization of Industrial Heat," The Brattle Group, Center for Climate and Energy Solutions, and Renewable Thermal Collaborative, with permission from the authors.*

Alternative fuels/fuel-switching

While industrial decarbonization should prioritize efficiency and electrification, particularly for low- and medium-temperature heat, the reality is that some facilities and processes will face a variety of constraints. These could include very high-temperature requirements for processes, facility retrofit complexity, space limitations, production system downtime risks, and/or electric grid and tariff limitations. In such cases, facilities may consider switching to lower-carbon fuels that can work with existing combustion-based systems. Major fuel candidates include biomass and biomass-derived waste, renewable natural gas (RNG), and hydrogen. Importantly, the climate benefit of these fuels varies widely and should be evaluated using a life-cycle assessment (LCA)-based approach rather than assumed.

Biomass and biomass-containing waste. Biomass and biomass-containing waste can include residual materials from industrial processes – such as bark, sawdust, dried pulp, or fruit pits – as well as construction and demolition debris. When burned, these materials can supply high-temperature heat for various industrial applications with a lower life cycle-based carbon footprint compared to fossil fuels. Practical considerations for using biomass as a fuel include

[43] For example: Xcel's pilot time-of-use (TOU) rates for large commercial entities in Minnesota.

handling requirements, compatibility with existing equipment, material composition, supply reliability, and proximity to the source. In some industries, such as pulp and paper, significant quantities of biomass waste are generated onsite, making utilization more feasible and economically viable.

As a GHG emissions reduction approach, the use of biomass for heat is most beneficial when it replaces landfilling. Decomposition in landfills often occurs under low-oxygen conditions, producing methane – a greenhouse gas far more potent than CO_2. However, in certain cases, repurposing or recycling biomass waste into new products may offer greater climate benefits by keeping carbon locked in materials rather than releasing it through combustion. As a rule of thumb, biomass use tends to deliver larger climate benefits when it avoids methane-producing disposal pathways and when air quality impacts are managed. For these reasons, biomass decisions are best guided by LCA and local permitting/air quality considerations.

Renewable natural gas (RNG). RNG is a pipeline-grade methane gas produced from renewable sources – primarily organic waste – rather than fossil reserves. It can be used interchangeably with conventional natural gas, making it a practical drop-in substitute for existing systems (most of which rely on natural gas today, see Figure 5). Current RNG production relies mainly on anaerobic digestion of feedstocks such as food and other organic waste, wastewater treatment byproducts, and animal manure. Future supply could expand to include agricultural residues, dedicated energy crops, forestry waste, and municipal solid waste, which today is disposed of in landfills. One challenge currently facing the broader adoption of these pathways is the need for thermal gasification – a process in early commercialization and generally considered more expensive than anaerobic digestion.

A 2025 American Gas Foundation (AGF) assessment estimated that depending on feedstock availability, market conditions, and policy support, the annual RNG potential in Minnesota could reach 49-122 trillion BTU for in-state sources[44] (both via anaerobic digestion and thermal gasification), which corresponds to about 9-24% of the state's current total annual natural gas consumption.[45] Animal manure and landfill gas are Minnesota's two largest potential sources for RNG obtained via anaerobic digestion, while agricultural residues are a major potential resource for the thermal gasification pathway.

Production costs for RNG vary widely, influenced by factors such as equipment, feedstock logistics, purification requirements, and project scale. Additional expenses arise from connecting production sites – often located far from demand centers – to existing infrastructure. According to the 2025 AGF assessment, averaged nationally, wastewater treatment- and landfill gas-derived RNG represent the lowest-cost options starting at about \$7 and \$8.6 per million BTU, respectively, while other sources are more expensive and can exceed \$19-\$40 per million BTU on the low end.[46] For comparison, over the past two decades, industrial natural gas prices in Minnesota have typically hovered around \$5 per million BTU, and have rarely exceeded \$8 per million BTU,[47] making RNG's higher cost a significant hurdle.[48]

When evaluating RNG as a decarbonization strategy, the cost of avoided emissions is an important consideration.[49] Given that the cost, as well as the carbon intensity, of RNG is

---

44 "Renewable Natural Gas Supply Assessment," American Gas Foundation, July 2025.

45 "Natural Gas Summary" for Minnesota on an annual basis, U.S. Energy Information Administration, accessed January 2026.

46 "Renewable Natural Gas Supply Assessment," American Gas Foundation, July 2025.

47 "Natural Gas: Minnesota Natural Gas Industrial Price," U.S. Energy Information Administration, accessed January 2026.

48 These costs are relevant to utility rates, while many industrial customers purchase outside of the utility market at presumably even lower rates.

49 According to analysis in the American Gas Foundation's 2025 assessment, RNG derived from food waste, dairy manure, and swine manure has especially high potential for mitigating GHG emissions from those sources.

strongly influenced by a variety of factors, as mentioned above, a complete LCA looking at the totality of environmental impacts combined with techno-economic analysis is essential to determine whether and when RNG could be a cost-effective decarbonization option for specific facilities.

Hydrogen. Hydrogen (H_2) is a clean-burning gas that produces only heat and water when combusted in the presence of oxygen.[50] Hydrogen burns hotter than natural gas and has been considered as a potential low- or zero-carbon fuel for generating high-temperature industrial heat. While this is a technically feasible option, several longstanding challenges, which are summarized below, currently make hydrogen an unlikely candidate as a viable decarbonization option for industrial heat.

Although hydrogen combustion is carbon-free, the life cycle-based carbon intensity of hydrogen use is heavily dependent on its production pathway. Currently, most hydrogen in the United States is produced via steam methane reforming (SMR) of natural gas, which is a carbon-intensive process that results in 10-11 kg CO_2e/kg H_2. Cleaner production pathways for hydrogen include SMR production coupled with carbon capture or the use of low-/zero-carbon electricity to split water into hydrogen and oxygen (i.e., electrolysis), which is an energy-intensive process. The main challenges for low-carbon hydrogen pathways are technology readiness, scalability, and costs. According to the U.S. National Clean Hydrogen Roadmap, hydrogen would need to cost roughly $1/kg to be considered as an economically realistic option for industrial heat. Unfortunately, recent analyses of hydrogen production pathways continue to estimate production costs for low- and zero-carbon hydrogen well above that target.[51,52]

The storage, transport, and burning of hydrogen require dedicated or modified equipment due to hydrogen's high reactivity, which would further raise costs for potential adopters. Additional challenges arise from competing uses for clean electricity (e.g., data centers and broad electrification targets) and existing higher-value applications for clean hydrogen (e.g., as a feedstock for ammonia, methanol, and semiconductor production). Finally, the early ending of the 45V federal clean hydrogen production tax credit, which was intended to incentivize clean hydrogen production, is likely to reduce interest from potential developers and investors in new projects.[53]

Based on the magnitude and combination of the above challenges and the shifting of priority decarbonization strategies at the federal level, the use of hydrogen as a fuel for industrial heat seems unlikely in the near term. However, the case for hydrogen as a potential low-carbon fuel for industrial heat should be re-examined periodically in the coming years to account for possible technological advances in existing low-carbon hydrogen production pathways, the emergence of new clean hydrogen resources (e.g., geologic hydrogen, which has garnered increasing interest in Minnesota's Iron Range region in recent years[54]), or changes in federal priorities.

---

[50] The burning of hydrogen still results in the formation of nitrous oxides because the high combustion temperature drives the reaction between nitrogen and oxygen in the air. See "Does the use of hydrogen produce air pollutants such as nitrogen oxides?," U.S. Department of Energy, accessed December 2025.

[51] "Pathways to Commercial Liftoff: Clean Hydrogen," U.S. DOE's Update 2024, December 2024.

[52] M. Kostylev, S. Benayoun, E. Boatman, "The Potential for Hydrogen to Support Low-Carbon Industry in Minnesota," 5 Lakes Energy, May 2025.

[53] 45V is a clean hydrogen production tax credit valued at up to $3.00/kg H_2 available for 10 years after the production facility is placed in service. The federal budget passed in summer 2025 severely constrained the potential impact of the tax credit by shifting the deadline to initiate construction of the production facility from December 31, 2032, to December 31, 2027, for eligibility.

[54] J. Lovrien, "After helium discovery, hunt for Minnesota hydrogen ramps up," Duluth News Tribune, December 9, 2025.

Cross-sector coupling

Minnesota's existing industrial subsectors could benefit from several distinct cross-sector coupling opportunities, including opportunities with the potential to both increase economic productivity in the state and further enable deeper decarbonization. The opportunities below are provided as a starting point — deeper study will be necessary to inform any choices to invest in or leverage these opportunities.

Paper mills and biofuels production. Operating on thin margins, integrated pulp and paper mills are already masters of efficiency strategies — with several Minnesota mills producing a significant fraction of their own electricity on-site. But pulp-based paper mills also have the potential to leverage their existing supply chains, material handling expertise, and production systems to become producers of biofuels for sale into regional markets.[55] Pulp-based mills produce large quantities of lignin-based liquor following pulping, which typically contains high fractions of fermentable sugars, the base ingredient for biorefining into low-carbon fuels. While traditional handling schemes have prioritized concentrating the liquor through evaporators for combustion, a portion could be extracted for use as biorefining feedstocks.

Pulp-based paper mills have the potential to leverage their existing supply chains, material handling expertise, and production systems to become producers of biofuels for sale into regional markets.

As demand for biofuels increases, diversifying the products manufactured by Minnesota's pulp-based paper mills offers one pathway for expanding mill productivity and protecting jobs in this critical industrial subsector. Ensuring that Minnesota's paper mills are prepared to meet the demand for biofuels also has the potential to support the state's broader industrial decarbonization goals, recognizing the potential demand for low-carbon fuels anticipated by indications that fuel-switching will be a priority strategy for industrial decarbonization.

Ethyl alcohol (ethanol) manufacturing and methanol production. The ethanol production process naturally produces a highly pure and concentrated waste stream of biogenic CO_2 (>85% by volume) from fermentation activity. While this biogenic CO_2 constitutes more than half of all scope 1 GHG emissions from the typical ethanol plant, it is also considered a net-zero emission.[56,57] That waste CO_2 stream could be recycled and used as a carbon feedstock for other chemical or e-fuel manufacturers, such as methanol producers. The co-production of methanol (or other fuels) with ethanol could benefit from the federal 45Z tax credit,[58] which provides up to $1.00 per gallon of low-carbon fuels depending on the carbon intensity of the fuel. Methanol produced from waste CO_2 could substantially increase the volume of corn-derived 45Z-eligible fuel, but will require significant low-carbon hydrogen inputs, which are not readily available today and present unique technical and economic challenges.[59] Modular systems for both hydrogen and methanol production exist, which could reduce barriers to market entry.

The waste biogenic CO_2 from ethanol production could be captured and used as a carbon feedstock for other chemical or e-fuel manufacturers, such as methanol producers.

---

[55] C. Abbati, "Could the Pulp and Paper Industry Play a Role in Producing Bio-Products?," Fisher International's ResourceWise blog, March 2022 (accessed December 2026).

[56] "Cost of Capturing CO_2 from Industrial Sources," U.S. DOE's National Energy Technology Laboratory, January 2014.

[57] "A Strategic Roadmap for Decarbonizing the U.S. Ethanol Industry," EFI Foundation, September 2024.

[58] While 45Q is also a relevant federal tax credit, 45Z would likely offer the greater incentive and, importantly, the credits cannot be stacked.

[59] M. Kostylev, S. Benayoun, E. Boatman, "The Potential for Hydrogen to Support Low-Carbon Industry in Minnesota," 5 Lakes Energy, May 2025.

The use of methanol, which benefits from well-established production technology, as a liquid fuel constitutes an emerging fuel market, especially in the maritime sector.[60] With seven ports total, Minnesota's key role in the Great Lakes maritime (three ports) and upper Mississippi (four ports) shipping industries[61] positions it well for entry into the methanol production market, either as an exporter or for portside refueling. Through the Duluth Seaway Port Authority, Minnesota's maritime industry exists as part of a complex system of ports and government bodies (several U.S. states and Canada). Fortunately, that system has already committed to developing a green shipping corridor throughout the Great Lakes and St. Lawrence seaway, and Minnesota's Duluth Seaway Port Authority is already a member of the Green Marine initiative. Many members see coordinated adoption of alternative fuels as a priority strategy for decarbonizing the shipping industry.[62] If this strategy pursues methanol as the fuel of choice, then Minnesota could become a supplier.

Vertical integration

Iron ore mining and clean iron production. The U.S.'s primary (ore-based) steel market relies predominantly on iron ore sourced from Minnesota's six mines, with a seventh scheduled to open in 2026.[63] The mines are some of the largest energy consumers in the state, due to their significant demand for electricity to power crushing and grinding operations and natural gas to drive indurating furnaces for ore pellet production. The pellets are currently then shipped by boat to primary (integrated) steel mills in Indiana, Michigan, Ohio, and Pennsylvania, first for conversion into crude iron using century-old, coal-based blast furnace technology, followed by conversion into crude steel using basic oxygen furnace technology.

> *The U.S.'s primary steel market relies predominantly on iron ore sourced from Minnesota's six existing mines. The ore pellets they produce are shipped by boat to steel mills in Indiana, Michigan, Ohio, and Pennsylvania.*

While this integrated production pathway, known as BF-BOF, has historically been the only integrated approach for producing high-grade steels, that status quo is now being challenged by modern technologies, previously constructed separately, that iron- and steelmakers are now stitching together to form a complete production chain. Specifically, the electric arc furnace (EAF), or 'mini-mill,' has produced recycled steel products for consumption in the U.S.'s construction sector for decades.[64] But with the emergence of direct-reduced ironmaking (DRI) technology, which typically utilizes large quantities of natural gas in a 'DRI' furnace for metal iron production instead of coal products in the incumbent blast furnace, EAF steelmakers can now source high-quality iron from DRI-only mills. This modern production scheme, DRI-EAF, is challenging the country's roughly seven remaining incumbent BF-BOF mills not only because the DRI-EAF production process is cheaper, but also because the supply chain's nature no longer necessitates co-location for iron- and steelmaking steps, in the same way that the BF-BOF production pathway does.

---

60 "DNV: Methanol Emerging as Scalable Marine Fuel but Economics Still Limit Uptake," MarineLink, December 2, 2025.

61 "Commercial waterways," Minnesota Department of Transportation, accessed January 2026.

62 "Summary Report: Green Shipping Corridor Network (GSCN) Collaborative Forum," U.S. Great Lakes St. Lawrence Seaway Development Corporation, April 4, 2023.

63 Mesabi Metallics.

64 Minnesota was previously home to one such EAF mill in Saint Paul, which recycled scrap steel for sale into the regional construction industry. Gerdau idled its EAF mill in Saint Paul in 2020 and has reportedly been stripping down the site and selling off assets.

Complicating this situation is the fact that all the existing primary steel mills (incumbent BF-BOF technology) in the United States are owned by two vertically integrated companies, Cleveland-Cliffs and U.S. Steel (recently acquired by Japanese steel company Nippon). In recent years, these companies and their integrated mills have faced increasing competition from both DRI-based ironmakers and EAF-based steelmakers. With two of three existing DRI mills already online in the South (the third is in Ohio) where natural gas is cheap and ports offer ready access to low-cost Brazilian ore imports, and at least two more projects expected to come online within the next half-decade, it's not just Minnesota's iron ore mine owners (Cleveland-Cliffs and U.S. Steel, also the owners of the BF-BOF primary mills) that are under threat — it's Minnesota's iron ore mines themselves.

Interest in supporting the emergence of DRI furnace-based ironmaking in Minnesota's Iron Range region has increased significantly in recent years. Iron made in Minnesota could then be sold to iron foundries, BF-BOF steel mills, or EAF steel mills. Mesabi Metallics, owner of the first iron ore mine scheduled to open in Minnesota in over three decades, has previously expressed an interest in developing DRI production at its site,[65] and Duluth-based Ecolibrium3 and Itasca Economic Development Corporation, with the City of Duluth and Minnesota Power (the electric utility serving the region), are currently participating in a 'green' iron plant feasibility study. The technical elements of that study are supported by U.S. DOE's national labs. While the study's focus is on green hydrogen[66]-based DRI production, many dimensions of their work will also reveal key insights for feedstocks critical to natural gas-based DRI production and other emerging ironmaking technologies, like molten oxide electrolysis, electrowinning, and electrolytic syngas production[67] (the gas used to chemically reduce iron oxide to metallic iron) — all of which would be clean electricity-intensive technologies.

Importantly, as Minnesota contemplates whether to enter the ironmaking market, and if so, how, the state is losing potential market share to others, like Louisiana and Arkansas. In Louisiana, South Korean carmaker Hyundai has announced plans to build a 2.7 million-ton-per-year clean steel plant that will rely on DRI technology for iron production, feeding into on-site EAF-based steel production.[68,69] The project is slated to create 1,300 direct jobs, inducing an estimated 4,100 additional jobs.[70] Financing of the Hyundai steel mill will benefit from the state of Louisiana's Industrial Tax Exemption Program and Quality Jobs Program — with some estimating a potential cost break of up to $1 billion.[71]

> *As Minnesota contemplates whether to enter the ironmaking market, and if so, how, the state is losing potential market share to others, like Louisiana and Arkansas.*

While plans for a DRI plant in Arkansas have only been recently announced by U.S. Steel's new owner, Nippon, the company's existing footprint in the state and access to cheap natural gas all suggest this is a project likely to come to fruition. The plant will reportedly source direct

---

65 Mesabi Metallics' production site is currently scheduled to come online (in 2026) as a pellet-only manufacturer.

66 'Green' hydrogen is the color designation reserved for hydrogen produced through electrolysis, a water-splitting technology, that is powered by clean electricity. It is one of the priority hydrogen types, based on production pathway, because of its low embodied emissions.

67 For example: Helix Carbon.

68 A. Kaufman, "Hyundai plant to make 'low-carbon' steel at $6B plant in Louisiana," Canary Media, March 25, 2025.

69 While Hyundai has publicly stated that the plant will come online using 'blue' hydrogen (production of hydrogen from natural gas using steam-methane reforming technology, paired with carbon capture) and later switch to 'green' hydrogen, no explicit plans for how this transition will be carried out have been described. As a result, many remains skeptical of both the company's commitment to 'green' steel production and the likelihood that it will become a reality.

70 "Louisiana Wins Again," Governor Jeff Landry & LED Secure $5.8 Billion Hyundai Steel Mill," Louisiana Economic Development, March 24, 2025.

71 For example, T. Bridges, "Hyundai's new steel mill, seen as a huge win for Louisiana, has a $600M taxpayer price tag," NOLA.com, May 29, 2025, and private communications.

reduction (DR)-grade iron ore pellets from U.S. Steel's recently-upgraded[72] Minnesota Keetac mining stake. Capital is expected to derive, in large part, from Nippon's required multi-billion dollar investment in U.S. Steel's existing assets and facilities.[73] U.S. Steel's last major investment in Arkansas' manufacturing ecosystem benefitted from a tax break[74] worth hundreds of millions of dollars, leading to the company's current Big River Steel EAF-based steelmaking site — the same site where Nippon is proposing to invest in DRI production, for yet another integrated DRI-EAF clean steel production facility.

The success of these projects compared to the lack of progress for primary mill modernization projects in Indiana, Michigan,[75] Ohio[76], and Pennsylvania suggests a range of learning opportunities for Minnesota, as the state considers how to enter the ironmaking market.

Agriculture and low-carbon fertilizer production.[77] At present, Minnesota farmers spend from $500 million to $1 billion per year on nitrogen fertilizer — with most of that money leaving the state. One approach to decarbonizing agriculture is to switch to low-carbon fertilizers, both in terms of the carbon intensity of the production process and the environmental behavior of the fertilizer when applied to a field. While most farmers prefer urea as a fertilizer because of its solid form, switching to 'green' ammonia or urea produced from green ammonia (in both cases yielding a 'green' or low-carbon fertilizer product) could be an appropriate strategy for reducing the carbon intensity of Minnesota's fertilizer supply. In this case, the 'green' is tied to green hydrogen, produced from water electrolysis using clean electricity. For urea from green ammonia, we also need a carbon-neutral source of CO_2, such as CO_2 from ethanol fermentation, as urea is made from ammonia and CO_2 (see *Alternative fuels/fuel-switching: Hydrogen*).

Green ammonia can be produced economically at smaller scales, as initially demonstrated by WCROC's pilot 'wind to ammonia' project. This could allow Minnesota's farming co-ops to become owners of fertilizer production systems, helping to stabilize their input costs while further supporting the state's interests in food systems decarbonization and the production of biofuels with low carbon intensities, like sustainable aviation fuel (SAF).

Green ammonia can be produced competitively at smaller scales, via modular reactors. The feasibility of this approach was initially demonstrated by the University of Minnesota's West Central Research and Outreach Center through a pilot 'wind to ammonia' project.[78] A next-generation pilot is under construction at the demonstration site.[79] The distributed approach to green ammonia production in Minnesota was explored in detail by RMI in 2024.[80] The large

72 D. Kraker, "U.S. Steel to invest $150 million at Minnesota mine," MPR News, June 28, 2022.

73 "U.S. Steel to Build DRI Plant on Big River Steel Works Campus," AIST, November 13, 2025.

74 W. Sparkman, "Arkansas governor signs tax cuts," AXIOS NW Arkansas, December 10, 2021.

75 Cleveland-Cliffs reportedly chose its Middletown site in Ohio over Dearborn Works in Michigan for a modernization project due to facility age, and thus, anticipated costs to implement. In 2025, the company chose to indefinitely idle the Dearborn Works steel mill, laying off about 600 unionized workers. Upstream impacts associated with the drop in production that precipitated this facility idling have included at least partial idling of two Minnesota iron ore mines.

76 Cleveland-Cliffs' Middletown steel mill was a grant recipient of the U.S. DOE's Industrial Demonstration Program. That $500 million award, slated for DRI construction at Middletown, has reportedly been renegotiated with the current federal administration. Although details of the final award and site project are not entirely public, the company has announced plans to reline its existing blast furnace and upgrade the facility with various automation systems.

77 M. Kostylev, S. Benayoun, E. Boatman, "The Potential for Hydrogen to Support Low-Carbon Industry in Minnesota," 5 Lakes Energy, May 2025.

78 "Taking the Lead in Green Ammonia," WCROC, April 27, 2023.

79 "4th Symposium on Ammonia Energy," WCROC, accessed January 2026.

80 Q. Homann, T. Kirk, A. Krimer, et al., "Roadmap for Distributed Green Ammonia in Minnesota," RMI, 2024.

fraction of Minnesota's farmers who currently belong to farming co-operatives creates a distinct opportunity for vertical integration of agricultural inputs and products. In this sense, farming co-operatives could become owners of fertilizer production systems, helping to stabilize their input costs and retain high fractions of economic benefits within the state.

While modular green ammonia systems are not yet cost-competitive on a cash production basis with large-scale, natural-gas-based ammonia plants, distributed production in the Upper Midwest could partially offset this disadvantage by avoiding long and volatile supply chains, reducing logistics costs, and capturing local retail margins. For farmer-owned cooperatives, this model emphasizes price stability, supply security, and local value retention rather than lowest theoretical production cost. This logic underpins the development of a modular green ammonia demonstration by Landus Cooperative in Boone, Iowa, using technology from Talus, alongside federal and state policy support.

This approach, in turn, would further support the state's interests in food systems decarbonization[81] and either the production of biofuels with even lower embedded carbon intensities or the production of new biofuel types with low carbon intensities, like sustainable aviation fuel (SAF). The state's interests in SAF have yet to fully materialize, despite the development of SAF-specific tax credits[82] and the Minnesota SAF Hub. Stakeholders in this space cite the limited availability of appropriate, low-carbon organic feedstocks at cost-effective price points as one barrier to lift off, including a SAF project announced in 2024. The DG Fuels project, sited in Moorhead,[83] initially planned to use waste timber and agricultural mass as its carbon inputs. Notably, the company's website no longer identifies the Moorhead site as a project.

Regardless of the downstream sector of focus, an estimated 900,000 tons of green ammonia would be needed to meet Minnesota's current annual nitrogen-based fertilizer demand.

Residual emissions

Carbon capture and storage (CCS). The industrial decarbonization strategies discussed above are constrained by a multitude of factors that include but are not limited to economic competitiveness, technological availability, and the high diversity of facility needs and designs. According to the 2022 U.S. Department of Energy Industrial Decarbonization Roadmap, energy efficiency, electrification, and alternative fuels are expected to reduce industrial emissions by about 40% by 2050, with most of the remaining emissions mitigated via carbon capture.[84] Carbon dioxide capture at the point source of emissions and sequestration via storage in geological formations is increasingly seen as a major strategy for addressing residual carbon emissions, and CCS is included in many industrial firms' long-term decarbonization plans. However, CCS remains a controversial decarbonization approach due to questions around its

According to the U.S. Department of Energy, energy efficiency, electrification, and alternative fuels are expected to reduce industrial emissions by about 40% by 2050, with most of the remaining emissions mitigated via carbon capture.

[81] That is, Minnesota Pollution Control Agency's U.S. EPA Climate Pollution Reduction Grant for Climate-Smart Food Systems.

[82] "Sustainable Aviation Fuel Credit," Minnesota Department of Revenue, accessed January 2026.

[83] D. Gunderson, "Sustainable fuels plant to be built in Moorhead and operational by 2030," MPR News, November 1, 2024.

[84] J. Cresko, E. Rightor, A. Carpenter, et al., "Industrial Decarbonization Roadmap," U.S. Department of Energy, September 2022.

scalability, economic viability, and the moral hazard of continued reliance on fossil fuels that CCS arguably enables.[85]

CCS involves three main steps: 1) CO_2 capture at or near the emitting facility, 2) compression and transport of the captured CO_2 to the storage site, and 3) sequestration of the captured CO_2 via permanent storage in depleted oil and gas fields[86] or suitable geologic formations.[87] Globally, 77 projects capturing a total of 64 million tons of CO_2 per year are currently in operation. Another 47 projects are in construction, with an expected capacity of 44 million tons of CO_2 capture per year. In addition, more than 600 projects are in various stages of development.[88] As with many of the decarbonization approaches described above, cost and scalability are major current barriers to CCS. Furthermore, Minnesota lacks well-suited geology for storing large amounts of carbon throughout the state,[89] which is certain to increase the overall cost of CCS due to greater transport distances from emission sources to the storage sites in neighboring states.

The established CO_2 capture processes[90] are highly energy-intensive and make up the largest fraction of the total cost of CCS. According to a 2024 Carbon Solutions report, which compiled data from several sources, the cost per ton of captured CO_2 in 2021 dollars ranges from about $20 to more than $70 depending on the industrial subsector.[91] Transport via pipelines and storage costs can add $12-$22 per ton of CO_2 depending on travel distance and storage site characteristics.[92] Costs in Minnesota are likely to be on the higher end due to greater transportation distances for the captured CO_2. It is also important to note that CO_2 capture cost estimates vary widely among publications, reflecting the high level of uncertainty associated with their modeling due to factors such as unique facility engineering requirements, energy costs, purity and concentration of CO_2 in the emission stream, and scale of operations.

As a result, the economic viability of CCS remains in question, requiring continued technological developments and support for demonstration projects that will generate real world data in a wide range of scenarios. The 45Q federal carbon capture tax credit, which provides up to $85 per ton of CO_2 captured for 12 years of operation, is considered an essential incentive for any industrial carbon capture project in the United States. However, based on above estimates and conversations with stakeholders, this credit may not sufficiently offset the costs of many CCS projects.

Besides storage, an alternative option for captured CO_2 is use as a feedstock for new products, such as fuels and chemicals, which could help reduce Minnesota's reliance on petroleum feedstocks. However, to achieve net-zero targets, any strategy for utilizing captured CO_2 should focus on long-term sequestration of the carbon in the final products, to limit changes that it

---

85 K. Lebling, A. Gangotra, K. Hausker, Z. Byrum, "7 Things to Know About Carbon Capture Utilization and Sequestration," World Resources Institute, accessed December 2025.

86 Another common application for captured CO_2 has been its use for extracting oil reserves (termed enhanced oil recovery or EOR). This approach is controversial because it supports the continued use of fossil resources, which should be phased out as part of a comprehensive decarbonization strategy.

87 Once the carbon has been stored, the site must be continuously monitored over the ensuing decades for potential leaks.

88 "Global Status of CCS 2025: Staying the Course," Global CCS Institute, October 2025.

89 See U.S. Geological Survey's "Geologic CO_2 Sequestration" map.

90 Most mature carbon capture technologies utilize amine-based solvents that bind and release CO_2 under different conditions. The release of CO_2 from the solvents requires a lot of heat, making the overall process energy intensive.

91 E. Middleton, M. Ford, M. Miranda, et al., "National Industrial Sector Decarbonization: Extent of Carbon Capture Opportunities and Network Optimization Across the United States," Carbon Solutions, May 2024. Funded by the Center for Applied Environmental Law and Policy (CAELP).

92 E. Middleton, M. Ford, M. Miranda, et al., "National Industrial Sector Decarbonization: Extent of Carbon Capture Opportunities and Network Optimization Across the United States," Carbon Solutions, May 2024. Funded by the Center for Applied Environmental Law and Policy (CAELP).

will be emitted within a short timeframe.[93] The potential impact of captured CO_2 utilization as a feedstock is difficult to predict due to the low level of technology readiness. One stakeholder consulted for background research suggested that creating CO_2 utilization industrial hubs could spur developments in this area, eventually helping advance the economic viability and environmental benefits of industrial carbon capture.

In summary, CCS is widely considered to be an important and potentially essential strategy for addressing residual industrial emissions. However, the economic viability and scalability of CCS remain uncertain due to the high costs associated with CO_2 capture from industrial streams. Minnesota's limited access to suitable geologic storage sites for the captured CO_2 presents an additional challenge, due to the extensive pipeline infrastructure that would be required for transporting CO_2 to appropriate injection sites, which may fall in neighboring states.[94] Infrastructure buildout can face unexpected costs and delays during the permitting process and from potential community opposition.[95]

Carbon dioxide removal (CDR). Although the range of decarbonization strategies and pathways discussed above provides many potential opportunities for facilities to reduce their emissions, a subset of industrial emissions is unlikely to be eliminated due to a combination of technical and cost constraints. The 2022 U.S. Department of Energy Industrial Decarbonization Roadmap estimates that by 2050, 13% of 2015-level industrial emissions — or more than 50 million tons of CO_2 — will necessitate mitigation via so-called 'alternate approaches' that remove CO_2 directly from the atmosphere.[96] A recent global assessment of CDR needs estimated that by 2050, 7-9 gigatons of CO_2 removal per year will be needed to achieve the Paris Agreement limit of a global temperature rise of no more than 2°C,[97] underscoring the overall scale of need for carbon removal. Industry can play an active role in the advancement of CDR efforts through a variety of pathways. These can include the incorporation of carbon removal in existing industrial operations, supplying large volumes of feedstocks and materials, including wastes, for certain CDR approaches, and/or the financing of external CDR projects.[98]

A variety of CDR approaches exist at different levels of technological readiness, scalability, sequestration potential, and durability.[99] The approaches can be broadly categorized as biogenic and geochemical.[100] Biogenic approaches rely on natural CO_2-fixing mechanisms, primarily photosynthesis, to convert CO_2 from the air to biomass. Established (or 'conventional') biogenic pathways include improved forest management and conservation, reforestation, afforestation, grassland and wetland restoration, agroforestry, soil carbon sequestration via regenerative agricultural practices, and durable wood products. Several emerging (or 'novel')

[93] Examples of potential durable materials that could utilize captured CO_2 include concrete and other construction materials, carbon fiber, and plastics. For a detailed discussion, see: J. Bobeck, J. Peace, F.M. Ahmad, R. Monson, "Carbon Utilization – a Vital and Effective Pathway for Decarbonization," Center for Climate and Energy Solutions, August 2019. As a note, the case of using CO_2 captured from ethanol refineries to make methanol, a non-durable fuel, as discussed elsewhere in this report, is somewhat unique in that the captured CO_2 is biogenic. Therefore, the CO_2-derived methanol in that scenario could be categorized as bio-based fuel produced in addition to the ethanol, which is the primary product.

[94] "Potential for Geologic Carbon Sequestration in Minnesota," Minnesota Geological Survey, accessed January 2026.

[95] For example, see: V. George, "Louisiana Residents Sue Over CO_2 Pipeline Land Seizures," Carbon Herald, November 21, 2025.

[96] J. Cresko, E. Rightor, A. Carpenter, et al., "Industrial Decarbonization Roadmap," U.S. Department of Energy, September 2022.

[97] S. M. Smith, O. Geden, M. J. Gidden, et al., "The State of Carbon Dioxide Removal: A global, independent scientific assessment of Carbon Dioxide Removal," University of Oxford's Smith School of Enterprise and the Environment, 2024 (2nd edition).

[98] C. Maesano, E. Mitchell-Larson, K. Clark-Sutton, D. Pike, "Seizing the Industrial Carbon Removal Opportunity: To reach net zero, and go beyond, heavy industries need to adopt carbon removal practices," RMI, April 2025.

[99] In the context of CDR, durability refers to the typical time scale that the captured carbon remains sequestered from the atmosphere, which is in the range of years to millennia, depending on the pathway. Although there is no universally defined time scale that is acceptable for CDR classification, only approaches that result in at least several decades of carbon storage are included in broadly accepted accounting methods. For example, corn-based ethanol, when combusted as a motor fuel, does not count as a CDR pathway.

[100] O. Geden, S. M. Smith, A. Cowie, Chapter 1: Introduction, in The State of Carbon Dioxide Removal 2024 – 2nd Edition, eds. S.M. Smith, et al.

biogenic CDR pathways[101] are in development, with many active pilot and demonstration projects in the United States and globally. Geochemical pathways rely on non-biological chemical processes that capture CO_2. Many such processes occur naturally but can be enhanced through human activity, such as reactions between minerals and atmospheric CO_2 that result in the formation of solid carbonates or dissolved bicarbonates. In other processes, specifically formulated solvents or suitable industrial wastes can be manipulated to bind and release atmospheric CO_2, producing a concentrated stream for utilization or storage. All geochemical CDR approaches can be categorized as novel because they are in earlier stages of development and are not yet deployed at scale.

The current average estimated amount of CO_2 removed from the atmosphere globally via CDR efforts is about 2,200 million tons per year,[102] with 99.9% being captured via conventional approaches (e.g., afforestation, reforestation, forest management). This estimate has large uncertainties associated with it due to the complexity of estimating carbon removal via improved forest management.[103] Although the overall global rate of CDR has slowed slightly in recent years, the research, development, deployment, and net capacity of novel CDR pathways is rapidly increasing.

Industry can play a major role in increasing the impact of both conventional and novel CDR pathways through financing, development, and/or integration of CDR with industrial activities. Companies can finance CDR projects by purchasing carbon credits on the voluntary carbon market, or by partnering directly with project developers. This is aligned with Minnesota's rumored interest in developing a carbon cap-and-invest scheme, similar to that recently implemented by the state of Washington.[104] The cost of CDR carbon credits[105] varies widely by approach. In 2023, the average paid prices per CDR credit generated via forest management and afforestation/reforestation methods were $12 and $16, respectively. Notably, these figures are significantly less than the current cost estimates to achieve the same amount of carbon abatement via CCS. Other CDR credits issued in 2023 were priced an order of magnitude higher, ranging from roughly $110 to $1,400 per credit, reflecting the need for continued research and development of alternative carbon removal pathways.[106]

Industry can play a major role in increasing the impact of both conventional and novel carbon dioxide removal (CDR) pathways through financing, development, and/or integration of CDR with industrial activities.

Industrial entities can identify opportunities to help lower CDR costs by utilizing appropriately scaled resources, such as waste materials that can be used in the CO_2 capture process. Industries can also provide valuable experience and infrastructure needed to handle and

---

[101] The most advanced emerging pathways include bioenergy with CCS (BECCS), and biochar. Other approaches include bio-oil storage, biomass burial or sinking, and ocean fertilization.

[102] J. Pongratz, S. Smith, C. Schwingshackl et al., Chapter 7: Current Levels of CDR in The State of Carbon Dioxide Removal 2024 – 2nd Edition, eds S.M. Smith, et al. Note that the 2,200 million tons of CO_2 captured per year via CDR is orders of magnitude more than the 64 million tons of CO_2 currently captured per year via CCS.

[103] Accounting for carbon removal via improved forest management is complicated due to the difficulty of determining how much carbon is removed from the atmosphere specifically due to human activity in addition to the inherent carbon uptake that occurs in natural systems. This aspect is referred to as 'additionality.' The other complication comes from accounting for the global impacts of reduced harvests in one area due to improved forest management, which can result in increased harvests elsewhere. This aspect is referred to as 'leakage'.

[104] "Washington's Cap-and-Invest Program," Department of Ecology, State of Washington, accessed January 2026.

[105] One carbon credit equals one ton of CO_2 removed from the atmosphere or avoided from being emitted. Although the distinction between carbon removal and avoidance in forest management projects has not always been clear historically, methods for better differentiating the two types of credits are improving.

[106] S. Fuss, I. Johnstone, R. Hoglund, N. Walsh, "Chapter 4: The voluntary carbon market," in The State of Carbon Dioxide Removal 2024 – 2nd Edition, eds S.M. Smith, et al.

process large quantities of materials (e.g., crushing rock), which can accelerate large-scale CDR project development. Industries should also work to identify novel approaches to directly and measurably incorporate CO_2 into durable manufactured products (e.g., construction materials), which can help companies meet their sustainability and net-zero goals in addition to potentially providing new revenue streams via the carbon market.

Although some CDR pathways — namely, forest management, afforestation, and reforestation — are already well established, scalable, and relatively inexpensive, the inclusion of CDR as an explicit approach to industrial decarbonization also faces barriers. Like CCS, CDR is susceptible to the criticism that its use creates a moral hazard because it can enable companies to continue relying on fossil fuels, while formally meeting carbon reduction goals. In addition, the CDR sector is undergoing active development related to technical, certification, and market development aspects, which means that there is a wide range of quality — and consequently confidence — in CDR projects and the carbon credits that they generate. Active engagement and collaboration among CDR stakeholders, including project developers, certifiers, governments, academia, and businesses, will likely be needed if CDR is to be employed as an effective tool at scale for addressing residual industrial emissions in Minnesota without disincentivizing the decarbonization efforts that minimize emissions in the first place.

Barriers to Decarbonizing Minnesota's Manufacturing Sector

SYSTEMIC BARRIERS

Long asset lives, high capital costs, and impact on operating costs

The industrial boilers, furnaces, and kilns that provide much of the heat that large (high-emitting) manufacturers rely on are designed to be long-lived workhorses, in service for two to three decades – *or longer*.[107] Because the up-front capital expenses (CAPEX) to replace these units scale roughly with their rated heat output, the boilers, furnaces, and kilns powering large manufacturers can cost upwards of hundreds of thousands to hundreds of millions of dollars to replace. As a result, companies not only prioritize life extension, but also must plan for unit replacement years in advance.

> *In Minnesota, the high cost of electricity relative to natural gas per unit of energy delivered, known as the 'spark spread,' can disincentivize manufacturers from electrification.*

Separately, manufacturers of all sizes are sensitive to energy costs, which impact their operating expenses (OPEX). In Minnesota, the high cost of electricity relative to natural gas (roughly 4×) per unit of energy delivered (known as the 'spark spread' or 'spark gap') can disincentivize manufacturers from electrification. But large (high-emitting) manufacturers can also present another challenge: to minimize risk, they commonly buy their natural gas or other fuels from third-party marketers, relying on Minnesota's natural gas utilities for transport services only. This approach allows manufacturers to lock in multi-year, fixed-price supply contracts[108] – interests that generally cannot be transferred or sold. This fact further underscores the importance of timing associated with state-led industrial electrification initiatives.

For any given facility, electrification can be accomplished through multiple technological pathways, generally requiring wholesale replacement of fuel-burning units, even in the case of smaller manufacturers.[109] One way of analyzing the potential of these different electrification scenarios is through 'levelized cost of heat' (LCOH). Relevant studies[110] suggest that without electric rate reform (beyond a simple switch to time-of-use rates), manufacturers in Minnesota would still face an LCOH disadvantage under the best circumstances when electrifying – such as electrifying by switching to a high-efficiency heat pump with extensive implementation of facility-wide

> *States most interested in decarbonizing their industrial sector must work with their utilities to implement electric rate reform practices, to reduce the levelized cost of heat and thus the operational expenses faced by their manufacturers.*

---

107 "How long do industrial boilers last?," Industrial Boilers America, accessed January 2026.

108 In today's market, typically three years or less. See: B.B. Henning, "Long-term Contracting for Natural Gas: Examination of the Issues that Affect the Potential for the Increased Use of Contracting to Stabilize Consumer Prices," ICF International, June 2011.

109 A.L. Roxas, et al., "Industrial Energy Efficiency and Decarbonization: Identifying Motivations and Barriers for Midwest Manufacturers," ASHRAE Transactions, 2024.

110 For example: N. Mariano, O. Quinn, A. Merlo, et al., "The Clean Heat Climate Opportunity: A Roadmap for Electrifying Low- and Medium-Temperature Industrial Heat," The 2035 Initiative, UC Santa Barbara, December 2025.

energy efficiency measures[111] (see Figure 9). Therefore, states like Minnesota most interested in decarbonizing their industrial sector must work with their utilities to implement electric rate reform practices,[112] to incentivize industrial electrification in a manner that can reduce the LCOH, and thus the OPEX, faced by their manufacturers.

The balance of CAPEX versus OPEX influences the payback period of the investment. While studies often cite preferences of less than five years, our recent interviews with a range of large Midwest manufacturers indicate that one to three years is preferable. Additional research shows that smaller manufacturers that consider payback in decision-making also broadly report a preference for periods shorter than three years.[113] In contrast, companies with ambitious sustainability goals may be willing to tolerate payback periods greater than five years if they can demonstrate that their investments are capable of significantly reducing their emissions footprint.

Importantly, manufacturing subsectors exhibit different sensitivities to changes in OPEX. For example, U.S. Economic Census data[114] indicates that paper manufacturers allocate nearly 5% of their expenses to energy, whereas a typical food manufacturer may allocate less than 2%. As a result, increasing energy costs may disproportionately impact a paper mill over a food manufacturer, and conversely, energy-saving technologies have greater potential to benefit a paper mill. This fact has contributed to recent trends related to paper mill closures in the United States,[115] where the industry cites increasing energy costs as cutting into already thin profit margins, exacerbated by increasing pressures to compete in a global market.

Manufacturing subsectors exhibit different sensitivities to changes in OPEX. For example, U.S. Economic Census data indicates that paper manufacturers allocate nearly 5% of their expenses to energy, whereas a typical food manufacturer may allocate less than 2%.

The need for tailored solutions

Like most states, Minnesota's manufacturing sector is diverse. Paper mills consume tremendous amounts of energy driving mechanical systems and dryers, while ethanol plants operate extensive distillation processes. Lime manufacturers may operate quarrying and crushing operations in addition to conveyor systems and kilns, while cheese producers operate pasteurizers, fermenters, coagulators, and more — each at its own specified temperature. Even within a subsector, no two manufacturing facilities are alike.

This creates challenges for companies striving to decarbonize their facility fleet, as much as for states seeking to develop and implement informed strategies. For example, energy efficiency rebate programs are relatively straightforward to develop for the residential sector — but beyond lighting and HVAC, which commonly fall under 'prescriptive' incentive programs, large

111 N. Mariano, O. Quinn, A. Merlo, et al., "The Clean Heat Climate Opportunity: A Roadmap for Electrifying Low- and Medium-Temperature Industrial Heat," The 2035 Initiative, UC Santa Barbara, December 2025.

112 Both ACEEE and NRDC have forthcoming studies focused on the effects of industrial rate structures on industrial electrification opportunities.

113 A.L. Roxas, et al., "Industrial Energy Efficiency and Decarbonization: Identifying Motivations and Barriers for Midwest Manufacturers," ASHRAE Transactions, 2024.

114 2022 Economic Census data, by way of N. Mariano, O. Quinn, A. Merlo, et al., "The Clean Heat Climate Opportunity: A Roadmap for Electrifying Low- and Medium-Temperature Industrial Heat," The 2035 Initiative, UC Santa Barbara, December 2025.

115 As reported by the Pulp and Paperworkers' Resource Council, accessed January 2026.

industrial customers often require custom rebates[116] (also known as 'measures'), which can be costly to develop, if offered at all. While small manufacturers may be more readily supported by prescriptive rebate programs and require few decisionmakers to agree, large manufacturers often must engage corporate leadership, facility managers and other staff, energy service providers, and engineering firms to develop and implement transition plans — as a result, large-scale engineering projects can cost a company hundreds of thousands to several million dollars for the planning phase alone.

Workforce impacts and gaps

The degree of industrial transformation needed to move the American manufacturing sector to net-zero by 2050 has significant implications for the workforce. In general, a facility that decarbonizes primarily by electrifying will need more electricians, electrical engineers, and workers skilled in automation and fewer (to no) boiler operators.

Minnesota is forecasted to need thousands of replacement workers (e.g., due to retirements) in existing sectors like paper and the skilled trades, as well as thousands more to fill new jobs, through 2032,[117] related in part to growth in the manufacturing and clean energy industries, as well as construction. Although indications from 2025 suggest that interest in the skilled trades is increasing in Minnesota,[118] it is important to recognize that the more advanced the state's manufacturing sector becomes through electrification and automation, the more skilled its manufacturing workers on average need to be.

Minnesota is forecasted to need thousands of replacement electricians, electrical engineers, and workers skilled in automation, as well as thousands more to fill new jobs, related in part to growth in the manufacturing and clean energy industries.

These are just a few examples — the point is that industrial transformation will fundamentally shift the numbers and types of jobs that a state's manufacturing and power sectors must fill, which has significant implications for the planning and program work that states pursue toward their net-zero end goals. Compounding this fact is the real social pressure for states to demonstrate positive impacts on jobs, capable of being filled by workers from within their existing population. Without careful planning related to industrial decarbonization interests, Minnesota may still need to import workers, which could increase the chance for public backlash, especially if 'new jobs' were touted to local communities or unions to win their support for projects.

The challenge of identifying the 'best' solution

As mentioned, large manufacturers are highly risk averse. Because of this, they tend to have a very high bar that perceived 'emerging' technologies must clear before they express a willingness to adopt them — even the technologies with a clear potential to reduce OPEX and emissions, like industrial heat pumps. In part, this fact explains why some clean technologies, like heat pumps, adopted in Europe are still struggling to gain market share here in the United States. Instead, manufacturers want to see clear evidence[119] from 'trusted' sources, like another manufacturer in their state producing in the same industry, that the technology can lower

[116] In Minnesota, these rebates are managed through the Department of Commerce's Energy Conservation and Optimization program.

[117] "Employment Outlook Projections," Minnesota Department of Employment and Economic Development, accessed January 2026.

[118] E. Adler, "More students enrolling in trade schools, helping fill shortage of skilled jobs," The Minnesota Star Tribune, October 27, 2025.

[119] For example, ACEEE has published a mapping tool that shows industrial electrification projects across the United States.

costs and/or emissions. Due to the diversity of any given state's manufacturing sector and the generally proprietary nature of this type of information, the desired evidence can be difficult to come by.

Without ready access to engineering firms who have experience with emerging clean technologies, manufacturers may struggle to access the information needed to commit to a particular technology transition. If these pieces fail to align in the year that a manufacturer is, for example, planning for boiler replacement, then a critical window may be missed.

This challenge is compounded by the need for manufacturers to sort through a range of emerging technologies or technology producers to determine which is the best fit for their facility, in part because changing one aspect of production could have extensive implications for other production systems, facility electrical, etc. Without ready access to engineering firms who have experience with these new technology types, manufacturers may also struggle to access the information needed to be able to commit to a particular transition choice. Clearly, if these pieces fail to align in the year that a manufacturer is, for example, planning for a boiler replacement, then a critical window may be missed.

Smaller manufacturers may be even less willing to transition than larger manufacturers, on average, because facility choices are often heavily steered by individual decision-makers, like plant managers. If those individuals have a definitive bias against new or alternative clean technologies — including established technologies like electric boilers — then smaller manufacturers will be more likely to put off transitioning to new (clean) technologies.

Market willingness to pay a 'green premium'

The costs associated with facility transformation to produce low-embodied-carbon products can sometimes be passed on to customers. When this happens, the low-carbon product is said to have a 'green premium' attached to it. In general, manufacturers who anticipate this outcome are producing a low-carbon product that the market has demonstrated demand for, meaning that the manufacturer's customers have indicated a willingness to pay more — before the manufacturer invested in facility transformation. Manufacturers who do apply green premiums to their low-carbon product lines typically use distinct branding and/or verified documentation, like an Environmental Product Declaration (EPD[120]), to distinguish the product and assure customers of the product's lower carbon footprint.[121] EPDs, which themselves can be expensive to develop,[122] are especially important for supporting low-carbon materials in the construction industry.

Manufacturers are often quick to point out the lack of markets for low-carbon products. This creates a critical opportunity for states to support early off-take through mechanisms like buy clean or other forms of cost-share.

[120] "EPD Basics: A Manufacturer's Guide to How and Why to Develop an Environmental Product Declaration," Minnesota Department of Administration, accessed January 2026.

[121] The Minnesota State legislature passed an EPD requirement for road materials in 2023. Several paving companies have already developed their EPDs, recorded in this register.

[122] Depending on data availability and sources, the first EPD can cost a company from $10,000 to $100,000 to develop. Additional EPDs, especially for similar products at the same company, usually cost just a fraction of this.

At present, the U.S. markets willing to pay green premiums are limited. While the European market has demonstrated a greater demand for low-carbon products, the E.U. is only now preparing to fully implement its planned carbon tax (scheduled to be fully enacted in 2026), otherwise known as its Carbon Border Adjustment Mechanism (CBAM). However, not all Midwest manufacturers sell into the European market. Combined, these factors explain why manufacturers are often quick to point out the lack of markets for low-carbon products. This creates a critical opportunity for states to support early off-take through mechanisms like buy clean[123] or other forms of cost-share.

The scale of clean electricity needs

Manufacturers are mixed on whether it makes sense to prioritize electrification before their regional power grid has been decarbonized. Even though many electrified heat-supplying units are more energy efficient than their natural gas-powered counterparts, manufacturers have concerns over the impact on their carbon footprint that electrifying could bring about, which they commonly cite as associated with two factors. The first is the potential for increased scope 2 emissions[124] associated with their electricity supply, and the second is the inherent efficiency losses associated with sourcing electricity from a natural gas-powered power plant versus burning natural gas on-site to deliver the same amount of process heat. Both factors are eliminated by prioritizing power grid decarbonization, consistent with Minnesota's carbon-free electricity standard.[125]

Regardless of grid decarbonization status, the scale of electricity needed to electrify large manufacturers will be tremendous (see Figure 6) — requiring, at minimum, costly upgrades to power substations and facility electrical elements. For older facilities, these upgrades could prove particularly complex. Compounding these challenges, utilities report that lead times to source many major power system components are on the order of years at present, in some cases "growing longer by the day."

On the utility side, the scale of electrification needed to support decarbonizing the economy depends on more than manufacturers' willingness to electrify — it also depends on the rate of battery electric vehicle (BEV) adoption, the rate of residential heat pump installations, etc. Further complicating the situation, utilities currently undertaking integrated resource planning work are doing so with major blind spots, especially as related to industrial electrification. With limited historical data and a lack of clear trends to lean into, utilities could struggle to accurately forecast near-future clean electricity needs, especially in the manufacturing sector.

The recent surge in demand for electricity to power large-scale data centers has the potential to significantly disrupt industrial electrification. While data centers may be willing to pay top-dollar for clean electricity, manufacturers operating on tight margins need rock-bottom electricity prices to overcome the spark spread and incentivize electrification.

At the same time, the recent surge in demand for electricity to power large-scale data centers has the potential to significantly disrupt industrial electrification.[126] While data centers may be willing to pay top-dollar for clean electricity, manufacturers operating on tight margins need rock-bottom

[123] "Buy Clean Requirements," State Climate Policy Dashboard, accessed January 2026.

[124] J. Millot and P. Smith, "Scope 2 emissions explained: Tracking, reporting, and reducing impact," Carbon Direct, March 2025.

[125] J. Olson, "Minnesota's 100% clean electricity law explained," Fresh Energy, February 2023.

[126] "Data Centers," MCEA, accessed January 2026.

electricity prices to overcome the spark spread and incentivize electrification.[127] This is an inherent conflict, with the potential to become especially pronounced for regions where utilities can keep data centers and manufacturers in the same portfolio, under the same tariff structure.

Permitting

In accordance with Minnesota statute, environmental review is required for any project with the potential to significantly impact the state's environmental quality attributes, such as air, water, and soil quality. The Environmental Quality Board manages the state's environmental review program, through which other state agencies, like the Minnesota Pollution Control Agency, engage in the environmental review process, and when appropriate, issue permits to approved projects. Certain types of projects, such as the construction of large manufacturing plants or changes to pieces of equipment or production systems considered major sources of pollution, automatically trigger a mandatory review, although petitions can be submitted for state review of projects that might not otherwise qualify.

In support of new manufacturers seeking to locate facilities in the state, as well as for existing facilities developing projects that affect permitting status, Minnesota developed an interagency team known as Minnesota Business First Stop. Coordinated by the Department of Employment and Economic Development, this resource provides both companies new to Minnesota and those with existing facilities in the state with early-stage project guidance on a case-by-case basis that aims to increase regulatory transparency for project partners and help them better define their regulatory path. The state also offers Coordinated Project Planning, following authorization by 2024 legislation.[128] This resource can support projects facing environmental review and permitting amendments and is reportedly still underutilized.

Despite these supporting resources, large manufacturers frequently cite Minnesota's environmental review process as "lengthy and cumbersome," creating challenges related to planning and securing resources for construction projects and major system upgrades. One large manufacturer that has actively been looking to site a new production facility contrasted Minnesota's full environmental review process against processes in other states that may only require permitting review, saying that what could take 6 months in a neighboring state would take at least 18 months in Minnesota.

Adding to this perspective, in recent years the air and water permitting steps of Minnesota's environmental review process have increasingly become a focal point for business frustrations. In response, the Minnesota Chamber of Commerce, which serves the state's business community including manufacturers, released a detailed report in 2024, which found that Minnesota's permitting review times were up to six times longer than those of peer states.[129] The Chamber's recommendations for ways to improve the permitting process led to a subsequent series of recommendations from Minnesota Governor Tim Walz during the 2025 legislative session[130] that the legislature adopt certain statutory changes and direct additional funding to MPCA to hire more staff to support the crucial activities of its permitting offices. Any relevant changes were adopted in the state's omnibus bill (SF3)[131] tied to the first special session in 2025, and thus went into effect in the latter half of 2025.

---

[127] For example: N. Mariano, O. Quinn, A. Merlo, et al., "The Clean Heat Climate Opportunity: A Roadmap for Electrifying Low- and Medium-Temperature Industrial Heat," The 2035 Initiative, UC Santa Barbara, December 2025. Additionally, both ACEEE and NRDC have forthcoming studies focused on the effects of industrial rate structures on industrial electrification opportunities.

[128] "Article 7: Environmental Review and Permitting," Minnesota Session Law 2024.

[129] "Streamlining Minnesota's Permitting Programs Can Boost Capital Investments to Grow the Economy and Meet Future Needs," Minnesota Chamber of Commerce, February 2024.

[130] "Permitting reform," Minnesota Pollution Control Agency, 2025.

[131] "2025 First Special Session Omnibus Bills," Minnesota Senate, accessed January 2026.

In the months since, there is a general sense that permitting lead times have already improved, benefitting greatly from the additional staffing. Even so, it will be important for the state to continue monitoring lead times on air and water permitting processes, as well as for the overall environmental review process – especially because a new step was recently added: a greenhouse gas emissions/carbon footprint ('climate assessment') review. Although considered an achievement by most, this additional step nonetheless adds one more layer of complexity that manufacturers will need to navigate.

Other external 'threats'

Large manufacturers frequently cite policy certainty as a major driver of large investment choices. For example, 8-10 years is seen as the minimum on-ramp that a state's policy environment must be able to support – this means policies (e.g., tax credits, permitting frameworks) that can survive changes in state administration, as much as federal. The change in federal administration between the Biden and Trump presidencies serves as an unfortunate example of how chaos in policy can significantly disrupt manufacturing investments – which some of Minnesota's manufacturers are feeling acutely. Not only were federal tax credit rules rewritten, but some grants awarded through federal programs like U.S. DOE's Industrial Demonstrations Program were canceled or forced through substantial renegotiations. Some large manufacturers consulted for background research explicitly commented on these examples as disruptive and harmful practices that, in the worst cases, have disastrously undercut large capital projects already underway.

It is also important to recognize that most manufacturers – especially large ones – operate in markets that extend beyond a given state's boundaries, at least regionally, but often globally. This means that requirements to meet certain state-imposed industrial decarbonization standards can expose manufacturers to global market risks to varying degrees. On the one hand, manufacturers competing with European companies to sell into the European market are likely to benefit from early facility decarbonization. On the other, aggressively pushing for decarbonization has the potential to push manufacturers to a breaking point that some fear could amount to facility closures or relocation to another state. Manufacturers most susceptible include those selling into regional markets or those with particularly thin profit margins, like lumber mills and paper mills,[132] especially if competing in international markets against other companies without decarbonization requirements and/or lower production costs and fewer environmental regulations.

Most manufacturers – especially large ones – operate in markets that extend beyond a given state's boundaries, at least regionally, but often globally. This means that requirements to meet certain state-imposed industrial decarbonization standards can expose manufacturers to global market risks to varying degrees.

INDUSTRY-SPECIFIC BARRIERS

Mining

Minnesota's mining sector, particularly iron ore mining in northeastern Minnesota, is among the state's most energy-intensive and emissions-intensive industrial activities. On-site emissions are driven primarily by pellet indurating furnaces, which require continuous, high-temperature (>1,000°C) heat currently supplied by natural gas combustion, although some non-stationary mining equipment burns diesel (not tabulated in U.S. EPA'S GHGRP records) and crushing,

[132] As reported by the Pulp and Paperworkers' Resource Council, accessed January 2026.

grinding, and concentration activities are large consumers of grid power (roughly 100 MW per site). Of all these emissions sources, the firing processes associated with taconite induration would be among the most difficult industrial processes in the state to electrify, even with commercially mature technologies.

Decarbonization in mining is constrained by long asset lifetimes, high capital costs (CAPEX), and exposure to volatile global commodity markets (see *Systemic Barriers*). Facilities are typically located in remote areas, where electric and gas transmission capacity, electricity prices, and infrastructure lead times are limiting factors. Energy cost sensitivity is acute, because mining margins fluctuate with iron ore prices, reducing tolerance for increases in operating expenses.

Near-term emissions reductions are most likely to come from energy efficiency, process optimization, and electrification of auxiliary systems, including conveying, pumping, material handling, and mobile equipment (see *Efficiency Improvements* and *Electrification*). Over the longer term, emerging options such as electrified or hybrid pellet indurating technologies, high-temperature thermal energy storage, and alternative reduction pathways may become viable, but will require demonstration, integration, infrastructure upgrades, and coordinated planning with utilities.

Because of their scale and material throughput, mining operations may also play a future role in carbon dioxide removal pathways such as mineralization or enhanced weathering (see *Carbon Dioxide Removal*), though these options remain at early stages of development. Progress toward decarbonization in the mining sector will depend on strategies that modernize existing assets, maintain competitiveness, and protect regional employment.

Ferrous metals

Minnesota's ferrous metals sector is currently defined by its role as the primary domestic supplier of iron ore pellets to American steelmakers, rather than by in-state iron or steel production. Minnesota was previously home to one steel mill (an electric arc furnace mill) in Saint Paul, which recycled scrap steel for sale into the regional construction industry, although that facility was idled in 2020 and its owner, Gerdau, has reportedly been stripping down the site and selling off assets.[133] That facility aside, as described in *Vertical Integration*, the emissions associated with ferrous metals in Minnesota arise upstream, during iron ore processing and pelletization, while downstream steelmaking emissions largely occur out of state.

> *As global steel markets shift toward lower-carbon production, demand for low-carbon iron inputs is expected to increase. This creates both risk and opportunity for Minnesota: status quo pellet production could erode competitiveness, while early investment in lower-carbon iron production schemes, like direct reduction technology, could strengthen the state's position in emerging clean steel supply chains.*

As global steel markets shift toward lower-carbon-intensity production, demand for low-embodied-carbon iron inputs is expected to increase. This creates both risk and opportunity for Minnesota: status quo pellet production could erode competitiveness, while early investment in lower-carbon-intensity iron production could strengthen the state's position in emerging clean steel supply chains.

133 "Gerdau to idle EAF, rolling mill in Minnesota," Argus, October 3, 2020.

Interest in in-state ironmaking, particularly via direct reduced ironmaking (DRI) technology, has grown in recent years (see *Iron Ore Mining and Clean Iron Production*). However, DRI and other advanced ironmaking pathways will depend heavily on access to natural gas and low-cost, reliable clean electricity, infrastructure upgrades, regulatory certainty, and other logistical factors, many of which were discussed in *Systemic Barriers* and *Scale of Clean Electricity Needs*. Broadly, many of these barriers can be classified together as site suitability issues. For example, even though the Iron Range already receives natural gas service, the construction of a hydrogen-ready DRI plant would, almost certainly, require expanded natural gas infrastructure, because the plant would most likely source natural gas for ironmaking until cost-effective green hydrogen could be accessed at scale. Moreover, competing projects in other states have benefitted from faster permitting and more aggressive incentive packages, highlighting the importance of coordinated state action if Minnesota seeks to capture value-added ironmaking.

Decarbonization strategies for the ferrous metals value chain therefore hinge on alignment between mining, energy planning, economic development, and permitting processes, as well as long-term market signals that support investment in low-carbon materials.

Non-ferrous metals

Minnesota's non-ferrous metals sector includes secondary metals processing, recycling, and specialty metals production, as well as emerging interest in critical minerals such as copper and nickel. Emissions profiles vary widely by facility, reflecting diverse processes, scales, and degrees of electrification. As noted in *Minnesota's Industrial Emissions*, many facilities rely on high-temperature furnaces and kilns that are challenging to decarbonize.

Compared to primary production, secondary metals processing and recycling generally offer lower emissions intensity, making efficiency improvements and electrification particularly impactful. Opportunities include electric and induction furnaces, improved scrap use, and electrification of auxiliary systems, though adoption is often constrained by electricity costs, concerns over product quality and certification, and long equipment lifetimes (see *Electrification* and *Systemic Barriers: Long asset lives, high capital costs, and impact on operating costs*).

Non-ferrous metals producers are highly exposed to global commodity markets, limiting their ability to absorb higher operating costs or pass on green premiums (see *Systemic Barriers: Market willingness to pay a 'green premium'*). As a result, targeted incentives, access to affordable clean electricity, and pilot and demonstration projects will be critical to reducing perceived risk and accelerating adoption of lower-carbon technologies.

Given the importance of non-ferrous metals to clean energy technologies, such as batteries, electric vehicles, and grid infrastructure, this sector represents a strategic opportunity to align industrial decarbonization with broader energy transition goals, if policy and infrastructure barriers are addressed.

Non-metallic minerals

Minnesota's non-metallic minerals sector, including lime, glass, mineral wool, and cement-related activities, is among the most difficult to decarbonize due to its reliance on continuous, high-temperature kilns and furnaces and, in some cases, associated process-related CO_2 emissions. As discussed in *Technical Approaches to Decarbonizing Industry,* these characteristics place the sector firmly in the 'hard-to-abate' category.

Near-term emissions reductions are most feasible through energy efficiency, waste heat recovery, and partial electrification of auxiliary systems (see *Efficiency Improvements*). Emerging technologies such as high-temperature electric kilns and thermal batteries show promise but remain at relatively low technology readiness for large-scale deployment. Despite this, thermal energy storage has the potential to play an important role in enabling electrification while maintaining continuous operation (see *Electrification: Thermal Batteries*).

Because process emissions are unavoidable in some non-metallic mineral production pathways, carbon capture and storage is often cited as a necessary long-term strategy (see *Carbon Capture and Storage*). Demand-side measures will be critical for this sector. Policies and procurement standards can help create early markets for lower-carbon materials, improving the business case for investment while supporting continued domestic production of essential construction inputs.

Food and beverage

Management in the food and beverage industry tends to focus on meeting shifting consumer preferences, reducing product defects, and ensuring production systems follow strict safety and quality standards — prioritizing products over the systems producing them.[134] Because energy costs in the food and beverage industry hover around 2% of OPEX,[135] companies tend to pursue investments that can produce foods with greater value-add instead of explicitly focusing on decarbonization (including energy savings and emissions reduction strategies). As a result, projects that clearly reduce downtime, labor intensity, or quality risk may compete successfully for capital, while projects framed primarily as emissions reductions may struggle without incentives, customer requirements, or clear additional co-benefits.[136]

Other significant barriers to decarbonizing Minnesota's food and beverage industry include: facility diversity; facility age and complexity of design (site suitability), which could restrict the potential for energy optimization via waste heat and cooling system interconnection; fluctuating markets;[137] and the predominantly rural setting of the state's 17 high-emitting food manufacturers. Furthermore, food and beverage manufacturers hold practical concerns related to new, electrified technologies, like electric conveyor ovens, and the market risks they could create related to product quality.

Finally, broader disagreement over whether farming activities or the food processing facilities that convert raw agricultural inputs into food and beverage commodities should be the primary target for industry decarbonization has the potential to undermine targeted state efforts focusing on food and beverage manufacturers.

While the state's Climate-Smart Food Systems grant program has the potential to spur meaningful decarbonization initiatives in this industrial subsector, but deeper decarbonization may require larger

> *While the state's Climate-Smart Food Systems grant program has the potential to spur meaningful decarbonization initiatives in this industrial subsector, the program's net value is small compared to the full amount of financial support that will be needed to decarbonize Minnesota's food manufacturers, and feasibility studies that take the state's current manufacturing ecosystem as immutable, future constraints — such as current electricity tariff structures — could risk delivering negative outlooks for industrial decarbonization.*

[134] B.J. Sovacool, M. Bazilian, S. Griffiths, et al., "Decarbonizing the food and beverages industry: A critical and systematic review of developments, sociotechnical systems and policy options," Renewable and Sustainable Energy Reviews, June 2021.

[135] 2022 Economic Census data, by way of N. Mariano, O. Quinn, A. Merlo, et al., "The Clean Heat Climate Opportunity: A Roadmap for Electrifying Low- and Medium-Temperature Industrial Heat," The 2035 Initiative, UC Santa Barbara, December 2025.

[136] A.L. Roxas, et al., "Industrial Energy Efficiency and Decarbonization: Identifying Motivations and Barriers for Midwest Manufacturers," ASHRAE Transactions, 2024.

[137] Minnesota's soybean oil processors faced increasing international market volatility in 2025 due to newly implemented federal tariffs, which disrupted export pricing and supply chain stability for agricultural biofuel feedstocks.

capital support, technical assistance, and attention to enabling conditions (for example, interconnection timelines and electricity rates structure). Feasibility studies that assume Minnesota's current food manufacturing ecosystem and electricity tariff structures are static risk hard-coding today's constraints into long-term projections, thereby biasing analyses toward negative conclusions on industrial decarbonization and obscuring pathways that depend on foreseeable regulatory, market, and infrastructure evolution.

Pulp and paper

Minnesota's paper mills are navigating a shifting demand landscape in an increasingly globalizing industry. In part, this has manifested as a decrease in demand for graphic paper and an increase in demand for other paper types,[138] like brown paper and packaging materials. These factors form the backdrop against which Minnesota's paper mills are weathering increasing energy costs, pressures to modernize antiquated facilities, and a struggle to recruit new talent into apprenticeship programs as the existing workforce ages toward retirement. Some mills have responded to these challenges by closing[139] or relocating to southeastern states. Fortunately, the opportunities that the state's paper mills offer as potential producers of biofuels could prove a boon to the state's economy — one that could also be leveraged to support broader industrial decarbonization interests via fuel-switching, while delivering a net-negative pulp and paper sector.

Minnesota's paper mills are navigating a shifting demand landscape in an increasingly globalizing industry, while weathering increasing energy costs, pressures to modernize antiquated facilities, and a struggle to recruit new talent as the existing workforce ages toward retirement. Fortunately, the opportunities that the state's paper mills offer as potential producers of biofuels could prove a boon to the state's economy while supporting industrial fuel-switching more broadly.

Minnesota's paper mills will face a range of industry-specific barriers in their pursuit of decarbonization interests. For example, Minnesota's mills have only low to moderate potential to implement carbon capture with utilization or sequestration (CCUS) at an effective cost point (even with access to the 45Q federal tax credit[140]). Compared to other industries, the equipment lifetimes in paper mills are exceptionally long — approaching, and in some cases exceeding, 40 years. Much of that equipment also operates at extremely high speeds, which creates safety risks if new systems underperform. New equipment must be able to deliver products in accordance with strict product performance specifications. Moreover, while drying systems tend to consume about one-quarter of facility energy needs, and thus are a common target of decarbonization via electrification, some electrified systems, like infrared dryers, create additional safety risks[141] due to their inherently high operating temperatures.[142] These factors combined, on top of the challenges described above, explain the high degree of pushback from many paper mills and their workers to commonly proposed decarbonization technologies.

---

[138] L. Pal, "Process Energy Efficiency in the Food Manufacturing Industry," North Carolina State University / U.S. Department of Energy, 2023.

[139] As reported by the Pulp and Paperworkers' Resource Council, accessed January 2026.

[140] D. Ulama, "Mapping Opportunities to Decarbonize the U.S. Pulp & Paper Industry," Clean Air Task Force, December 2025.

[141] Some infrared paper dryers operate at 1000°C, which is above the threshold for autoignition of paper. This poses a risk when paper breaks occur, because the thin paper feed is then exposed to concentrated high heat instead of quickly moving through the infrared heat exposure points that can lead to fires. It is unclear how extensive this issue has been in reality, but the problem is highlighted as a concern by workers.

[142] L. Pal, "Process Energy Efficiency in the Food Manufacturing Industry," North Carolina State University / U.S. Department of Energy, 2023.

Securing buy-in to a sector-specific decarbonization strategy from Minnesota's paper mills will likely require explicit acknowledgement of these factors — especially safety risks — in addition to assurance from the state that biogenic emissions will be tabulated as net-zero. More targeted support for apprenticeship programs may also be necessary, especially if the state pursues a strategy that includes paper mill diversification into biofuels production. Additionally, industry buy-in will likely require coordinated pursuit of any carbon offsets programs deemed necessary to support economy-wide decarbonization goals.

Finally, because Minnesota's paper mills are competing against a larger industry in neighboring Wisconsin, and some mills have common ownership structures, it may benefit Minnesota to pursue a cross-state, coalition-type approach to paper sector decarbonization.

Biomass

Minnesota's agricultural, forestry, other biomass-related industries, and ag-adjacent industries like pulp and paper, food and beverage manufacturers, and biofuels/chemicals producers are deeply interconnected. This interconnection is felt in both vertical and circular fashions, where low-carbon inputs (like fertilizer) have the potential to influence farmers' ability to produce low-carbon-intensity crops (like corn), which in turn have the potential to influence the accessibility of the low-carbon-intensity grain or residual biomass feedstocks necessary for producing low-carbon-intensity biofuels — the same biofuels that may be necessary for supporting broader decarbonization of Minnesota's manufacturers through the identified priority strategy of fuel-switching.

While the shift toward a net-zero agricultural sector is largely beyond the scope of this work, certain priority strategies and their associated barriers are worth highlighting, because of interdependencies with the state's manufacturing sector. For example, one priority strategy is the shift toward low-carbon-intensity inputs, like 'green' fertilizer (see *Vertical Integration: Agriculture and low-carbon fertilizer production*). The major barrier to this strategy is the increased cost to produce low-carbon-intensity fertilizer, which Minnesota's farmers are not in a position to bear.[143]

Other barriers include the need to influence longstanding agricultural practices and the increasing impact of local climate fluctuations.[144] In addition to disrupting growing seasons, such fluctuations may continue to shift the location of appropriate farming locations for different types of crops. All these factors will influence the potential for Minnesota to realize its interests in green fertilizer production and the manufacturing of biofuels, including priority fuels like sustainable aviation fuel (SAF).

Minnesota's agricultural and forestry industries are also key stakeholders in any state interests related to carbon offsets.[145] The state will need to play an active role in defining the rules and regulations related to carbon markets to ensure their compatibility with manufacturers' needs tied to fuel-switching, biofuels production, and general competitiveness. Criticism of some recent carbon offset projects, especially those tied to forestry, must be addressed through deeper appreciation of the needs of forestry product industries, including the paper sector. Reportedly, the lack of regulations has led to projects without active forestry management requirements, which directly threatens the state's forestry product industries by creating off-limit forest tracts that increase the potential for tree diseases and forest fires to harm the remaining accessible tracts. Unless the state manages to secure buy-in from the forestry product industries, it could

---

143 M. Kostylev, S. Benayoun, E. Boatman, "The Potential for Hydrogen to Support Low-Carbon Industry in Minnesota," 5 Lakes Energy, May 2025.

144 "Climate Guide: Supporting Low-Carbon Transitions," Minnesota Food Union, November 2024.

145 "Climate Guide: Supporting Low-Carbon Transitions," Minnesota Food Union, November 2024.

face significant opposition to some future carbon offset projects needed to support state-wide industrial decarbonization and risk the loss of established manufacturers — with the potential to deepen the economic harm felt in certain regions of the state, like the northeast.

Liquid fuels

Liquid fuels production in Minnesota currently includes a combination of 17 ethyl alcohol (ethanol) refineries and 2 petroleum refineries, the latter of which are also home to two 'gray' hydrogen production facilities. This existing infrastructure and history as a biofuels producer creates a favorable context for Minnesota to continue investing in alternative fuels production,[146] to support both economy-wide and manufacturing sector-specific decarbonization via fuel-switching.

For example, it may prove more cost-effective for the state to convert its existing petroleum refinery infrastructure to biofuels production than to build new biorefineries, and neighboring Canada is also pursuing an alternative fuels strategy[147] that could be leveraged through an existing cross-state energy and trade market. While there is potential here, it is also important to note that the existing feedstocks for biorefining are generally more expensive than the prices that the resulting product can command in the current market, and the new supply systems to support the adoption of new feedstocks at scale would be expensive to develop. For example, both liquid feedstocks and finished products are typically moved in dedicated pipelines — which would likely need to be re-constructed, thereby exposing refineries to new costs to essentially duplicate much of their infrastructure and incur additional public opposition to the incremental pipeline projects. For these reasons, refineries indicate that the economics for converting existing facilities to biorefineries currently don't pencil out.

Separately, Minnesota has significant feedstock resources (second generation biomass, waste oils and animal fats, fresh water, geologic hydrogen potential) that could support the emergence of new biofuel and e-fuel producers, and the state has signaled a willingness to support fuel innovation by investing in a tax credit program for sustainable aviation fuel (SAF) production. Despite these favorable signals, Minnesota will likely face a range of barriers on its path to becoming a leading producer of biofuels and e-fuels, toward a net-zero economy.

Petroleum refining. In general, priority decarbonization strategies for petroleum refineries include fuel-switching, electrification, and CCUS.[148] However, the major challenges to implementing CCUS at petroleum refineries include the low concentration of CO_2 in the exhaust streams, which would require concentration for cost-effective transport, the logistics of building out CCUS infrastructure in a suburban area, and the number of exhaust points spread over significant distances throughout the facility. The large number of exhaust points, in particular, is problematic for most refineries, because each requires its own capture technology, thereby increasing both the CAPEX and OPEX associated with carbon capture, even though the captured carbon could potentially be used in on-site e-fuels production.[149] Refineries, like many industries today, point to these costs as excessive.

Other barriers to petroleum refinery decarbonization are largely tied to external factors, like low technology readiness of alternative, electrified technologies (e.g., electric furnaces, oxyrefining methods), and the low cost of natural gas, which restricts interest in efficiency projects. Coupled to this barrier is the vast amount of clean power that would be required to electrify a refinery — comparable in scale to what many new data centers are demanding.

---

[146] R. Maxwell, "Green Refineries: Decarbonize, Convert, or Close," DNV, accessed January 2026.

[147] "Energy Innovation Program: Clean Fuels & Industrial Fuel Switching," Natural Resources Canada, accessed January 2026.

[148] Z. Byrum and C. Dellesky, "Technologies to Decarbonize Petroleum Refineries," World Resources Institute, October 21, 2021 (accessed January 2026).

[149] "Refinery of the Future: Executive Summary," Clean Air Task Force, July 2024.

To minimize on-site energy costs, refineries currently burn large quantities of fuel gas, a refining byproduct produced on-site (see Figure 5) that is constituted by less marketable (and unmarketable) portions of production byproducts. Widespread electrification would therefore restrict the demand for fuel gas to power process activities, even though those process activities would still be producing it — potentially creating additional economic and environmental challenges. Finally, the economy's broad dependence on petroleum products and uncertainty in the electric vehicle market, with mixed signals from the federal government regarding long-term interests, will pose at least a short-term challenge for decarbonization interests at Minnesota's refineries.[150]

Ethyl alcohol (ethanol) manufacturing. Most biofuel produced today, including in Minnesota, is in the form of ethyl alcohol (ethanol), and most of that ethanol is used as an additive in gasoline, in support of the federal government's renewable fuel standard (RFS). As a result, the ethanol industry's interests in decarbonizing are largely tied to the RFS, which only requires a 20% life cycle-based reduction in emissions versus a 2005 baseline for gasoline.[151] While other market factors could help drive ethanol decarbonization, the sector's direct ties to the RFS are likely to restrict Minnesota's short-term potential to rely on its ethanol industry to support industrial fuel-switching as a decarbonization measure. Moreover, grain-based ethanol production schemes may face mounting criticism associated with the carbon intensity of the associated farming practices[152] and perceived increased competition with food agriculture.

Other biofuels and e-fuels. Unfortunately, the U.S. Environmental Protection Agency reports that the conditions necessary to open alternative markets for low-carbon fuels have shifted little over the last decade, and thus continue to restrict their development[153] — and Minnesota has felt this fact first-hand, especially related to manufacturers' lack of access to low-carbon inputs at favorable cost points.

For example, nearly all biofuel and e-fuel production pathways require hydrogen, which remains cheapest to produce through steam reforming of the methane in natural gas (i.e., natural gas SMR, which creates a 'gray' hydrogen product[154]). This is a carbon-intensive process that can only be made 'clean' by coupling with carbon capture and utilization or storage, thereby converting the 'gray' hydrogen to 'blue' hydrogen. With limited potential to access the federal 45V clean hydrogen tax credit, Minnesota's best opportunity for clean hydrogen to support clean fuels production may be through geologic hydrogen schemes, which the state has yet to invest in despite a recent push by advocates.[155]

The state's 'second generation' biomass resources[156] will also be important for biofuels and e-fuels production — yet their development for these purposes is restricted by various factors, ranging from a lack of access to cost-effective, low-carbon-intensity fertilizer to uncoordinated or inconsistent market signals. Both factors have constrained Minnesota's burgeoning SAF industry despite state financial support.[157]

---

[150] "Refinery of the Future: Executive Summary," Clean Air Task Force, July 2024.

[151] "Overview of the Renewable Fuel Standard (RFS) Program," U.S. Environmental Protection Agency, accessed Jan 2026.

[152] S. Herbstritt, J. Lewis, K. Fallon, and M. Sasso, "U.S. Renewable Fuel Standard: Challenges & Opportunities on the Path to Decarbonizing the Transportation Sector," Clean Air Task Force, June 13, 2023.

[153] "Biofuels and the Environment," U.S. Environmental Protection Agency, accessed Jan 2026.

[154] See Table 1 of M. Kostylev, S. Benayoun, E. Boatman, "The Potential for Hydrogen to Support Low-Carbon Industry in Minnesota," 5 Lakes Energy, May 2025.

[155] "HF 2934: An Act Relating to Energy; Appropriating Money to Evaluate the State's Geologic Hydrogen Potential," Minnesota Office of the Revisor of Statutes, March 27, 2025.

[156] In biofuels production, 'second generation' feedstocks are biomass that would not otherwise be consumed for food, e.g., wood matter (second generation) versus corn (first generation).

[157] M. Kostylev, S. Benayoun, E. Boatman, "The Potential for Hydrogen to Support Low-Carbon Industry in Minnesota," 5 Lakes Energy, May 2025.

Cross-Cutting Stakeholder Perspectives

This section summarizes feedback received from a wide spectrum of stakeholders, including community members, Tribal Nations, union members, and the environmental advocates community. Input was gathered as a part of this process as well as through broader community engagement activities that occurred under the Midwest Industrial Transformation Initiative (MITI). The perspectives below are generalized and anonymized.

COMMUNITY IMPACT

Stakeholders consistently emphasized that the success of industrial innovation will be judged by the extent to which it strengthens local communities, not just by whether it reduces emissions. Across geographies, stakeholders described an interest in clear community benefits tied to industrial activity: stable jobs, reduced local pollution, public services, and infrastructure improvements that benefit quality of life.

> *Community stakeholders emphasize that the success of industrial innovation will be judged by the extent to which it strengthens local communities, not just by whether it reduces emissions. Clear benefits sought by community stakeholders include stable jobs, reduced local pollution, public services, and infrastructure improvements that benefit quality of life.*

At the same time, priorities varied by place and industry. In northeastern Minnesota, stakeholders pointed to the outsized role of mining and related industries in supporting schools, jobs, and local infrastructure. That translated into a preference for pathways that protect competitiveness and keep facilities operating while they modernize – paired with credible commitments to environmental performance. In agricultural parts of the state, some stakeholders emphasized opportunities to build local wealth through new clean economy supply chains, especially where ownership models could retain value in rural communities (for example, farmer- or co-op–owned approaches for emerging fertilizers). Stakeholders noted that energy and heat sharing may offer localized benefits in certain settings (such as data centers), but only where early coordination and upfront design make it feasible.

Concerns among communities and community-based organizations were equally clear. Multiple stakeholders pointed to low trust in the promises made by industry or other outside entities, shaped by past experiences. Interviewees reflected that the message matters: some communities respond to manufacturing competitiveness or local jobs, others find 'climate framing' to be polarizing, while still others stated that they immediately write-off industry-led messages due to a lack of trust.

There were also concerns about affordability and cost increases associated with industrial transformation – particularly where energy or compliance costs could hit local communities, energy costs, and schools. Some stakeholders also expressed concerns about major ownership and governance changes that could lead to questions about long-term rates and their affordability, as well as accountability.

TRIBAL CONCERNS AND INTERESTS

Tribal perspectives emphasized that industrial decarbonization interests intersect with Tribal Nations' priorities around sovereignty, community wellbeing, workforce and economic opportunity, and long-term stewardship. Stakeholders described strong interest in clean energy and related industries — especially where projects can support sustainable jobs, local hiring, and skill-building for the next generation. Several comments highlighted practical barriers that shape participation, including childcare, transportation, and the capacity constraints that come with high staff turnover and limited program resources.

Tribal stakeholders also noted the importance of not viewing industrial transformation in isolation or through a single-technology lens. Instead, it should be packaged together with other priorities like childcare, jobs, housing, and natural resource stewardship. That means industrial decarbonization opportunities that align with community-scale energy projects, remediation, or local ownership can be more compelling than narrow pilots that do not connect to broader community goals.

On governance and engagement, stakeholders underscored the importance of working in ways that respect Tribal sovereignty, process, and decision-making structures. Some suggested that statewide coordination may benefit from engaging with intertribal leadership structures[158] in addition to individual Nation-level relationships, depending on the topic. Finally, several perspectives flagged that volatility in federal policy and funding creates risk for long-horizon projects; sustainable approaches need to be resilient to shifting administrations and funding cycles.

> *Tribal perspectives related to industrial decarbonization emphasize intersection points with Tribal Nations' priorities around sovereignty, community wellbeing, workforce and economic opportunity, and long-term stewardship. Interest in clean energy and related industries is strongest where projects can support sustainable jobs, local hiring, and skill-building for the next generation.*

UNION CONCERNS AND INTERESTS

Interviews with Minnesota labor unions and union-represented workforce stakeholders across multiple industrial sectors revealed a shared understanding that industrial decarbonization is no longer a future concept, but an active force shaping investment decisions, infrastructure planning, and job outlooks across the state. While unions represent different industries and trades, there is broad agreement that effective decarbonization efforts should be designed to strengthen existing industries, protect workers, and support clear pathways for long-term employment. From a labor perspective, the central concern is not whether decarbonization

> *While unions represent different industries and trades, there is broad agreement that effective decarbonization efforts should be designed to strengthen existing industries, protect workers, and support clear pathways for long-term employment.*

158 For example, the Minnesota Indian Affairs Council or the Tribal Advocacy Council on Energy.

should take place, but whether it can be implemented in ways that sustain industrial competitiveness while retaining and delivering new high-quality jobs.

A consistent theme across sectors was the importance of anchoring decarbonization in the preservation and modernization of existing industrial facilities. Workers in energy-intensive industries, including manufacturing, construction, and power generation, view decarbonization positively when it supports continued domestic production and avoids outcomes that accelerate offshoring or facility closures. There was alignment with policies or technologies that prioritized retrofits, efficiency improvements, and process upgrades rather than wholesale replacement or closure of facilities that may underpin regional economies. Maintaining and upgrading existing assets was seen as essential to retaining skilled workforces and sustaining industrial communities. Moreover, across discussions, unions expressed concern that decarbonization initiatives are often framed primarily in technical or environmental terms, with insufficient attention to labor impacts. Interviewees emphasized that decarbonization is not experienced in the abstract, but through changes to daily operations, skill requirements, and job stability. When workforce considerations are not addressed early, projects face increased risk of implementation challenges, workforce shortages, and resistance.

On the other hand, early and meaningful engagement with unions can improve implementation, align expectations, and ensure that new technologies or changes can be integrated smoothly into existing operations. Unions highlighted their ability to provide practical insights on workforce readiness, safety considerations, and training needs when included at the beginning of planning processes. They noted that proactive engagement can reduce risk and strengthen outcomes for both employers and workers.

Public policy and incentives were widely viewed as critical levers for advancing industrial decarbonization, particularly when they are paired with strong labor standards. Unions broadly supported incentives that encourage facility modernization, energy efficiency, and emission reductions. Still, they emphasized that investments should deliver benefits to workers (similar to the labor standards found in the Inflation Reduction Act). Participants also raised concerns about policy uncertainty and shifting federal and state priorities, noting that inconsistencies can make it difficult for employers and workers to plan for long-term investments and workforce development.

Taken together, these perspectives reflect a shared view among Minnesota's unionized workforce: industrial decarbonization presents a significant opportunity when it is aligned with job quality, industry retention, and worker engagement. These perspectives underscore the importance of a workforce-centered approach to industrial decarbonization, one that supports job quality, workforce stability, and long-term career pathways for Minnesota's workers as industries evolve.

ENVIRONMENTAL CONCERNS AND INTERESTS

Minnesota hosts a variety of sensitive ecosystems that citizens and advocacy groups aim to protect. Numerous flora and fauna are already threatened or endangered due to habitat loss and the degradation of natural environments. Environmental organizations seek to hold communities and industrial operators accountable for protecting Minnesota's ecosystems through a variety of approaches, with a focus on defending air and water quality, while promoting sustainable land use practices.

Interviews with environmental organizations provided insight into their priorities, but also highlighted broader concerns about the perceived disconnect between environmental and climate initiatives. Although both efforts are important and often complimentary, there are instances where trade-offs appear to be necessary, especially regarding permitting. An often-cited example is the challenge of balancing clean energy project siting with associated environmental impacts. This complicated dynamic will continue to escalate as climate advocates stress the need for expedited permitting of clean energy projects in order to meet the growing demand for clean energy. Another example of trade-offs can be seen in the increased demand for sourcing critical minerals, some of which is associated with mineral resources located within the state, related to clean energy technologies.

Interviews with environmental organizations highlighted broader concerns about the perceived disconnect between environmental and climate initiatives in Minnesota.

Environmental advocates suggested that lawsuits are an effective tool to hold operators accountable for following regulations, as designed by the state. They also aim to impact legislation to create a landscape that promotes long-term environmental protections. The state, on the other hand, has the challenge of balancing regulations and incentives for operators. Industrial businesses currently vocalize reluctance to site operations in Minnesota, due to the perception of environmental review and/or permitting headwinds. Finding a pathway that encourages economic development, while protecting the environment and decarbonizing operations, is a challenging, but necessary, objective.

Climate and environmental efforts both struggle to secure sufficient funding to support their work. Although advocacy organizations attempt to communicate the long-term price of inaction, the cost of implementing programs is typically high for both climate- and environment-focused initiatives, creating doubts about the value of investment in these spaces. Federal funding has also been reduced recently, creating a more competitive project financing landscape for advocates to navigate. With limited budgets, advocates and legislators are forced to prioritize which solutions are the most critical, exacerbating the issue of trade-offs between well-intentioned efforts.

Minnesota's ecosystems are sensitive to the immediate impacts of pollution and unsustainable land and water use, but they are also threatened by warming temperatures and changing weather patterns. Climate and environmental protection initiatives are both equally important to support, but environmental advocates note that messaging efforts are not aligned. A perspective shared by environmental organizations suggested that, for many people, climate change feels "big and unsolvable," while issues like air pollution and access to clean water have more direct impacts on people's health, as well as clearer pathways for solutions.

Ultimately, the environmental groups interviewed noted that there needs to be more care with how these initiatives are introduced to the broader public, in order to "bring them with us." They

Environmental stakeholders emphasized that industrial decarbonization is inextricably linked to public health and community impacts. Many noted that when discussions focus only on greenhouse gas reduction, the public can feel overwhelmed, whereas discussions that also address air pollution and local health outcomes can make the issues feel more concrete and actionable for communities.

stressed that messaging needs to focus on the need to come together "for the good of our overall wellbeing." While there are still trade-offs that the state must navigate, there seems to be optimism that advocates can align messaging to drive industrial decarbonization interests forward.

Environmental stakeholders further emphasized that industrial decarbonization is inextricably linked to public health and community impacts (for example, see *GET THE FACTS: Industrial Electrification Can Benefit Community Health, Too* and *GET THE FACTS: New Cumulative Impacts Legislation Will Help Reduce the Health Harms of Industrial Air Pollution*). Many noted that when discussions focus only on greenhouse gas reduction, the public can feel overwhelmed. When discussions also address air pollution and local health outcomes, the issues can become more concrete and actionable. Several perspectives also highlighted ongoing tensions in communities where pollution burdens are high and where the largest emitters are not always located in the same places as those experiencing the greatest cumulative impacts.

Stakeholders described a mix of 'carrot and stick' drivers in their views of the role of the state in industrial decarbonization. Incentives, pilots, and early investment can help reduce risk and bring more business to the table; while standards, enforcement, and greater staffing in permitting and review offices are required to overcome regulatory delay. Some also emphasized the value in aligning industrial policy with market-building tools such as 'Buy Clean,' and tying these tools to workforce outcomes so that emissions reductions and job creation/retention move together.

'Green steel' and advanced iron production emerged as promising possibilities in the minds of environmental groups that could both improve job prospects and environmental outcomes. Fertilizer and other agricultural supply chain strategies for emissions reductions were described as early, uncertain, and unclear.

A few themes emerged as both opportunities and potential points of contention. 'Green steel' and advanced iron production emerged as promising possibilities in the minds of environmental groups that could both improve job prospects and environmental outcomes. Fertilizer and other agricultural supply chain strategies for emissions reductions were described as early, uncertain, and unclear. Data centers and other large new loads were described as an urgent statewide issue that has the potential to reshape grid planning, energy costs, and community politics. Here, stakeholders flagged the need for a coordinated, rather than a project-by-project, approach. Finally, several groups noted that disagreements within the broader environmental coalition — such as around biomass and forest carbon — can create friction unless the state is clear about its goals, definitions, and how tradeoffs will be managed.

The Role of Minnesota's State Agencies

Minnesota's industrial decarbonization landscape is shaped by a wide range of state agencies that influence energy planning, utility regulation, environmental review and permitting, economic development and financing, workforce training and applied research, and natural resource management. Through these roles, state agencies influence how industrial projects are planned, financed, permitted, and carried out across the state. Although many of the relevant programs and processes already exist, industrial decarbonization cuts across policy areas that are managed by different agencies with distinct roles and timelines. The following sections describe how state agencies currently engage in this work and where stronger coordination could help support long-term industrial transition.

EXISTING MECHANISMS FOR STATE AGENCIES TO ENGAGE

Energy planning, utility regulation, and conservation programs

Several Minnesota state agencies shape the energy system conditions that have the potential to influence industrial decarbonization through long-term energy planning, utility regulation, and conservation and innovation programs. In particular, the Minnesota Department of Commerce and the Minnesota Public Utilities Commission (PUC) play central roles in determining energy costs, infrastructure investment, and system planning decisions that directly affect industrial facilities.

Through its Division of Energy Resources, the Department of Commerce leads statewide energy planning and administers the Energy Conservation Optimization (ECO) program, which establishes energy savings requirements for electric and natural gas utilities and provides a formal mechanism for supporting efficiency improvements and certain fuel-switching activities across customer classes, including industrial users. Commerce also manages a suite of financing and technical assistance programs, including Property Assessed Clean Energy (MinnPACE) financing and Conservation Applied Research and Development (CARD) grants, and facilitates access to federal funding opportunities that can support energy-related investments by manufacturers. The findings of a forthcoming effort funded through Commerce are expected to reveal critical insights needed for the state to effectively carry out long-term power system resource planning to ensure that Minnesota's power sector can reliably meet the state's carbon-free electricity standards as economy-wide decarbonization interests are pursued.[159]

The PUC regulates electric and (most) natural gas service across the state, approving rates and terms of service, and reviewing utility proposals related to integrated resource planning, grid modernization, and major energy infrastructure investments. Through these regulatory processes, the Commission influences gas and electricity pricing structures, system reliability planning, and long-term infrastructure decisions, all of which have material implications for the feasibility of industrial electrification and fuel-switching. In addition, the PUC administers the Natural Gas Innovation Act, under which utilities may pursue pilot projects intended to reduce greenhouse gas emissions from the natural gas system.

Taken together, these planning, regulatory, and conservation mechanisms provide Minnesota with an established institutional framework for engaging industrial energy use and emissions.

[159] "Minnesota Pathways to Carbon Free 2040 Study," Minnesota Commerce Department, posted December 15, 2025.

Environmental review, permitting, and climate initiatives

Environmental permitting and environmental review determine how industrial projects are evaluated and approved in Minnesota. These processes affect whether projects proceed and influence the timing and predictability of major capital investments. For new businesses that have identified site(s) in Minnesota for potential expansion and companies with existing locations in the state looking to undertake significant facility modifications, the Minnesota Business First Stop organized by the Department of Employment and Economic Development (DEED) offers customized support in navigating the state's permitting process. Some sources have praised the support received from Minnesota Business First Stop for being helpful, and in some cases, for reducing the total time to receiving permit approvals by significant margins (as great as 30%).

The Minnesota Pollution Control Agency (MPCA) administers air, water, and waste permitting programs that apply to a wide range of industrial facilities, including manufacturing, mining, and energy-related operations. MPCA's permitting responsibilities also include oversight of facility modifications and new source reviews, which directly shape how existing industrial sites can upgrade or expand. In addition to permitting, MPCA manages several programs related to emissions reduction and climate policy. These include greenhouse gas reduction initiatives, climate planning activities, and sector-specific efforts such as program activities related to the state's sustainable aviation fuel interests and Climate-Smart Food Systems awards, which will support pilot projects and feasibility studies relevant to industrial decarbonization.

The Minnesota Environmental Quality Board (EQB) coordinates the state's environmental review process for projects that may have significant environmental impacts. The EQB provides a structured process (including associated rules) for information gathering, cross-agency coordination, and public input that informs permitting processes. The EQB also specifies which types of projects fall under the 'mandatory' category for environmental review.

Economic development, financing, and site readiness

The Minnesota Department of Employment and Economic Development (DEED) supports industrial projects through programs focused on site readiness, community engagement, and business expansion. DEED's economic development and brownfield redevelopment programs can support the reuse or upgrading of existing industrial sites, including through contamination cleanup and site investigation grants that reduce redevelopment risk for new owners.

DEED also administers workforce-related and business support programs that can help industrial employers train workers and plan for expansion. Programs such as the Partnership Program (companies throughout the state are eligible to apply), Job Training Incentives Program (new or expanding companies in Greater Minnesota only), and the State Trade and Export Promotion (STEP) Program provide targeted support to manufacturers as they scale operations, adopt new processes, or enter new markets.

In northeastern Minnesota, the Department of Iron Range Resources and Rehabilitation (DIRRR) provides regionally focused financing and technical assistance using revenues from iron ore production taxes. DIRRR offers loans, grants, and loan guarantees for businesses locating or expanding in the region, including support for equipment purchases, energy efficiency retrofits, and workforce development. This includes Workforce Development grants that support training and skills development for local workers tied to new or expanding industrial activity.

In addition, the Minnesota Department of Revenue administers tax-based incentives that intersect with industrial decarbonization, including the sustainable aviation fuel (SAF) production tax credit. While not specific to industrial heat or manufacturing broadly, this credit could influence investment decisions in energy-intensive fuel production processes, and establishes a framework for similar production tax credits that the state could develop to support industrial decarbonization.

Together, these economic development, financing, and site readiness mechanisms give the state multiple ways to engage with industrial investment decisions and reduce financial and siting risks associated with industrial decarbonization projects.

Workforce development, education, and applied research

The Minnesota Department of Labor and Industry (DLI) oversees the state's registered apprenticeship system and administers several grant programs that support the development and expansion of apprenticeship and training opportunities. These include the New and Expanded Registered Apprenticeship Program Grant, the Clean Economy Occupations Grant, and the Dual Training (Pipeline) Grant program, which support both the creation of new apprenticeship programs and the upskilling of existing workers in fields such as advanced manufacturing and clean economy occupations. Targeted use of these programs could help Minnesota fill vacancies in subsectors like pulp and paper, in addition to filling new roles that could be created by supporting the development of emerging sectors like alternative fuels production.

DLI also administers programs that support broader workforce access and early career pathways, including the Labor Education Advancement Program (LEAP), the Youth Skills Training Grant, and the Introduction to Registered Apprenticeship for Educators Grant. Together, these programs can help connect more employers, educators, and workers to apprenticeship pathways relevant to industrial sectors.

The Minnesota Office of Higher Education supports workforce and industry engagement through the Minnesota State Centers of Excellence, including centers focused on advanced manufacturing, engineering, and energy. Through these centers, educational institutions work directly with industry partners to assess workforce needs, explore emerging markets, and align training and applied research with industry demand, including engagement with Tribal communities and higher education systems.

In addition, some research institutes support industrial transformation through applied research and technical engagement with industry and public stakeholders: for example, the Agricultural Utilization Research Institute (AURI), and others within the University of Minnesota system, such as the Natural Resources Research Institute (NRRI, also home to the Midwest Industrial Transformation Initiative or MITI) and West Central Research and Outreach Center (WCROC).

Natural resources, forestry, mining, and bio-based industries

The Minnesota Department of Natural Resources (DNR) oversees forest management, mineral resources, and land use planning, and plays a central role in activities related to forestry, biomass, and mining. Through forest management plans, mineral permitting, and data collection on resource availability, DNR influences the feasibility of bio-based materials, biomass energy, and other resource-intensive industrial operations.

The Minnesota Department of Agriculture (MDA) supports agricultural and bio-based industries through programs related to fertilizer management, renewable fuels, and agricultural innovation. These programs intersect with industrial decarbonization by shaping feedstock supply, production practices, and emissions associated with agricultural and bio-based manufacturing.

Additionally, entities such as the Minnesota Forest Resources Council and the Minnesota Geological Survey provide research, coordination, and data resources that inform forest management, land use, and mineral development decisions. These institutions help connect research with industry, land managers, and public agencies through guidance documents, assessments, and stakeholder engagement.

Cross-cutting coordination and advisory bodies

The Minnesota Environmental Quality Board (EQB) supports cross-agency coordination on environmental issues affecting Minnesota's water, land, air, energy, and climate. EQB serves as the coordinating body for the state's Environmental Review Program, which is an information-gathering process established in state statute to assess the potential environmental impacts of proposed projects, part of which includes permitting process.

EQB also produces public reports and studies, including the Minnesota Environment and Energy Report Card, which tracks environmental conditions and related actions in alignment with the state's Climate Action Framework.

In addition to the agencies with explicit responsibilities related to environment and energy, the Minnesota Department of Transportation (MnDOT) leads programs, initiatives, and investments that can aid industrial decarbonization. MnDOT, in collaboration with nonprofit organization The Ray and Next Generation Infrastructure (NGI) Consulting, completed a feasibility study for co-locating electrical transmission infrastructure in highway right-of-way (ROW) locations.[160] As of 2024, Minnesota adopted its first policy allowing the co-location of high-voltage transmission lines in existing state and interstate highway ROW sites,[161] which could help address barriers of electricity cost, availability, and reliability for industrial sites.

Further, MnDOT's Office of Sustainability and Public Health recently engaged stakeholders in assessing the feasibility of a clean fuels standard in the state, leading to a 2024 report to the legislature,[162] and the Freight and Railway Planning unit convenes the Minnesota Freight Advisory Committee, which recommends policy and actions that promote safe, reliable, and efficient freight systems. Both the clean fuels standard and low-carbon freight modes are opportunities for the industrial sector to reduce their impact and promote economic growth.

ADDITIONAL OPPORTUNITIES FOR CROSS-COLLABORATION AMONG STATE AGENCIES

Clarifying agency roles and improving navigation for industry

Stakeholder input indicates that many industrial companies and trade associations look to state agencies and policy makers for guidance on how to pursue decarbonization, highlighting an opportunity for Minnesota to more clearly articulate the roles of state agencies involved in net-zero and industrial transition efforts. Clearer definition of agency

160 "NextGen Highways Feasibility Study for the Minnesota Department of Transportation," The Ray, 2022.

161 "161.45 Utility on Highway Right-of-Way; Relocation," 2025 Minnesota Statutes, accessed January 2026.

162 "Clean fuels standard," Minnesota Department of Transportation, accessed January 2026.

roles and engagement pathways could help reduce barriers to coordination and support more constructive cross-agency engagement.

Stakeholders emphasized the importance of coordinated engagement across agencies, particularly in contexts involving regulatory frameworks or siting considerations. Clearer coordination across agencies responsible for utilities, transportation infrastructure, site development, incentives, and workforce programs could help address non-financial barriers and support Minnesota's competitiveness in contexts where companies with national or international operations may be evaluating investment decisions across states. Stakeholder input from advocacy and Tribal perspectives further underscored the importance of clear and coordinated engagement frameworks that reflect broader economic priorities and appropriate governance structures.

Aligning infrastructure, incentives, and regional economic development

Stakeholder input highlighted opportunities to better align state incentive programs with infrastructure readiness and regional economic development efforts. Industry participants noted that while grants can help reduce project costs, state support for utility upgrades and transportation infrastructure can be equally important for enabling industrial projects to move forward.[163]

Stakeholders also pointed to the potential value of stronger coordination at the regional level, including through regional economic development organizations and public-private site development efforts. While Minnesota has nine regional development commissions that play a vital role in regional project coordination and funding, anecdotally challenges remain, often associated with a strong feeling of competition among neighboring communities for limited resources (e.g., state and federal grants). Community and labor perspectives emphasized that regional, infrastructure-backed approaches can help maximize local economic benefits, including job creation and tax base impacts, compared to isolated, project-by-project investments. Aligning state agencies, regional partners, and utilities around shared infrastructure and development priorities could support more integrated, multi-company approaches to industrial decarbonization. Additionally, these stakeholder coalitions can help socially validate projects, building community readiness for development through consistent, clear communication with their unique audiences.

Coordinating research, workforce, and cross-sector demonstration efforts

Stakeholders identified opportunities to strengthen coordination across research institutions, workforce development programs, utilities, and industry to support industrial decarbonization. Academic and utility stakeholders noted that closer coordination among state-funded universities and applied research centers, utilities, and industry could help translate research findings into practical applications while ensuring that workforce training keeps pace with emerging technologies and operational needs.

Stakeholders also identified value in collaborative demonstration and pilot efforts that span multiple sectors. Several participants pointed to opportunities to coordinate industrial decarbonization with related transportation and freight initiatives, as well as with federal and regional partners, to advance projects that test new approaches and support longer-term industrial competitiveness. Labor and community perspectives highlighted the importance of ensuring that these efforts support durable workforce pathways and inclusive economic outcomes alongside emissions reductions.

---

[163] For example: Minnesota Department of Transportation grant opportunities, Minnesota Public Facilities Authority infrastructure funds and programs, and Minnesota Department of Employment and Economic Development's business development funding opportunities.

Key Take-Aways and Next Steps

SUMMARY OF KEY FINDINGS

The primary objectives of this work were to incorporate multiple research threads, including literature research, expert perspectives, and direct stakeholder engagement, to develop a comprehensive understanding of the major barriers that Minnesota's manufacturing sector will face in the pursuit of a decarbonized future, as well as to identify where major opportunities may lie — all contextualized in an analysis of the current state of the sector.

Accordingly, the results of this effort can be summarized in the following key findings:

- Just 37 high-emitting facilities belonging to 7 manufacturing subsectors contribute 87% of all CO_2e emissions associated with manufacturing activity in Minnesota. The state's 59 high-emitting manufacturing facilities contribute an estimated 94% of all manufacturing CO_2e emissions produced each year.
- Minnesota's manufacturers are highly dependent on fossil fuels — especially natural gas, which is responsible for 60% of fuel-based CO_2e emissions from the state's 59 high-emitting manufacturers. In contrast, most of the natural gas consumed by these facilities (and thus most of the natural gas consumed by Minnesota's manufacturers) is purchased from third-party marketers, and not from the state's utilities, limiting the Minnesota Public Utility Commission's jurisdictional authority to implement efficiency improvements and reform gas rate design.
- With most high-emitting manufacturing facilities operating around-the-clock, nearly every day of the year, Minnesota's manufacturers consume an estimated 4.3 GW of heat energy at any given moment. Electrifying just low- and medium-temperature heat needs in the state's food and beverages manufacturing subsectors could require as much as 500 MW of clean power supply.
- Energy efficiency improvements, process heat electrification (paired with continued grid decarbonization), and switching to alternative low-carbon fuels are priority strategies for tackling industrial carbon emissions. Regardless, carbon capture and carbon removal technologies will likely be needed to bring the manufacturing sector's emissions to net-zero by 2050.
- Even with energy efficiency improvements, Minnesota's manufacturers will remain reluctant to consider electrification without the adoption of new, alternative electricity tariff schemes designed specifically to support industrial electrification.
- Electrification of process heat through emerging technologies like industrial heat pumps and thermal batteries has the potential to drastically improve energy efficiency within Minnesota's manufacturing sector, while helping to balance supply and demand mismatch in the power grid — a crucial opportunity, as intermittent renewables penetrate deeper into the power sector.
- Minnesota's large biomass resources and certain industrial cross-sector coupling opportunities could help position the state as a producer of low-carbon-intensity biofuels and e-fuels, which in turn could support industrial decarbonization via fuel-switching.
- Vertical integration opportunities related to green ammonia production and ironmaking could help boost Minnesota's economy, by 'onshoring' production processes currently happening in other states.

- The major barriers to industrial decarbonization in Minnesota, like other states, include the long asset lives of heat-supplying units (two to three decades or more), the high up-front capital costs associated with new equipment purchases, and sensitivity to changes in operational costs that can result from fluctuating fuel and electricity prices (or fuel-switching).

Moreover, industrial innovation to support sector-wide decarbonization must prioritize a range of stakeholder interests:

- Communities desire stable jobs, reduced local pollution, and infrastructure improvements;
- Tribal Nations seek to prioritize sovereignty, community wellbeing, workforce and economic opportunity, and long-term stewardship;
- Unions and labor seek opportunities that can strengthen existing industries, protect workers, and support clear pathways for long-term employment; and
- Environmental groups emphasize the need to prioritize community wellbeing by focusing on broader environmental impacts than greenhouse gas emissions alone, such as air and water pollution.

NEXT STEPS FOR MINNESOTA

Based on the findings of this work, contextualized in the greater landscape of current state activities, our current sociopolitical reality, technology readiness considerations, and other relevant factors, Minnesota should:

- Reflect these findings in the implementation of the 'industrial innovation' thread of the state's new Climate-Smart Food Systems grant program.
- Explore policy options to encourage grid-focused strategies (like load-shifting and use of curtailed generation) and reduce the spark gap, as well as other stackable incentive options (like tax credits) — all to help reduce the additional operating costs (OPEX) currently associated with industrial electrification.
- Seek opportunities to better align incentive programs with infrastructure readiness and regional economic development efforts, with a particular emphasis on stronger coordination at the regional level.
- Continue to clarify the roles of state agencies and pathways for engaging industry in industrial decarbonization efforts, while striving for greater coordination across program areas — especially programs related to utilities, transportation infrastructure, site development, incentives, and workforce development, all of which impact the health and vitality of Minnesota's communities.
- Develop and implement a comprehensive, cross-sector education and outreach strategy related to market-ready industrial electrification technologies, to more rapidly advance clean technology adoption.
- Explore the creation of CO_2 utilization industrial hubs to spur developments related to carbon capture, utilization, and sequestration.
- Articulate related areas where additional, deeper insights may be needed to support the state in progress toward its goals, especially where significant interdependencies across economic sectors may exist.