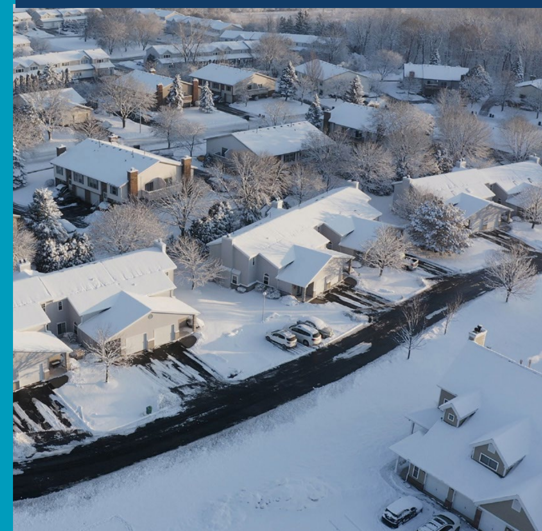
REPORT TO THE LEGISLATURE

JANUARY 2025



Greenhouse gas emissions in Minnesota 2005-2022

Biennial inventory report tracking the state's greenhouse gas emissions contributing to climate change.

MINNESOTA

Pollution Control Agency
Department of Commerce

Greenhouse gas emissions in Minnesota 2005-2022:

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Report to Legislature, January 2025. Jointly submitted by the Pollution Control Agency and the Department of Commerce

Legislative charge

Minn. Stat. § 216H.02 Greenhouse gas emissions control.

Subd. 1. Greenhouse gas emissions-reduction goal. It is the goal of the state to reduce statewide greenhouse gas emissions across all sectors producing those emissions to a level at least 15% below 2005 levels by 2015, to a level at least 30% below 2005 levels by 2025, and to a level at least 80% below 2005 levels by 2050. The levels shall be reviewed based on the climate change action plan study.

Minn. Stat. § 216H.07 Emissions-reduction attainment; policy development process.

Subd. 3. Biennial report. (a) By January 15 of each odd-numbered year, the commissioners of commerce and the Pollution Control Agency shall jointly report to the chairs and ranking minority members of the legislative committees with primary policy jurisdiction over energy and environmental issues the most recent and best available evidence identifying the level of reductions already achieved and the level necessary to achieve the reductions timetable in section 216H.02. (b) The report must be in easily understood nontechnical terms.

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Introduction

More information about climate trends and the impacts of climate change is available from the **Department of Natural Resources** www.dnr.state.mn.us/climate

The reality of climate change continues to have a profound impact on the lives of Minnesotans. The extreme conditions Minnesota experienced in 2023 and 2024, including an exceptionally warm winter and major spring rains, were consistent with ongoing climate change trends. The changes in our climate are being felt across Minnesota's communities, economy, cultures, and ecosystems.

Heavy rains are now more common in Minnesota and more intense than at any time on record. Long-term observation sites have seen dramatic increases in 1-inch rains, 3-inch rains, and the size of the heaviest rainfall of the year. Frequent and intense storms are damaging homes, businesses, infrastructure, farms, and ecosystems.

Minnesota's winters are also becoming shorter and milder. This climate trend is called "cold weather warming," and it means that the average temperature of winter months is increasing faster than the average temperature of summer months. Over the last 50 years, Minnesota's winter has warmed an incredible 13 times faster than summer. Warmer winters allow some pests like ticks and certain invasive species to survive and multiply. Over those 50 years, Minnesota lakes have also lost an average of 10 to 14 days of ice, affecting lake and fish health, outdoor recreation opportunities, and business owners.

Simply put, Minnesota is getting warmer and wetter. Changes to our climate, such as heavier and more frequent rainfall events and warmer winters, are caused by human activities that release greenhouse gases (GHGs). Our changing climate has economic and environmental impacts for Minnesotans. Over the past decade, for instance, our state has been experiencing a much higher rate of natural disasters, with a higher number of individual storms that cause more than $1 billion in damage.

This report summarizes what we know about GHG emissions in Minnesota, including the major sources and trends over time. Tracking GHG emissions and identifying their sources are two important ways that state government can help Minnesotans understand how our actions contribute to our changing climate and how we can curb our climate pollution.

To guide our response to climate change, the State of Minnesota has developed a Climate Action Framework (mn.gov/framework). The Framework identifies immediate, near-term actions to reduce climate pollution and prepare Minnesota communities for the impacts of climate change. The Framework is currently being updated to include a comprehensive set of actions that help us achieve those goals. Analyzing Minnesota's emissions through this inventory allows us to track progress on the Framework goals and focus on actions with maximum impact to address climate change.

This inventory documents Minnesota's GHG emissions from 2005 through 2022 and shows the impact of actions taken by individuals, organizations, and governments across Minnesota to reduce climate pollution. The COVID-19 pandemic changed how Minnesotans lived and worked in 2020. As Minnesotans returned to regular activities, emissions that dropped steeply in 2020 rebounded, reflecting a similar trend nationally. Despite the rebound, emissions from sectors like transportation, electricity generation, industrial, agriculture, and waste remain below 2019 levels, indicating lasting changes toward increased energy efficiency and a low-carbon economy.

Billions of dollars in state and federal climate investments made between 2022 and 2024 will reduce GHG emissions in Minnesota. The impacts of these investments cannot yet be seen in the data of this report, and the momentum of those investments will be felt for decades to come. While there is much work ahead to meet our climate goals, this inventory demonstrates that collaborative action and smart policy-making work.

Evaluating greenhouse gas emissions

Greenhouse gases (GHGs) warm the planet's atmosphere and surface. Human activity increases the amount of GHGs in the atmosphere, leading to changes in Earth's climate. The Minnesota Greenhouse Gas Emissions Inventory accounts for the six GHGs originally covered by the Kyoto Protocol of the United Nations Framework Convention on Climate Change: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), sulfur hexafluoride (SF_6), and two types of compounds called hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

GHGs come from a variety of sources in our state:

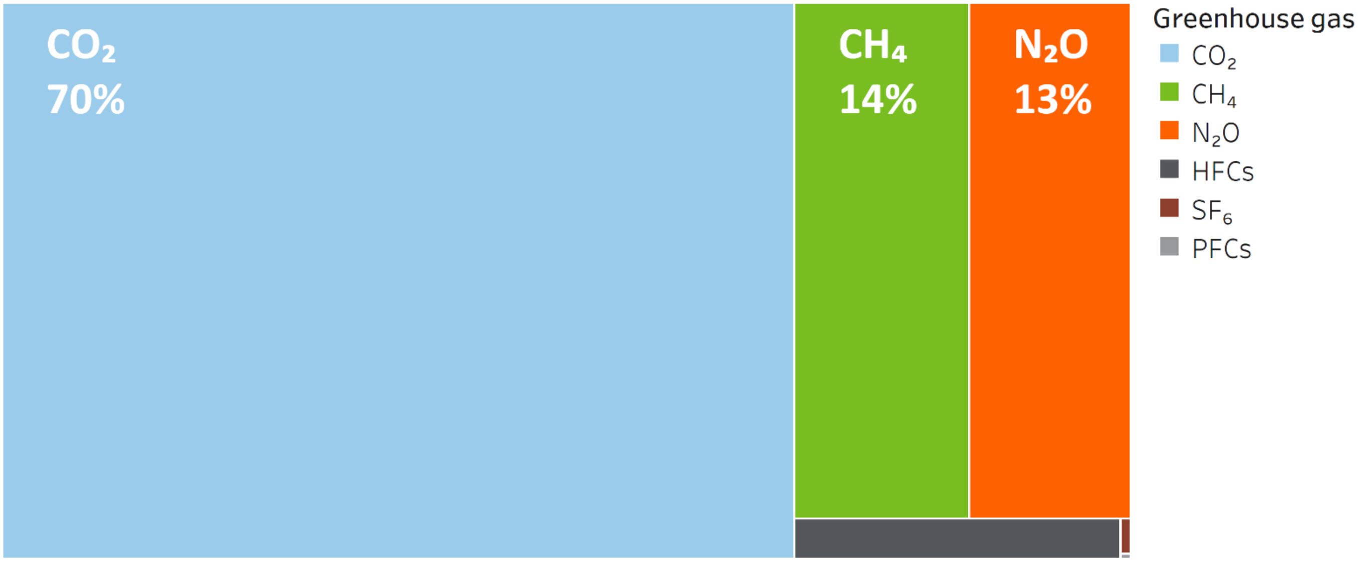
- Fossil fuel combustion is responsible for most carbon dioxide emissions in Minnesota and the United States. The majority of fossil fuels used today are burned to generate electricity, fuel vehicles, and provide heat for homes and industrial processes, all of which are significant sources of emissions.
- Animal agriculture is responsible for most methane emissions in Minnesota. Materials decomposing in landfills and in bodies of water also emit methane.
- Agricultural nutrient management practices, including fertilizer application and subsequent mineralization, cause over 50% of nitrous oxide emissions.
- Most hydrofluorocarbon emissions are from refrigerants used in vehicle and building air conditioners.
- Perfluorocarbons and sulfur hexafluoride account for a small portion of GHG emissions and are released from technical applications like semiconductor manufacturing and electricity transmission.

Carbon dioxide is the primary GHG emitted by human activities, followed by methane and nitrous oxide. Other GHGs are emitted in smaller amounts, but trap heat more effectively than carbon dioxide, and some stay in our atmosphere for a very long time, contributing more to climate change.

Global warming potential (GWP) is a relative measure of how much heat a GHG traps in the atmosphere. To compare different emissions and pollutants, we use the effect of carbon dioxide on our climate as a standard reference. In this report, emissions are reported as metric tons of carbon dioxide-equivalent (CO_2-e), meaning emissions are stated in relative terms that reflect their impact on global temperatures.

Minnesota's net GHG emissions in 2022 by gas

Emissions are expressed as percent of total CO_2-equivalent and includes carbon sequestration.



Greenhouse gases, their 100-year global warming potentials, and their persistence in Earth's atmosphere.

Greenhouse gas	Global warming potential (GWP)	Persistence in Earth's atmosphere
Carbon dioxide (CO_2)	1	Variable, up to thousands of years
Nitrous oxide (N_2O)	265	121 years
Methane (CH_4)	28	12 years
Sulfur hexafluoride (SF_6)	23,500	3,200 years
Hydrofluorocarbons (HFCs)	Up to 12,400	Up to 242 years
Perfluorocarbons (PFCs)	Up to 11,100	2,600 to 50,000 years

Source: IPCC Fifth Assessment Report, Working Group 1 Chapter 8

Tracking statewide emission reduction progress

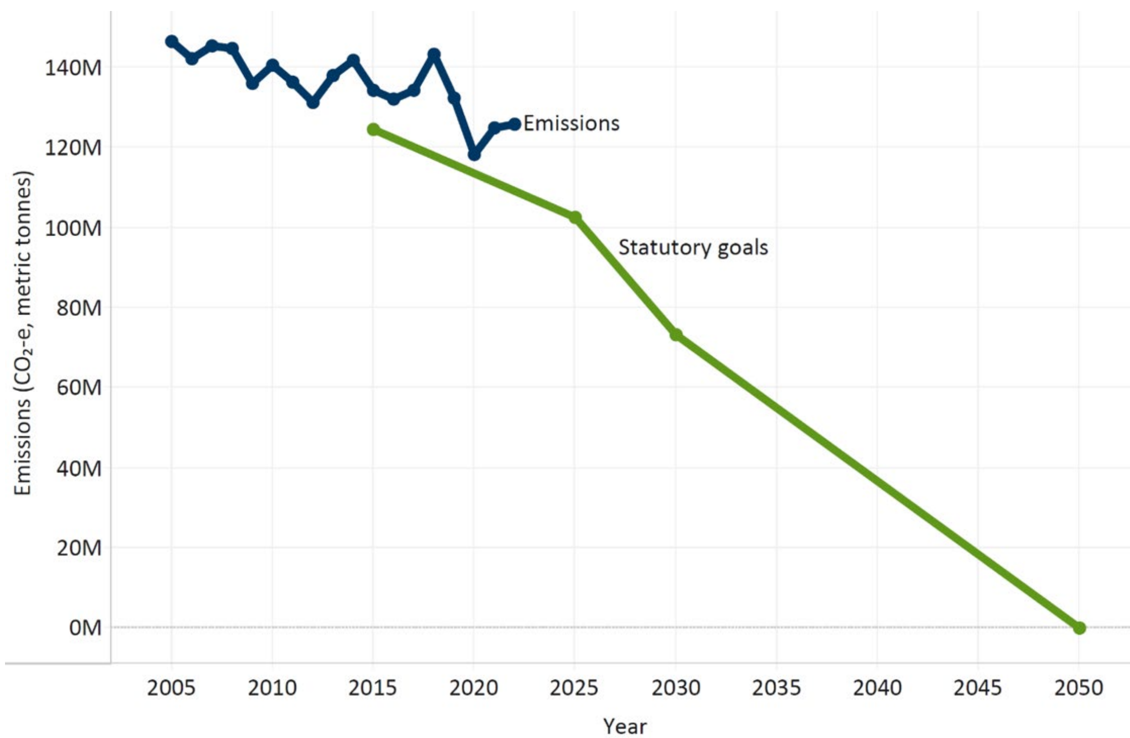
In 2007, the Minnesota Legislature passed the Next Generation Energy Act, setting our state's first science-based goals to reduce our GHG emissions in the state compared to our emissions in 2005.[1] Since then, Minnesota has reassessed and updated our state's GHG emissions goals in the Climate Action Framework, and subsequently in statute, based on current scientific evidence. Now, Minnesota's GHG emissions reduction goals are to reduce emissions by 15% by 2015, 30% by 2025, 50% by 2030 (from a 2005 baseline), and to reach net-zero by 2050.

Minnesota did not reach the statutory goal of reducing emissions by 15% by 2015. Between 2005 and 2022, Minnesota's GHG emissions fell by 14%, making it difficult to achieve our goals if we maintain current trends. Changes in fuels used for electricity generation have resulted in significant emission reductions from the electricity generation sector and are the most significant contributor to statewide emission reductions between 2005 and 2022.

Between 2020 and 2022, emissions rose due to economic activity resuming after the height of the COVID-19 pandemic, reflecting increased energy use and transportation demands. The emission increases in 2021 and 2022 are consistent with nationwide emission increases calculated by the US EPA. The good news is that 2022 emissions reflect a continuation of pre-pandemic long-term downward trends.

Recent emission reductions show that action can get us on track to achieve our statutory goals and reach net-zero emissions by 2050. The rate of reduction since 2005 shows that much work remains to achieve these ambitious and necessary goals.

Minnesota's greenhouse gas emissions and statutory goals

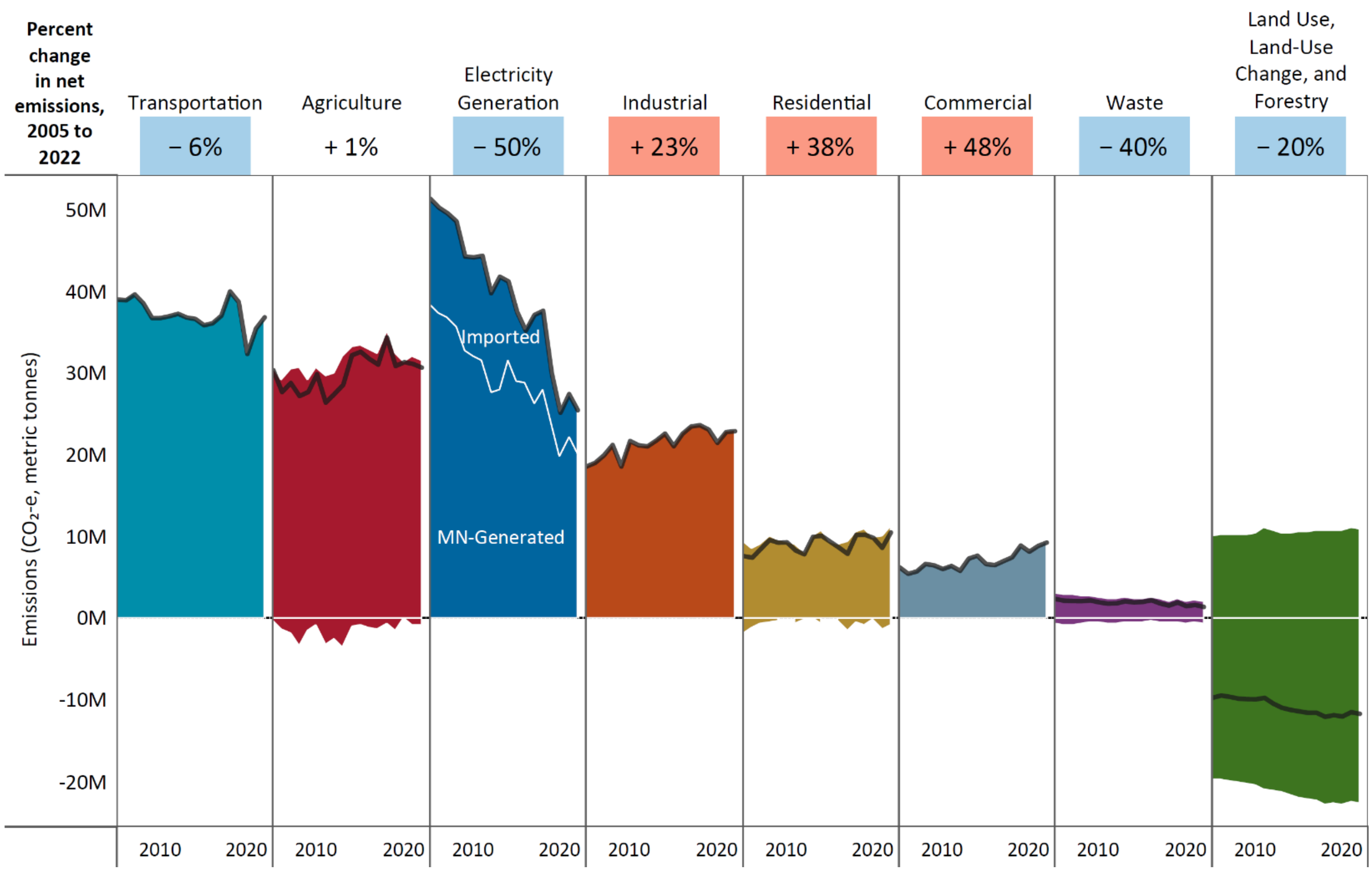


[1] Data revisions and changes in methodology can cause the baseline to change, but continuity is provided when making relative year-to-year emissions comparisons.

Sectoral greenhouse gas emissions

This section reports annual GHG emissions and terrestrial sequestration of carbon from 2005 through 2022 for the eight economic sectors in Minnesota: transportation; agriculture; electricity generation; industrial; residential; commercial; waste; and land use, land-use change, and forestry. The "agriculture" and "land use, land-use change, and forestry"sectors have replaced the "agriculture, forestry, and other land use" sector from previous inventories to allow for better alignment with the EPA's national GHG quantification approach and to provide greater detail than in previous reports. Interactive data visualizations are available at https://www.pca.state.mn.us/air-water-land-climate/climate-change-trends-and-data.

Minnesota's GHG emissions across economic sectors from 2005 to 2022, ranked by net 2022 emissions.

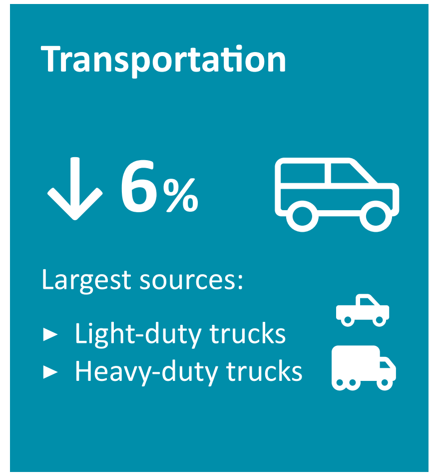


Dark lines represent the net emissions for each sector (gross emissions minus sequestration). Carbon sequestration is shown as negative emissions, present in the agriculture; residential; waste; and land use, land use change, and forestry sectors. The electricity generation sector differentiates emissions from electricity generated in Minnesota versus those from imported electricity. The percent change from 2005 to 2022 is shown above the chart by sector. Blue and red indicate reductions and increases in emissions, respectively.

Transportation

Minnesota's largest source of GHG emissions is the transportation sector, accounting for about 29% of the state's total emissions. Since the baseline year of 2005, total GHG emissions from transportation have decreased by about 6%. While emissions from aviation and light-duty trucks rebounded after the height of the pandemic in 2020, they remain below pre-pandemic levels. In contrast, emissions from heavy-duty trucks are now higher than pre-pandemic levels.

GHG emissions 2005-2022



Emissions sources in the transportation sector include:

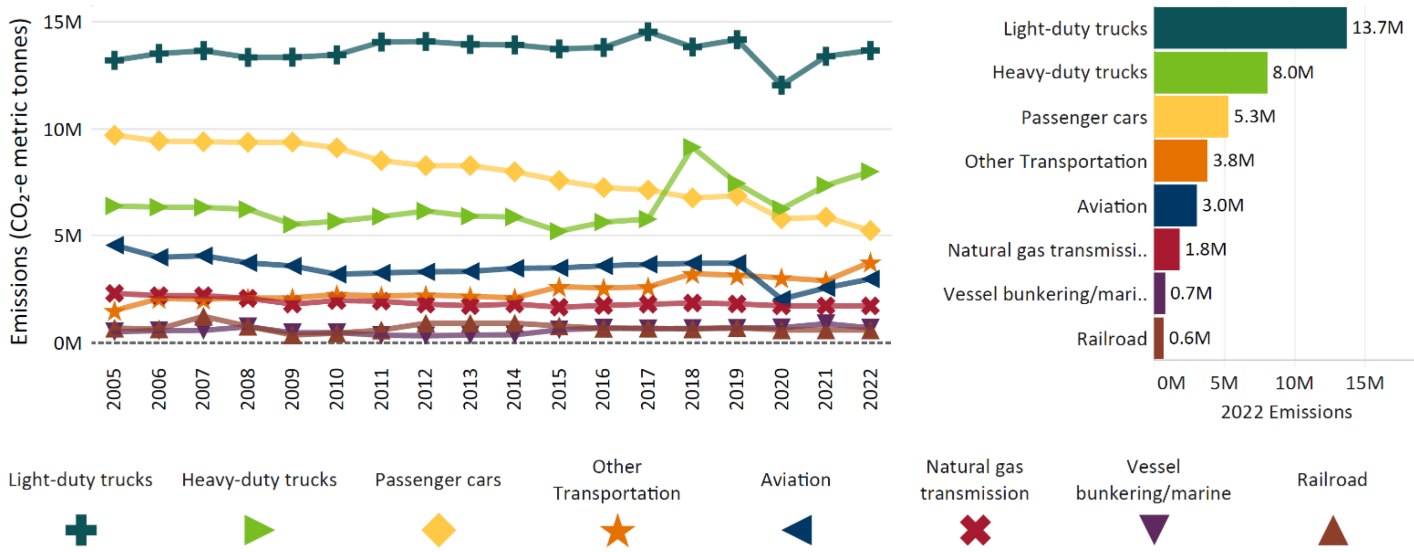
- on-road vehicles, including passenger vehicles, light-duty trucks, medium- to heavy-duty trucks, RVs, buses, and motorcycles
- airplanes and other aviation equipment
- trains
- marine vehicles
- off-highway gasoline vehicles and equipment, including military vehicles, ATVs, and snowmobiles
- vehicle air conditioning units
- natural gas transmission pipelines

Our personal choices have a significant impact on emissions, especially when it comes to how we move around. Passenger vehicles account for about 14% of emissions in this sector, while light-duty trucks (including pickup trucks, minivans, and SUVs) make up about 37%. Medium- to heavy-duty trucks (including delivery vans, large commercial vehicles, and tractor-trailers) produce about 22% of emissions in this sector.

While stronger federal vehicle emissions standards have helped reduce GHG emissions overall, long-term trends in consumer preferences for larger vehicles and the increasing number of miles driven (except during the pandemic) have slowed potential progress in reducing emissions. Although the adoption of electric vehicles is growing, the trend toward larger, higher-emitting vehicles challenges the pace at which electric vehicles and vehicle emissions standards can reduce emissions.

Continued investment in cleaner vehicles and expanding transportation options, such as public transit, biking, walking, and rolling, is essential to achieve further emission reductions in this sector. Also important to the reduction of transportation sector emissions are changes in land use development patterns that promote denser development and housing near amenities and transportation options. This type of development makes the use of transportation options other than cars more convenient and encourages shorter trips.

Transportation sector GHG emissions



Emissions by subsector from 2005 to 2022 (left) and only 2022 (right). "Other Transportation" includes bus, motorcycle, RV, mobile air conditioning, and miliary/other off-highway emissions.

Agriculture

Minnesota's second-largest source of GHG emissions is the agriculture sector, accounting for about 25% of the state's net emissions. Since 2005, net GHG emissions from agriculture are essentially unchanged.

In previous versions of this report, agriculture, forests, and other land uses were grouped into a single sector. Separating agriculture into its own sector results in better alignment with the US Environmental Protection Agency's (EPA) national approach to GHG quantification, allows more detail, and clarifies that sequestration in natural landscapes offsets emissions from all sectors, not only agriculture.

Emission sources and sequestration in the agriculture sector include:

- livestock digestion
- manure storage and land application
- fertilizer use
- methane emissions avoided due to the anaerobic digestion of manure (a process that captures methane that would otherwise be emitted to the atmosphere)
- emissions and sequestration of carbon within cropland soils*

*Due to the difficulty of differentiating grazed from ungrazed grasslands, carbon stock changes within all grasslands are included in the land use, land-use change, and forestry sector

Within agriculture, GHG fluxes (i.e., emissions and sequestration) are largely driven by plants and the microbes in soils, manure storage areas, and cattle digestive systems. It is not possible to directly measure these fluxes across the state, so we use scientific models to estimate them. Models of GHG fluxes within agricultural systems continue to become more sophisticated, useful, and accurate. While coarse data on management decisions (e.g., aerial imagery, grower surveys, and product sales records) are sources of uncertainty in these estimates, models provide helpful estimates of the impacts of crop and livestock management practices, environmental conditions, and other variables on GHG emissions and sequestration.

Agricultural practices in Minnesota are responsible for 96% of the state's nitrous oxide emissions and 44% of the state's methane emissions. The largest sources of nitrous oxide are the land application of synthetic fertilizers and manure, and the subsequent mineralization and runoff of that nitrogen. Methane emissions are caused by cattle digestion and manure storage practices.

The largest source of carbon dioxide from the agricultural sector is the use of drained organic soils for crop production. Compared to other states, Minnesota is uniquely rich in organic soils, which form within peatlands (a class of wetlands that includes bogs) over thousands of years and have high soil carbon content. When left untouched, peatlands are massive stores of carbon. However, during the 20th century in Minnesota, there was significant drainage and tillage of peatlands for crop production. Lowering the water table exposes these large carbon stocks to the air,

GHG emissions 2005-2022

Agriculture

↑ 1%

Largest sources:

- Fertilizer
- Animal agriculture

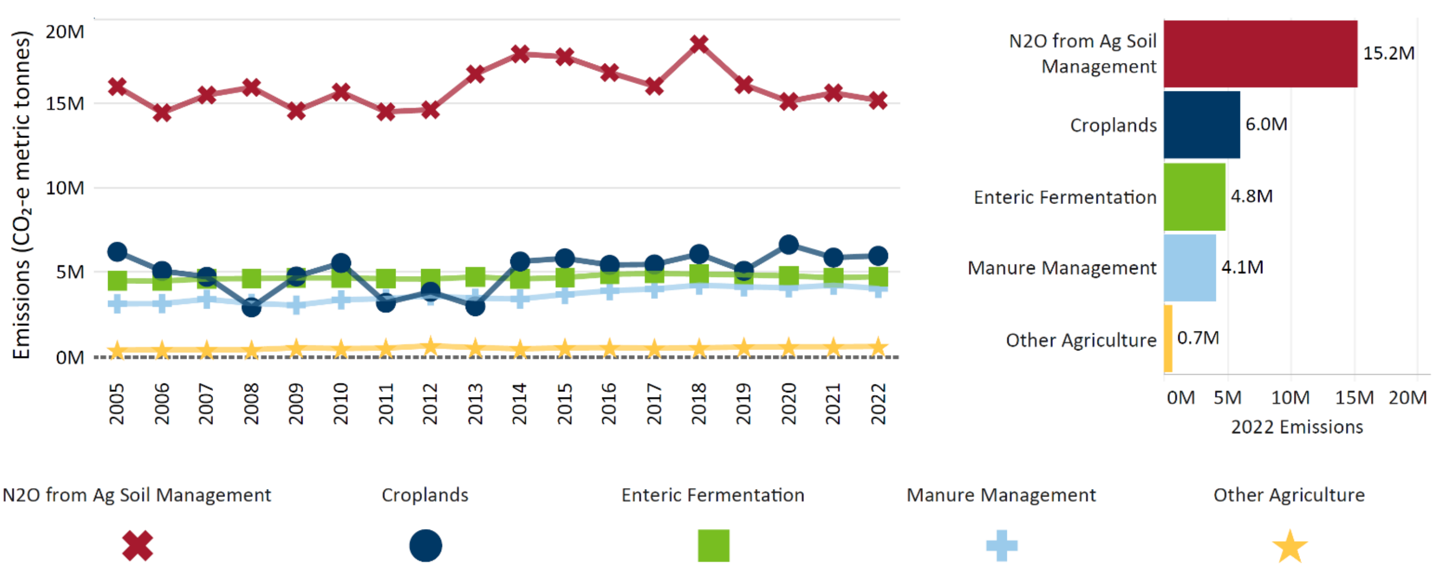
Minnesota agriculture summary

- Minnesota has over 65,000 farms operating on 21.5 million acres of cropland, 3% of which are irrigated.
- Minnesota has 650 organic farms on 164,000 acres.
- Minnesota ranks in the top 10 for over 20 agricultural products, including #1 in turkeys and sugar beets, #2 in hogs, #3 in soybeans, and #4 in corn.
- Minnesota has approximately 25,000 farms with animals, including 8.9 million hogs, 2.1 million cattle and calves, 14.9 million turkeys, 14.5 million laying hens, and 7.8 million broiler chickens.

Sources: US Department of Agriculture, Minnesota Department of Agriculture which which allows them to decompose and release carbon dioxide for several decades unless they are rewetted. Regardless of the soil health practices employed, drained organic soils lose more carbon than they can gain. In contrast, there are approximately 20 million acres of croplands on mineral soils (i.e., non-peat soils) in Minnesota, which, on average, are sequestering soil carbon. The carbon sequestered by Minnesota's approximately 20 million acres of croplands on mineral soils is outweighed by the carbon dioxide emissions from the roughly 405,000 acres of croplands on drained organic soils. This area, approximately equivalent to the size of Hennepin County, represents a significant source of greenhouse gas emissions. The most effective way to reduce these emissions is to restore drained organic soils where practicable to their natural state as peatlands. In addition to curbing emissions, restored peatlands provide critical habitat for unique native species and help protect downstream water quality. Efforts to rewet peatlands are already underway on private, public, and tribal lands, with additional public funding for this work becoming available soon.

While net emissions from Minnesota agriculture have not changed significantly since 2005, improved efficiency and more sustainable agricultural management practices have resulted in our farms producing more food, biofuel, and fiber than ever before. Agriculture is the second-highest emitting sector in the state, as emissions from electricity generation have declined substantially since 2005. Significant opportunities remain for emission reductions and additional carbon sequestration while maintaining agricultural productivity. Investments are being made at the state and federal levels to support sustainable agricultural practices and on-farm energy and efficiency projects, such as the recent EPA-awarded $200 million grant to cut climate pollution from our state's food systems through the federal Climate Pollution Reduction Grants program.

Agriculture sector GHG emissions



Emissions by subsector from 2005 to 2022 (left) and only 2022 (right). "Other Agriculture" includes field burning of agricultural residues, CO_2 from carbon containing fertilizers, and rice cultivation.

Reducing emissions and sequestering carbon through crop agriculture

Within crop agriculture, nitrous oxide emissions can be reduced through the efficient use of nitrogen fertilizers. Successful nitrogen use results from applying the right source of nitrogen at the right rate, time, and place to maximize plant uptake and minimize losses to the environment. To enhance nitrogen efficiency, timing strategies can be complemented with the use of nitrification inhibitors, urease inhibitors, and other controlled-release fertilizers. These products extend the duration of nitrogen availability to growing crops, reducing nitrogen losses and GHG emissions by about 21 metric tons of CO_2-equivalent per 100 acres per year. If applied to 10 million acres per year, these products could reduce agricultural soil emissions by about 2 million metric tons of CO_2-equivalent annually, equivalent to removing about 500,000 gasoline-powered passenger vehicles from the road for one year.

Actions aimed at improving soil health and water quality can also boost carbon sequestration in plants, soil, and aquatic ecosystems. Examples include planting perennial field borders; incorporating trees and shrubs; retiring marginal lands into conservation easements; and the long-term adoption of reduced tillage, perennials in crop rotations, and cover crops. Cover cropping has been shown to prevent soil erosion, reduce nutrient losses, suppress weeds, and accumulate organic carbon in soil. According to United States Department of Agriculture surveys, from 2012 to 2022, the number of acres in Minnesota with cover crops increased from about 408,000 to 760,000. Although results vary, a typical implementation of cover crops in Minnesota results in a net reduction of about 15 metric tons of CO_2-equivalent per 100 acres per year. Therefore, in 2022, cover crops likely reduced net emissions by over 113,000 metric tons of CO2-equivalent, comparable to removing about 26,000 gasoline-powered passenger vehicles from the road for one year. There is potential to significantly increase cover cropping in Minnesota. If cover cropping was implemented and maintained on about 13 million of the 20 million acres of crop agriculture in Minnesota, this could also reduce net GHG emissions from agriculture by up to 2 million metric tons of CO_2-equivalent per year, comparable to removing about 500,000 gasoline-powered passenger vehicles from the road for one year.

Reducing emissions from animal agriculture

Within animal agriculture, methane is the dominant GHG and is produced through cattle digestion and manure storage. An important long-term action to limit methane from cattle digestion (or “enteric fermentation”) is to incorporate relevant genetics into herds to increase feed conversion efficiency, reduce cull rates, and influence other aspects of digestion, including the rumen microbial community. Increasing feed digestibility also helps, though Minnesota cattle already feed on high-quality forage compared to much of the globe. A variety of feed additives can also reduce enteric methane production by up to 30% during certain life stages, but research is ongoing and cost is currently a barrier to adoption.

Another source of avoidable methane emissions is manure stored as a liquid under anaerobic conditions, such as in open lagoons. Where manure is stored as a liquid, managed anaerobic digestion systems can capture the resulting methane and sell or use it as a replacement for fossil fuels. Anaerobic digestion systems work better for some species and types of manure infrastructure than others. They are most economical at large farms or in cooperative models (with manure from multiple farms combined in a single system), where market incentives promote renewable fuels (e.g., via low carbon fuel standards), and where other materials can be co-digested. Alternatively, managing manure as a solid and grazing livestock in pastures generates little methane because the manure is broken down by aerobic microbes. Other methane-reducing manure management interventions include composting and avoiding land application during wet field conditions.

Electricity generation

Electricity generation is the third-largest source of GHG emissions in Minnesota, accounting for about 20% of the state's net emissions. Burning fossil fuels, especially coal, to generate electricity for Minnesotans, whether produced in-state or out-of-state, is this sector's primary source of GHG emissions. Other smaller sources include:

- methane from coal storage
- carbon dioxide from scrubbing other air pollutants from facility emissions
- sulfur hexafluoride from electricity transmission and distribution

Since 2005, emissions from the electricity generation sector have declined by 50%. The significant decrease is mainly a result of the transition away from coal toward renewable energy sources to generate electricity. Renewable sources produced 32% of Minnesota-generated electricity in 2022.

Previously, Minnesota's electricity generation sector was the largest source of GHG emissions, and the greatest emissions reductions have been made here.

In Minnesota, we use more electricity than we generate inside our borders. As required by the statute, this report measures total GHG emissions from electricity generation, including emissions from electricity generated at facilities within the state, and provides an estimate of the electricity used here in Minnesota that is generated outside of our state borders (imported). Emissions from both Minnesota-generated and imported electricity generation have decreased since 2005.

Emissions per kilowatt-hour from electricity imported from the regional electrical grid are higher than in-state generation because some neighboring states haven't reduced their emissions as much as Minnesota. The amount of electricity imported into Minnesota continues to decrease as in-state generation increases, reducing the amount of estimated imported electricity and associated GHG emissions.

GHG emissions 2005-2022

Electricity generation

↓ 50%

Largest sources:

- ► Coal
- ► Natural gas

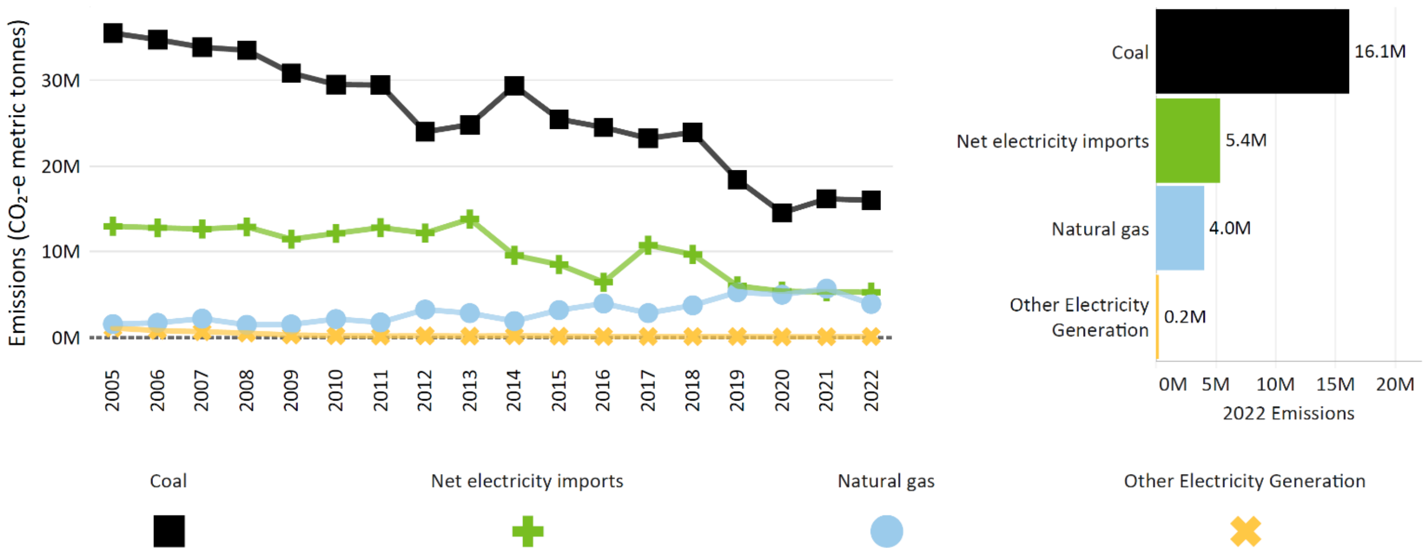
Percentage of Minnesota electricity utility generation (resource mix), 2022

Coal	27.4%
Wind	25.6%
Nuclear	24.9%
Gas	14.8%
Solar	3.2%
Biomass	2.0%
Hydroelectric	1.6%
Other fossil	0.4%

Source: eGRID

GHG emission reductions will continue in the electricity generation sector as a result of planned closures of coal-fired power plants in Minnesota, as indicated in the table below. In addition, in 2023, the Minnesota Legislature adopted a new Clean Electricity Standard that requires electric utilities to provide net-zero, or 100% carbon-free, electricity by 2040. Carbon-free electricity is important to help the state reduce emissions through electrification of other uses of fossil fuel combustion, such as vehicles and building heating. Continued focus on thoughtful transition to support an electric grid that is reliable, safe, affordable, and increasingly clean is vital to achieving economy-wide GHG emission reduction goals.

Electricity generation sector GHG emissions



Emissions by subsector from 2005 to 2022 (left) and only 2022 (right). "Other Electricity Generation" includes oil, SF6 emissions related to transmission, non-CO2 emissions from biofuels, coal storage, and flue-gas desulfurization.

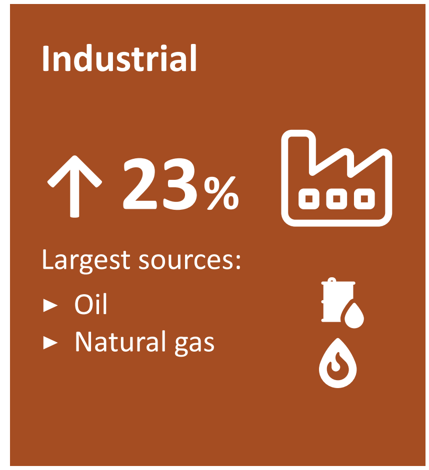
Utility-owned coal-fired electricity generating units in Minnesota (as of December 2024)

Facility	Size (MW)	Status
Hibbing Public Utilities Commission		
Hibbing 3	10	Standby/backup: available for service but not normally used
Hibbing 5	20	Standby/backup: available for service but not normally used
Hibbing 6	6	Standby/backup: available for service but not normally used
Minnesota Power		
Boswell Unit 3	365	Operating: Cease coal-fired operations by year-end 2029
Boswell Unit 4	558	Operating: Proposed to cease coal-fired operations by 2035
Hibbard Energy Center Unit 3	30	Operating
Hibbard Energy Center Unit 4	32	Operating
Xcel Energy		
Sherburne County 1	680	Operating: full retirement by 2026
Sherburne County 3	876	Operating: full retirement by 2030
Allen S King	511	Operating: full retirement by 2028

Industrial

The industrial sector is the fourth-largest source of GHG emissions in Minnesota, accounting for about 18% of the state's net emissions. The industrial sector includes direct emissions from industrial facility processes and fossil fuel combustions. Emissions from electricity use in the industrial sector are accounted for under the electricity generation sector. Since 2005, emissions have increased in this sector by 23%.

GHG emissions 2005-2022



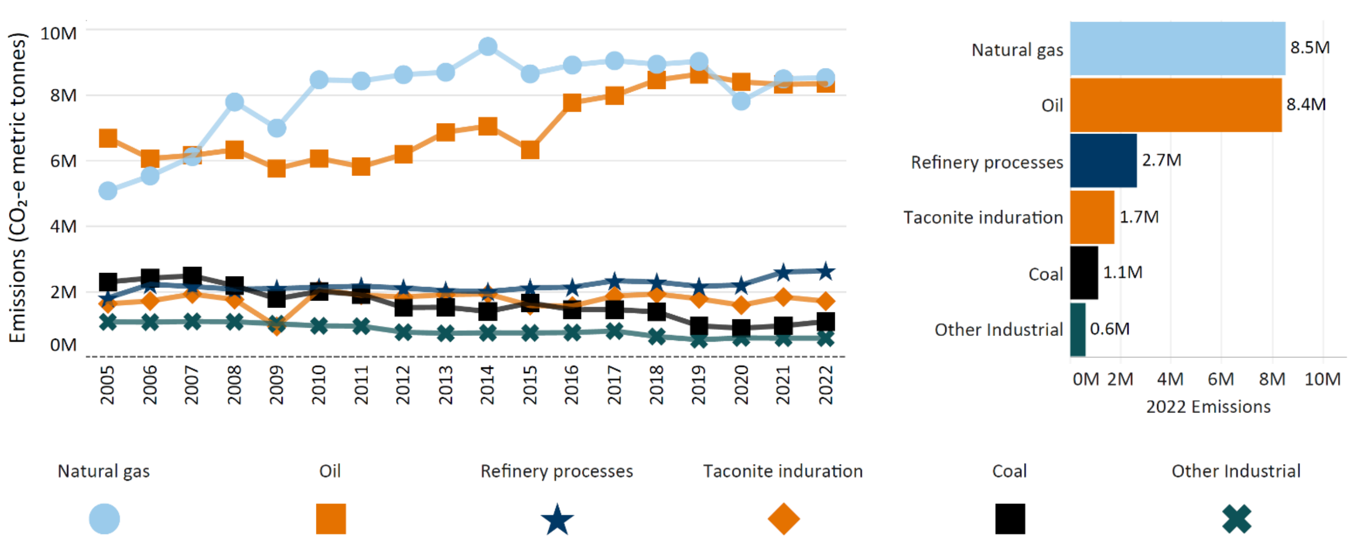
Emissions sources in the industrial sector include:

- fossil-fuel combustion
- petroleum refining
- taconite processing
- lead recycling
- industrial wastewater treatment
- solvent use
- manufacturing of steel, glass, and semiconductors

While total GHG emissions from the industrial sector have declined since a peak in 2018, they are still higher than the 2005 baseline. The trends in emissions from specific fuels used are more varied. Industrial emissions from coal have declined since the 2005 baseline, while emissions from natural gas and oil (e.g. fuel oil, waste oils, propane, etc.) have increased relative to the 2005 baseline.

Changes are needed in industrial activities to meet statutory goals. Emissions from the industrial sector are closely tied to economic activity, but reductions in emissions do not require that our growth and productivity slow or decline. The Climate Action Framework includes a focus on transforming Minnesota's economy through innovation. With federal funding and technical assistance, industrial businesses can be national leaders in changing operations to increase efficiency and reduce fossil fuel use through electrification or the use of other greener fuels. The state is embarking on a study of the specific types of industrial and manufacturing processes that generate GHG emissions in the state. This study and the facility GHG emission data the MPCA receives will inform the development of a strategy to reduce emissions in the industrial sector and Minnesota's Climate Action Framework.

Industrial sector GHG emissions



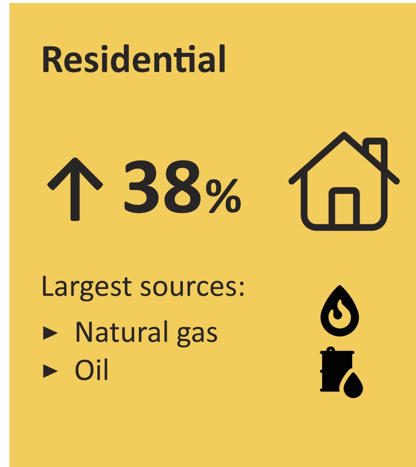
Emissions by subsector from 2005 to 2022 (left) and only 2022 (right). “Other Industrial” includes VOCs and toxics release, industrial wastewater treatment, semiconductor manufacturing, non-CO_2 emissions from biofuels, industrial solvent release, oil refining, and several sources related to specific manufacturing processes.

Residential

The residential sector is the fifth-largest source of GHG emissions in Minnesota, accounting for about 8% of the state's net emissions. The residential sector includes direct combustion of fossil fuels for heating and appliances, emissions from consumer products, and carbon stored in structural materials.

Since 2005, net emissions from the residential sector have increased by 38%. The largest residential emissions source is natural gas used for home heating and appliances. Emissions from residential natural gas and oil (e.g. propane and fuel oil) use have exceeded pre-pandemic levels. Annual variation in weather influences heating demand, affecting the GHG emissions in this sector. Improving home energy efficiency through weatherization and switching to electric technologies like heat pumps and appliances can significantly reduce residential emissions.

GHG emissions 2005-2022



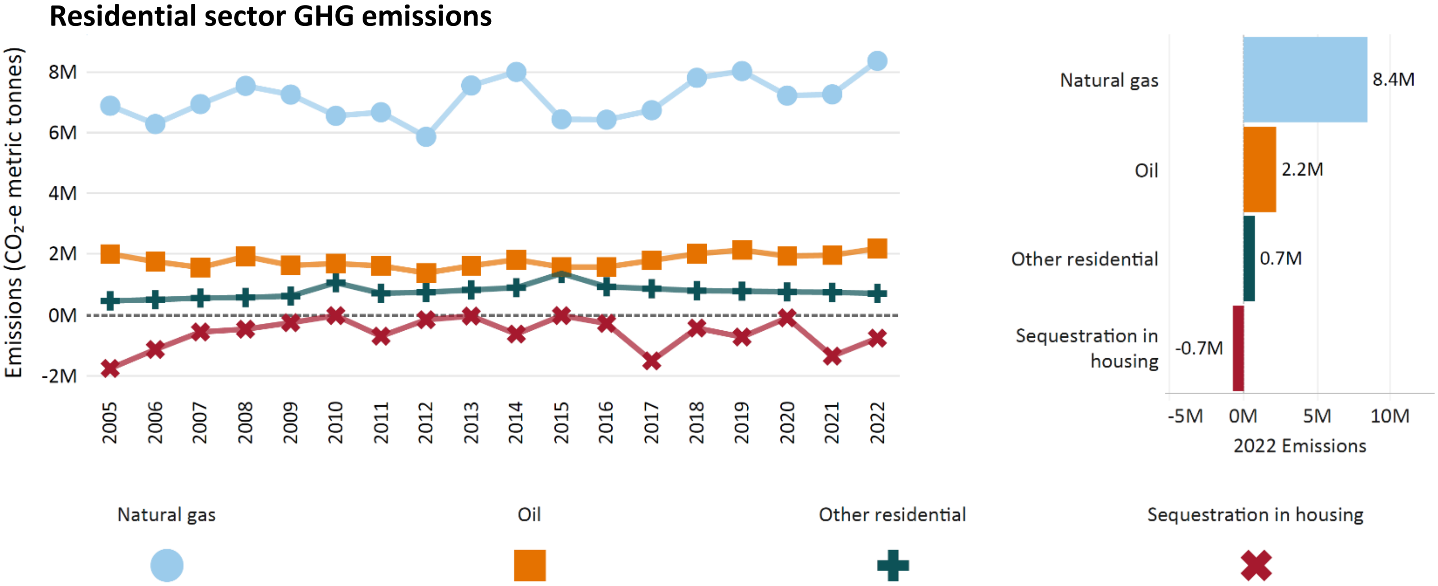
It's important to note that emissions from electricity use in residences are not included in the residential sector; they are accounted for under the electricity generation sector.

Emissions sources in the residential sector include:

- fossil-fuel combustion for heating and in-home appliances, such as furnaces, water heaters and clothes dryers
- home-product use
- food additives
- refrigerant leakage from air conditioners and refrigerators

This category includes carbon sequestered in wood construction materials. Over the lifetime of a house, carbon is stored and effectively removed from the atmosphere for decades, which offsets some emissions.

Residential sector GHG emissions



Emissions by subsector from 2005 to 2022 (left) and only 2022 (right). "Other Residential" includes non-CO_2 emissions from wood burning, aerosols, soaps/detergents, HFC emissions from air conditioning and refrigeration, carbon loss from wood in housing, and food additives.

Commercial

The commercial sector is the sixth-largest source of greenhouse gas emissions in Minnesota, accounting for about 7% of the state's net emissions. Emissions from the commercial sector are predominantly derived from fuel combustion to provide buildings with heating, in addition to refrigerant leakage from air conditioning and refrigeration equipment. This sector includes buildings that house businesses, institutions, and government facilities. Business buildings include retail stores, offices, and food service establishments. Institutional buildings include schools, corrections facilities, and hospitals. As with the residential sector, emissions from electricity use in the commercial sector are not included in this inventory sector; they are accounted for under the electricity generation sector. Since 2005, emissions from the commercial sector increased by 48%.

GHG emissions 2005-2022

Commercial

↑ 48%

Largest sources:

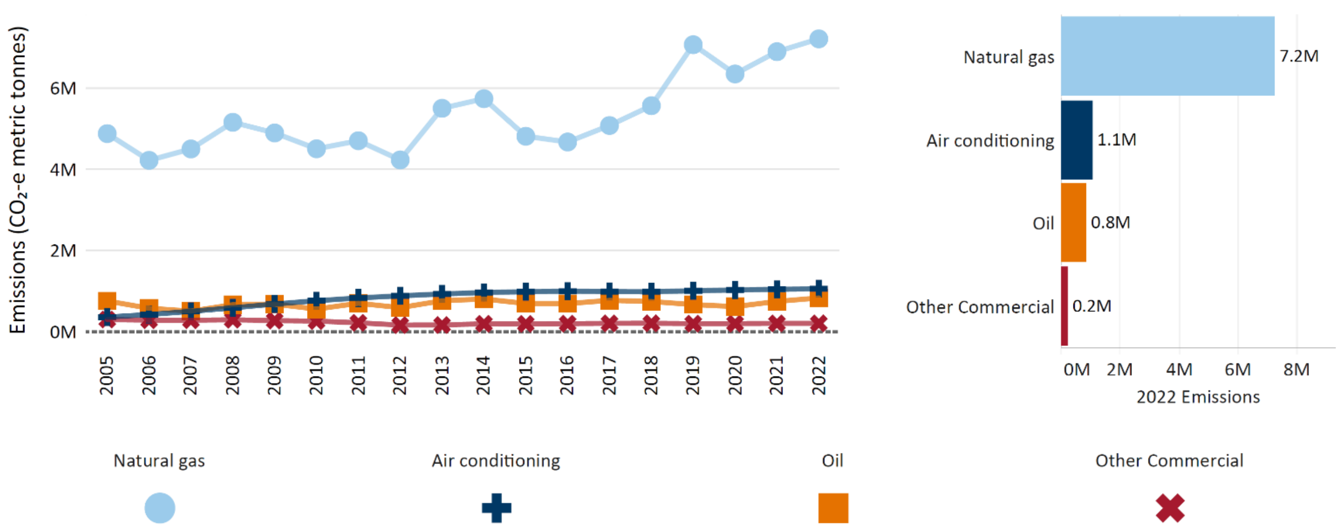
- Natural gas
- Air conditioning, refrigeration

Emissions sources in this sector include:

- fossil-fuel combustion
- air conditioning
- solvent use
- medical N_2O emissions

The increase in emissions from the commercial sector is predominantly driven by the increase in combustion of natural gas. Natural gas emissions in this sector have increased by nearly 50% since 2005, with 2022 being the highest year on record. Emissions from air conditioning and refrigeration chemical leakage have continued to increase, though their growth has slowed since 2015. Investments in energy efficiency, electrification, and building efficiency will help commercial and institutional sources reduce fossil fuel use and energy consumption. The scheduled phase-down of high global warming potential hydrofluorocarbons refrigerants will also reduce the total GHG emissions from this sector.

Commercial sector GHG emissions



Emissions by subsector from 2005 to 2022 (left) and only 2022 (right). "Other Commercial" includes coal, solvent use, medical uses of nitrous oxide, non-CO2 emissions from biofuels, and limestone use.

Waste

The waste sector produces about 1% of GHG emissions annually in Minnesota. Compared to the 2005 baseline, GHG emissions from the waste sector have decreased by about 40%.

GHG emissions 2005-2022

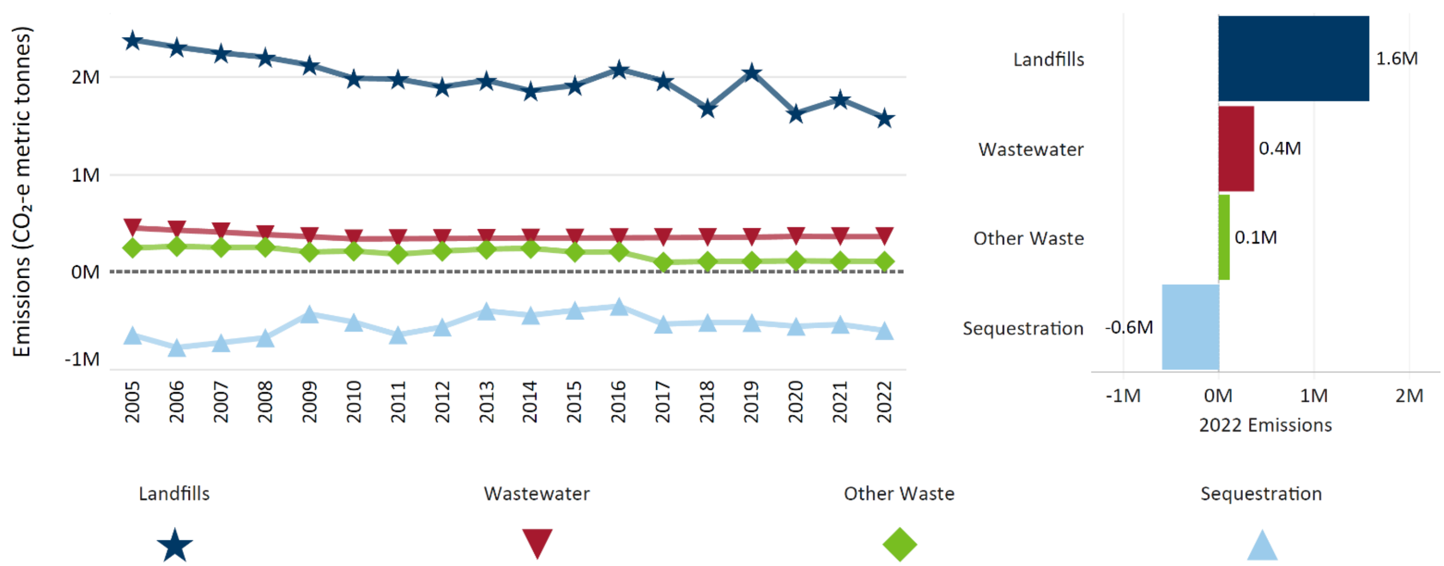
Emissions sources in the waste sector include:

- fossil fuel combustion in waste processing
- incinerator fuels
- waste incineration
- methane from landfill gas and wastewater treatment

The waste sector includes one emissions sink, which is the landfilling of wood construction materials. Although reuse and recycling of lumber and wood products is preferable, construction waste disposed of within construction and demolition landfills stores carbon for many years. In Minnesota, more construction waste is landfilled than the amount that decays within landfills each year, resulting in carbon sequestration that partially offsets other waste emissions.

Gradually decreasing methane emissions from landfills drives this sector's overall GHG reduction trend. This decline in methane emissions is due to a combination of factors. Aging waste in operating landfills results in lower emissions because older waste emits less methane as the organic fraction decomposes and becomes more stable. Also, gas capture technologies used at landfills reduce methane emissions by combusting it in a flare or using it to produce usable energy. As the closed landfill program administrator, the Minnesota Pollution Control Agency (MPCA) is working to address methane emissions from these facilities.

Waste sector GHG emissions



Emissions by subsector from 2005 to 2022 (left) and only 2022 (right). "Other Waste" includes processing-related emissions from waste-related facilities and incineration-related emissions from waste facilities and rural open burning

Land use, land-use change, and forestry

Minnesota’s land use, land-use change, and forestry (LULUCF) sector sequesters more GHGs than it emits, resulting in net negative emissions of 11.6 million metric tons of CO_2-e in 2022, offsetting 8.4% of all other emissions in the state. The rate of net sequestration has increased by about 20% since 2005, a trend that has largely been driven by growth within and expansion of Minnesota’s forests.

GHG emissions 2005-2022

Land use, land-use change, and forestry

↓ **20%** **8.4% offset**

Largest carbon sinks:

- Existing forests
- Land converted to forest

The LULUCF sector consists of non-agricultural lands and waters. In the context of GHG accounting, “land use” refers to categories of land surfaces based on vegetation, hydrology, and human activities; it does not refer to land use planning and zoning in urban and suburban contexts, which is another common use of this term. International GHG reporting standards recommend quantifying land-use-related GHG emissions and sequestration if they occur on managed lands or are associated with human activity. In practice, all lands and waters in Minnesota are managed or influenced by humans to some extent, so we aim to include all land use types for which robust accounting methodology exists.

The “land-use change” component of this sector accounts for emissions and sequestration caused by conversions between forest lands, grasslands, surface waters, and settlements. Lands converted from croplands to any of these uses are included. However, lands remaining in, or converted to, croplands are included in the agriculture sector. We use the same land use definitions as the US Environmental Protection Agency[2] (EPA) and lands are considered remaining within a given use type if in continuous use for more than 20 years.

Rates of plant growth and decay, weather, and management decisions influence the exchanges of GHGs between lands, waters, and the atmosphere. While the science of land-use-related GHG accounting has developed rapidly, some land-use types do not yet have quantification methods or require input data that are not readily available. Wetlands have particularly complex GHG exchanges, so the only wetland-associated estimates currently included are emissions caused by peat harvesting. Trees outside of forests and developed areas (e.g., between crops or along rivers and streams) and carbon stored in harvested wood products are also not yet included due to limitations in data and methods.

Minnesota land use summary

Minnesota’s total surface area is approximately 54 million acres and more than 70% of the land is privately-owned.

Percent of Minnesota’s surface area by land use:

- Croplands: 39%
- Forests: 34%
- Grasslands: 8%
- Wetlands: 8%
- Open water: 6%
- Settlements: 5%
- Barren/other: <1%

Sources: US Geological Survey, MN DNR

Different land-use types store carbon and exchange greenhouse gases with the atmosphere at different rates. Conversion from carbon-rich natural systems, like forests, grasslands, and wetlands, to intensively managed croplands or developed lands, results in carbon emissions. Conversely, restoration of natural lands typically results in carbon sequestration. For lands remaining in a given land use, rates of sequestration and emissions depend on factors such as time since establishment, soil type, hydrology, and local management (e.g., timber harvest, grazing, fire, and fertilizer use).

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[2] https://www.epa.gov/ghgemissions/methodology-report-inventory-us-greenhouse-gas-emissions-and-sinks-state-1990-2022

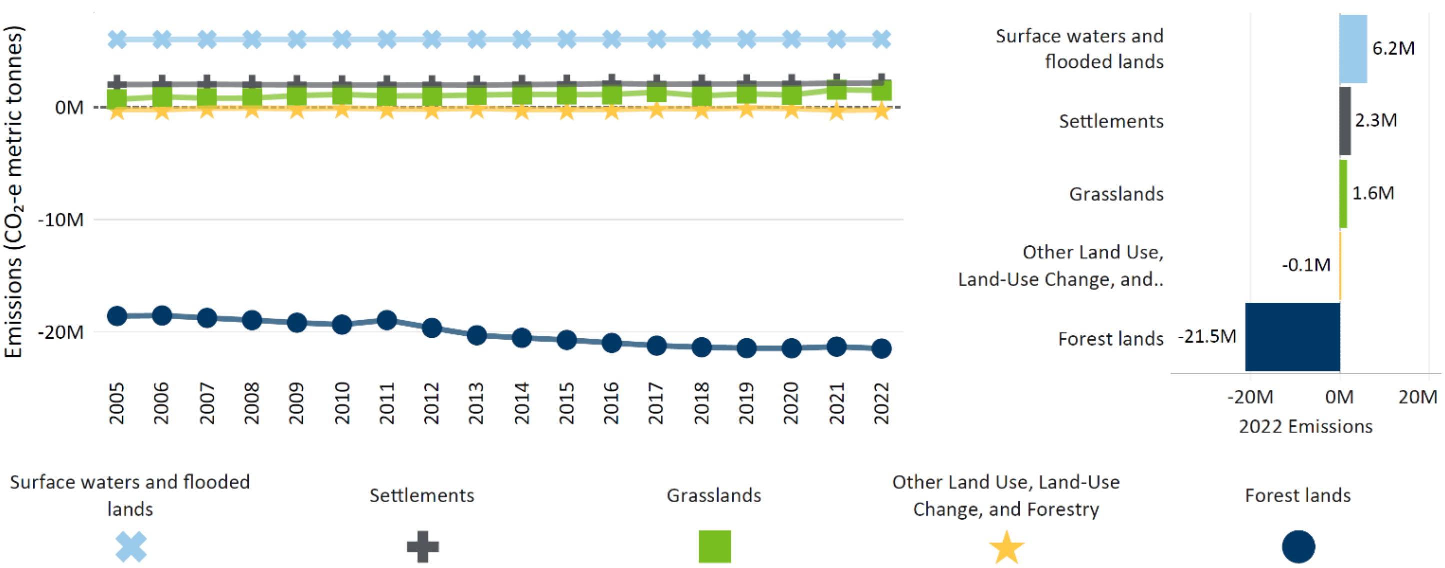
Forests in Minnesota sequester significant amounts of carbon dioxide each year (about 15% of total statewide emissions in 2022). The strength of Minnesota's forest carbon sink is attributable to multiple factors, including continued regrowth following the decades of widespread forest clearing for agriculture and unsustainable forest management practices throughout the 19th century. In addition, adopting sustainable timber harvesting practices in the 20th century played an important role in enhancing Minnesota's forest carbon sink.

Surface waters are the largest source of emissions in this sector. Reservoirs, canals, and ditches are significant human-caused sources of methane emissions. While lakes and rivers are natural water bodies, human contributions of nutrients to these waters increase their methane emissions above natural levels.

Settlements (which include cities, roads, and other developed lands and both categories of converted and remaining settlements) are the second largest net source of GHGs in this sector in 2022. The conversion of natural and working lands to settlements results in emissions, especially when organic soils are drained to allow for development. Many urban, suburban, and ex-urban communities in Minnesota also have robust tree canopies, however, which offset about a third of settlements' gross annual emissions.

Minnesota's grasslands are the third largest net source of emissions in 2022. Grasslands contain large stores of soil carbon, but the characteristics of the soils beneath these grasslands largely determine whether a given site emits or sequesters carbon. Ungrazed or moderately grazed grasslands on mineral soils typically sequester carbon, but a relatively small acreage of grasslands on drained organic soils (i.e., former peatlands) releases more carbon each year than is stored by grasslands on mineral soil. See the agriculture sector for further explanation of emissions from drained organic soils.

Land use, land-use change, and forestry sector GHG emissions



Emissions by land use type from 2005 to 2022 (left) and only 2022 (right). Several types of surface waters have been combined into "Surface waters and flooded lands." Lands remaining in and converted to a given land use (i.e. settlements, grasslands, and forest lands) have also been combined for this figure. See the interactive online data vizualizations for more details.

Harvested wood products

Harvested wood products store carbon—sometimes for long periods of time—and can also substitute for fossil-fuel-intensive products such as concrete and steel. The statewide GHG inventory currently does not include the net emissions associated with carbon stored in and emitted from wood products harvested from Minnesota's forests, except as estimates of wood used in residential construction and stored in construction and demolition landfills (see Residential and Waste sectors). A more complete accounting of the exchange of GHGs between Minnesota's forests and the atmosphere would include comprehensive annual estimates of carbon stored in and emitted from all harvested wood products, such as lumber, plywood and particleboard, and pulp and paper products.

When forests are managed with timber harvest, a large portion of the wood absorbed and stored in trees is transferred into wood products where it is stored for variable amounts of time. Long-lived wood products such as engineered wood and lumber are typically disposed of in landfills, where decomposition proceeds slowly.

Nationally, harvested wood products, both in use and in solid waste disposal sites, represent a consistent carbon sink that is roughly 12% of the magnitude of the national forest carbon sink. If this nationwide proportion is roughly true for Minnesota, harvested wood products might represent an additional 2.5 million metric tons of CO_2-e of sequestration and increase Minnesota forests' net sink from -21.5 million to -24 million metric tons of CO_2-e. We are developing a methodology for accounting for harvested wood products in Minnesota's GHG inventory and plan to include harvested wood products in the next iteration of this report.

Increasing carbon sequestration and storage through land management

As the only sector that currently sequesters more GHGs than it emits, Minnesota's Land Use, Land Use Change, and Forestry sector will be critical to achieving the state's net-zero emissions goal. Fortunately, when our lands and waters are managed well, they not only release lower amounts of GHGs and absorb and store more carbon, they can also enhance climate resilience, support healthy plant and animal populations, and sustain our quality of life.

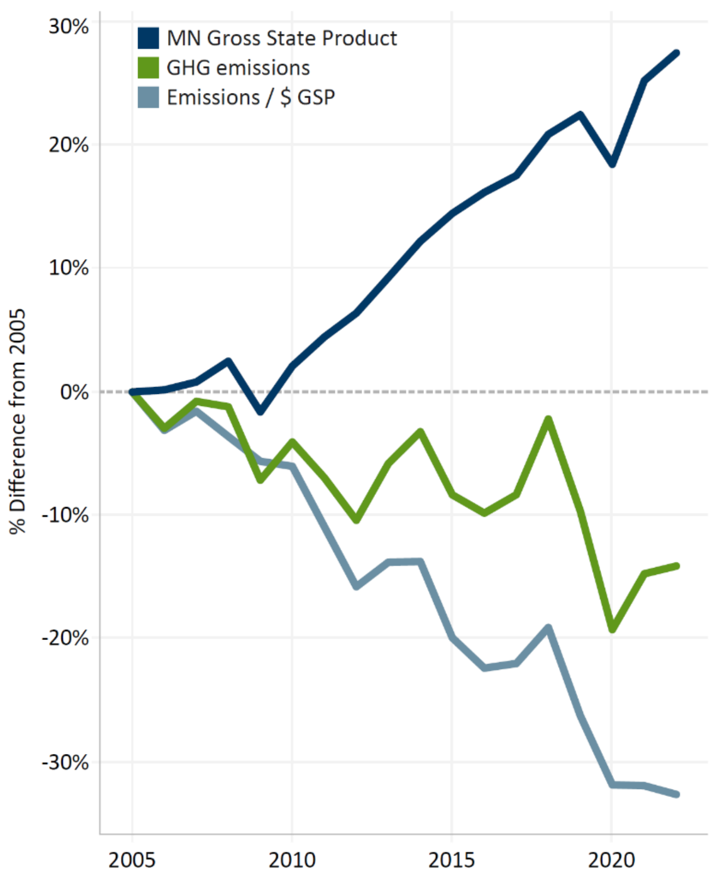
Examples of actions that support healthy landscapes and mitigate climate change:

- Forest managers can follow site-level guidelines and best practices to manage forests for wildlife habitat, recreation, clean water, timber, and climate resilience benefits over the long term.
- Grassland and prairie managers can establish a diverse mix of plant species – which has been demonstrated to enhance carbon storage – and adopt grazing practices that protect and enhance diversity and continuous cover.
- State, local, federal, and tribal governments can restore degraded lands, wetlands, and waterbodies to provide habitat, water quality, climate, economic, and recreational benefits.
- Residents, landowners, and communities can plant and care for native trees, wildflowers, and grasses.

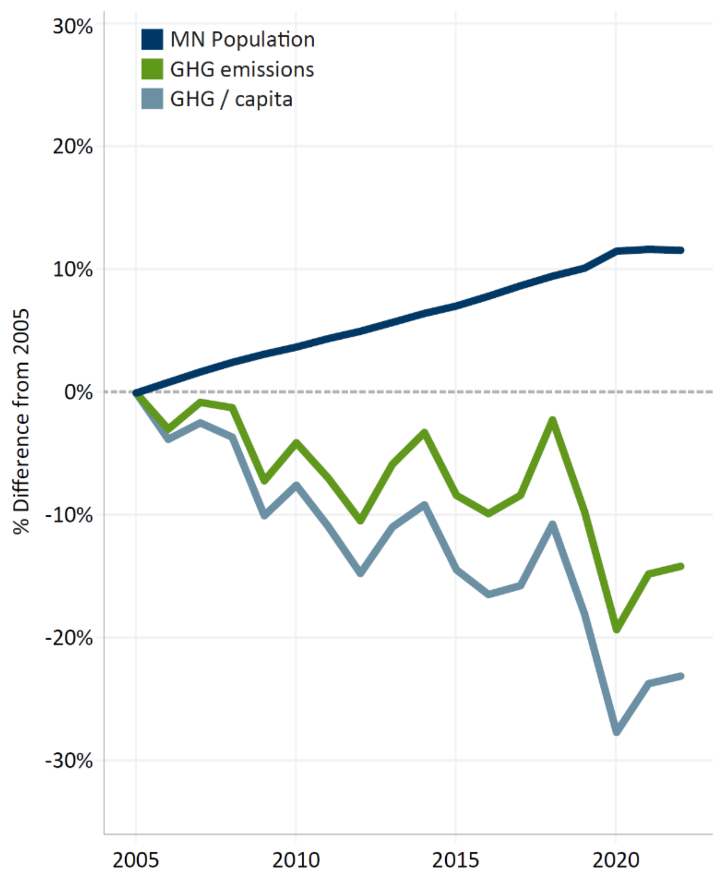
Greenhouse gas emissions and our economy

Measuring the amount of GHG emissions compared to other economic indicators is one way to understand how GHG emissions relate to the state's economy. Trends show that Minnesota has begun disconnecting economic growth from GHG emissions. Minnesota's gross state product has grown since 2005, while GHG emissions have generally decreased, demonstrating that the state economy can grow without increasing GHG emissions. Similarly, Minnesota's generally decreasing GHG emissions show that population growth can occur while reducing GHG emissions. Though the population in Minnesota is increasing, there is a growing decrease in emissions per person. The Climate Action Framework outlines initiatives to advance Minnesota's transition to a clean economy, helping to ensure greenhouse gas emissions reductions align with the goals in state law.

GHG emissions per dollar gross state product
2005 to 2022



GHG emissions per capita
2005 to 2022



Our path forward: Minnesota’s Climate Action Framework

In September of 2022, Minnesota’s Climate Action Framework was released. The Framework, developed with input from 3,000+ Minnesotans, sets a vision for how the state will address and prepare for climate change. It identifies near-term actions we must take to achieve the long-term vision of **a carbon-neutral, resilient, and equitable future for Minnesota**.

The Framework is organized around six climate action goals with specific steps and progress measures to guide and evaluate our work.

- **Clean transportation**
  Transportation represents the greatest opportunity to reduce climate pollution. The Framework aims to connect and serve all people through a safe, equitable, and sustainable transportation system.
- **Climate-smart natural and working lands**
  Minnesota can manage natural and working lands to address climate change by absorbing and storing carbon, reducing emissions, and sustaining local economies.
- **Resilient communities**
  Communities experience the impacts of climate change differently, and solutions must be tailored to local needs. The state can prepare communities with the resources they need to plan and build a more resilient future for themselves.
- **Clean energy and efficient buildings**
  Minnesotans can benefit from investments in clean energy and energy efficiency that will create jobs, lower energy costs, and contribute to a more stable climate.
- **Healthy lives and communities**
  Changes in Minnesota’s climate threaten the health of every community, but not everyone experiences these impacts equally. The Framework’s goal is to protect the health and well-being of all Minnesotans in the face of climate change.
- **Clean economy**
  Transitioning to a cleaner economy must include solutions that benefit everyone. Minnesota will build an economy that addresses climate change and equitably provides family-sustaining job opportunities.

The Framework will guide the state of Minnesota’s priorities for addressing climate change in the coming years. Actions identified in the document will be developed into new policies, programs, and grants to reduce our greenhouse gas emissions. The Framework is currently being updated to include a more comprehensive set of actions that help us achieve those goals. Analyzing Minnesota’s emissions through this inventory allows us to track progress on the Framework goals and focus actions for maximum impact to address climate change.

Learn more about our next steps to tackle climate change and how you fit into this work by visiting **mn.gov/framework.**

Conclusion

Since launching our Climate Action Framework in 2022, Minnesota has made significant progress on climate action, including historic climate funding and policies adopted in 2023. These state funds combined with billions of dollars federal funding have advanced dozens of programs to cut climate pollution and prepare our state for a warmer, wetter Minnesota.

Minnesota has successfully reduced emissions by approximately 14% since 2005, but we have significant work to do to meet our goal of being carbon-neutral by 2050. While emissions bounced back after the most disruptive period of the COVID-19 pandemic, our overall emissions have not returned to 2019 levels, indicating we are still on a downward trend.

This inventory report doesn't capture the impacts of historic climate action funding at the state and federal level since 2022, which will result emission reductions in the coming years and decade. To achieve our goals, we must continue Minnesota's commitment to climate action by government, businesses, institutions, and individuals that reduces climate pollution while fostering economic growth and jobs across Minnesota.

Minnesota is updating our Climate Action Framework in 2025 to include a more comprehensive set of actions with a stronger focus on collaboration, community benefits, and workforce needs. Though we have made progress, we must accelerate the pace and scale of our climate actions to achieve our long-term vision of a carbon-neutral, resilient, and equitable future.

Appendix: Methodology

Greenhouse gas emission inventory

The GHG inventory reports progress toward statutory goals and transparently provides information with high confidence in our results. The long record of emissions and high level of data disaggregation using the best available data and methods based on EPA and Intergovernmental Panel on Climate Change (IPCC) recommendations helps ensure the inventory is complete, consistent, transparent, accurate, and relevant. The EPA produces a national GHG inventory and a downscaled state-level GHG inventory. Both national and state EPA inventory versions are useful and incorporated in many parts of this inventory. However, there are differences between the MPCA inventory and others, such as the focus on activities like energy use or process emissions rather than on economic sectors, the division of electricity sector emissions, and the inclusion of imported electricity emissions. Inventories may present different details but are helpful as comparisons despite their differences.

Minnesota's state-level emission reduction goals are expressed as percentage reductions from estimated emissions in a historical baseline year (2005). Like most GHG inventories, the Minnesota GHG inventory has undergone substantial revisions since it was first built. It is continuously revised as methods and data improve and new emission sources are incorporated. When possible, these changes are applied to all inventory years to ensure consistency, including the 2005 baseline year. Developing a consistent time series of emissions estimates is essential to measure progress.

Not all emissions are included in statewide emission totals. Only those sources which can be included in the baseline year are evaluated. While it would be ideal to inventory and track all sources of GHG emissions from activities within Minnesota, in practice, the inventory consists of only those sources for which a well-developed scientific understanding of the physical and biological processes involved in the production and emission of GHGs exists. To include an emission source in the inventory, generally accepted protocols or methods must exist, and continuous data or reasonable quality must be available to support estimation.

Only emissions that occur within the geographical borders of the state are estimated, with two exceptions. Our estimate includes net electricity imports to meet Minnesota's electricity demand, which exceeds in-state electricity production. Emissions from the combustion of aviation fuel purchased in Minnesota but not necessarily combusted within Minnesota air space are also included.

GHG inventory protocols require accounting for photosynthetically-removed carbon dioxide stored in biomass in forests, landfills, and structures. Long-term storage of wood-carbon in residential structures and demolition and construction landfills is included in statewide GHG emission totals as sequestration because the materials will remain as carbon stores for a long time. Forest carbon fluxes are included from forest land that remains forest land and land converted to forest land following the EPA state methodology report (2022).

Within the agriculture and LULUCF sectors, some specific inclusions and exclusions are worthy of mention: Croplands enrolled in contract-based conservation programs (e.g., Conservation Reserve Program) are included in this sector because they are relatively likely to return to crop production, while former croplands that have been converted to wetlands, grasslands, forests, or settlements are instead included in the land use sector. Because grasslands are not exclusively used for agricultural purposes, grassland biomass and soil carbon fluxes are included in the land use sector, but any emissions from grazing livestock and manure are accounted for within the agriculture sector. Trees within croplands (e.g., windbreaks, agroforestry) are not included in the agriculture sector because quantification methods are not yet available. Finally, upstream emissions associated with the production of inputs such as fertilizers and equipment are out of scope for the agriculture sector; if these activities occur within Minnesota, their emissions are accounted for in the industrial sector.

Emissions are estimated from 1990 to 2020, though presented here in an abbreviated timeline. With a few exceptions, the methods used to develop these estimates are derived from the following sources:

- US Environmental Protection Agency (2022) Inventory of US greenhouse gas emissions and sinks: 1990-2020.
- US Environmental Protection Agency (2022) Methodology Report: Inventory of US greenhouse gas emissions and sinks by state: 1990-2020.
- US Environmental Protection Agency Motor Vehicle Emissions Simulator (MOVES) Models (versions 2014b and 3.1)
- Intergovernmental Panel on Climate Change (2006) IPCC guidelines for national greenhouse gas inventories. Vol. 1-4.
- Intergovernmental Panel on Climate Change (2019) 2019 Refinement to the 2006 IPCC Guidelines on National Greenhouse Gas Inventories.
- Radian Corporation (1996) Methane emissions from the natural gas industry. Volumes 1-15. Prepared for the US Environmental Protection Agency and the Gas Research Institute.
- California Air Resources Board, et al. (2010) Local government operations protocol for the quantification and reporting of greenhouse gas emissions inventories, version 1.1.
- The Climate Registry (2008) General reporting protocol, version 1.1.

Changes in methods and data sources

The methods used to develop the emission estimates are generally consistent from year to year, and changes made since the last report are discussed here.

Data collection methods implemented by the Minnesota Department of Transportation improved our accounting of vehicle miles traveled and the breakdown of miles traveled by vehicle type. However, these improved data are only available for recent years. Comparisons to 2005 details are therefore less accurate, but the overall trend in emissions is similar to the information reported in EPA's Inventory of US Greenhouse Gas Emissions and Sinks report and is still useful for tracking overall progress.

Since the last report, significant changes have been made to estimate GHG fluxes within the agriculture and land use, land-use change, and forestry sectors. In a shift from previous inventories, we now primarily use estimates provided by the EPA [3] for both of these sectors and have replaced historical estimates for consistency. The EPA inventory uses more sophisticated modeling with more complete coverage of both sectors than previously provided in this report.

Within the agriculture sector, this shift allows the inclusion of soil carbon fluxes in mineral soils (previous versions only included fluxes from organic soils). Other methods differ slightly from our previous approach, but estimates for each flux are generally similar to those derived using our previous methods.

Within the LULUCF sector, this shift to using EPA estimates allows us to include grasslands, settlements, and canals/ditches for the first time. EPA's estimates for lands converted to reservoirs were corrected for a known area overestimate. Lawn-applied nitrogen fertilizer emissions were previously accounted for within the residential sector but are now accounted for within settlements in the LULUCF sector. Estimates for emissions from lakes/ponds and rivers/streams are not included in the EPA inventory and are calculated using emission factors derived from peer-reviewed literature. For detailed definitions and methods of land use, see the

[3] US EPA's Inventory of US GHG Emissions and Sinks by State 1990-2022. https://www.epa.gov/ghgemissions/methodology-report-inventory-us-greenhouse-gas-emissions-and-sinks-state-1990-2022

associated Technical Supporting Document, which will be published shortly following this report and available on the same website: https://www.pca.state.mn.us/air-water-land-climate/climate-change-trends-and-data. We are committed to continuing to adopt the best available methods across all land use types and aim to include all GHG fluxes associated with wetlands, trees outside of forests and settlements, and harvested wood products in the future.

We strive to use the best available data and methods and are currently developing analyses using the US Department of Agriculture's Carbon Management & Emissions Tool (COMET) farm tool for potential future use to estimate fluxes from all of agriculture, as well as grasslands within LULUCF.

The Energy Information Administration (EIA) Fuel Oil and Kerosene Sales Report had previously been used to disaggregate fuel types and uses within economic sectors; however, that dataset has been discontinued. Now, the best available data is from the EIA State Energy Data System (SEDS), which is not as disaggregated with regard to fuel type or sector. As a result, we are no longer able to report agricultural diesel use nor distinguish biodiesel blends from total distillate fuel oil. This results in a small overestimate of CO_2 emissions from biodiesel in non-transportation uses. In addition, data derived from SEDS includes agriculture-related fuel combustion within industrial fuel combustion; therefore, these emissions are now included in the industrial sector totals.

In previous versions of this report, emissions related to peat harvesting were reported in the industrial sector. Those emissions are now reported in the land use, land-use change, and forestry sector, in alignment with the EPA's sectoral arrangement.

In previous versions of this report, methane emissions from hydroelectric reservoirs were duplicated in the electricity generation and the former agriculture, land use, and forestry sectors. These hydroelectricity-related emissions are now included only in land use, land-use change, and the forestry sector, which aligns with the EPA's sectoral arrangement.

Ozone-depleting substances (ODS) historically used as common refrigerants were replaced by other compounds, namely hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), collectively known as ODS substitutes. These ODS substitutes are high global warming potential GHGs whose emissions are included in this inventory. In previous reports, the procedure for estimating emissions from ODS substitutes in the commercial sector included scaling down national emissions to the population of Minnesota and subtracting emissions from state-level residential and transportation sectors. In this report, the estimation has been changed to leverage the state-level EPA GHG inventory, which estimates sector-specific emissions from ODS substitutes for Minnesota.

In the previous report, residual fuel oil was overestimated in the off-highway category of the transportation sector due to duplication in the railroad, marine, and military and other off-highway categories. It is now accounted for only in the marine category. An additional clerical error in the military and other off-highway category was corrected.

Finally, in the last report, commercial sector emissions associated with fuel oil combustion were overestimated. This error has been corrected in calculations for the current report.

The overall impact of these methodological changes is an improved understanding of Minnesota's progress toward statutory emissions reduction goals. Ongoing improvement in methodologies will continue to improve our understanding of Minnesota's historic emissions in future versions of this report.

Uncertainty of estimates and opportunities for improvements

It is difficult to calculate the precise amounts of GHG emissions; however, getting a reasonable estimate is still critical in understanding the general scope of emissions.

Several methods and data sources are used to estimate emissions from each activity within a sector to get a comprehensive view. Some of the methods for generating the estimates are very detailed and result from site-specific measurements for both activity and emissions. In contrast, others use a model with only general data to characterize the source of emissions.

The accuracy of data for different economic sectors can vary:

- Fossil fuel combustion in each sector, such as electricity generation and industrial uses, has low uncertainty, especially when aggregated to state totals because the activity is regulated and tracked.
- Emissions from on-road transportation are estimated using the MOVES model, which depends on vehicle population and vehicle miles traveled data. Methods to measure vehicle miles traveled and types of vehicles on our roads have changed over time. This means that we understand current transportation activity much better than we did in the past, and it also means that there is more uncertainty in estimates for past years. However, our emissions trend is similar to other published estimates, such as the EPA state inventory.
- Methane generated from municipal solid waste in landfills is modeled. There is some uncertainty from data inputs and the model's underlying equations and assumptions.
- Emissions and sequestration from agriculture, forestry, and land use have a higher degree of uncertainty due to the multitude of factors influencing biological processes and the difficulty of obtaining accurate, relevant, detailed information.