Air Quality Agreement

Progress Report 2020-2022

Canada – United States

The International Joint Commission Requests Your Comments on This Report

The Canada-United States Air Quality Agreement directs the International Joint Commission (IJC) to invite public comments on progress reports prepared by the Air Quality Committee and provide a synthesis of comments to the Governments of Canada and the United States in order to assist them with implementing the Agreement.

The IJC is interested in your views on the draft 2022 Progress Report reflecting the Governments' important work being carried out under the Agreement:

- *What do you think about the ongoing efforts of our two countries to address transboundary air quality?*
- *What issues do you think should have the highest priority?*
- *What do you think about the information provided in this report?*

The IJC invites you to send written comments on this draft progress report until August 31, 2023, using one of the following methods:

1. Online at: (www.ijc.org/en/what/engagement/consultations)
2. Email at: (AirQuality@ijc.org)
3. Mail at:

Canadian Section
Secretary, Canadian Section
International Joint Commission
234 Laurier Avenue West, 22nd Floor
Ottawa (Ontario) K1P 6K6

United States Section
Secretary, U.S. Section
International Joint Commission
1717 H Street NW, Suite 835
Washington, DC 20006

United States spelling is used throughout this report except when referring to Canadian titles.

ISSN: 1910-5223
Cat. No.: En85-1E-PDF

Aussi disponible en français.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLE

FIGURES

TABLE

INTRODUCTION

In 1991, the United States (U.S.) and Canada established an Air Quality Agreement (Agreement) to address transboundary air pollution. The Agreement initially focused on reducing levels of acid deposition, or acid rain, in each country, and in 2000, the Agreement was amended to also address ground-level ozone. A bilateral Air Quality Committee, established in the Agreement, is required to issue a report every two years, highlighting progress on the commitments included in the Agreement and describing the continued efforts by both countries to address transboundary air pollution. This is the 15th such progress report[1] under the Agreement.

Working collaboratively under the Agreement, both countries have made remarkable progress over the last three decades in reducing acid rain, controlling ozone in the transboundary region, improving the environment, and achieving better air quality for residents of the United States and Canada. Significant reductions in emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs) have resulted from regulatory and non-regulatory programs—some of which are specifically designed to meet commitments set in the Agreement—implemented by both countries.

In addition, the Agreement has provided a mechanism, in the form of work plans, for cooperation on the development and implementation of harmonized regulations to reduce vehicle and engine emissions and for addressing emissions from the oil and gas sector.

In 2021, the Agreement marked its 30th anniversary. This Agreement has provided important opportunities for collaboration between Canada and the United States and has achieved tangible improvements in the environment.

[1] Due to delays from the COVID-19 pandemic, the 2020 and 2022 editions of the progress reports have been combined into a single edition.

ACID RAIN ANNEX

Acid deposition, more commonly known as acid rain, occurs when emissions of SO_2 and NO_x, from power plants, vehicles, and other sources, react in the atmosphere (with water, oxygen, and oxidants) to form various acidic compounds that exist in either a wet form (rain, snow, or fog) or a dry form (gases and particles). These acidic compounds can harm aquatic and terrestrial ecosystems (particularly forests); affect human health; impair visibility; and damage automotive finishes, buildings, bridges and monuments.

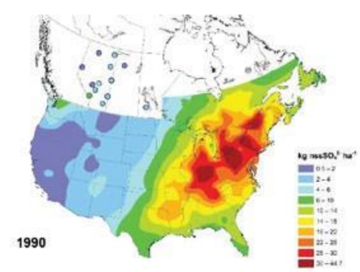
The Acid Rain Annex to the 1991 Agreement established commitments by both countries to reduce emissions of SO_2 and NO_x, the primary precursors to acid rain, from stationary and mobile sources. The Agreement also included provisions aimed at prevention of air quality deterioration, protection of visibility, and continuous monitoring of emissions. Reductions in SO_2 and NO_x emissions in both Canada and the United States between 1990 and 2019 have led to major decreases in the wet deposition of sulfate and nitrate over the eastern half of the two countries. Implementation of various regulatory and non-regulatory actions for more than two decades in Canada has significantly reduced emissions of SO_2 and NO_x and ambient concentrations. Implementation of similar programs, especially regulatory programs in the electric power sector, has significantly reduced emissions of SO_2 and NO_X and ambient concentrations in the United States as well.

ACID DEPOSITION TRENDS

Wet deposition of sulfate and nitrate is measured by precipitation chemistry monitoring networks in Canada and the United States. The annual measurement data, presented in kilograms per hectare (kg ha^{-1}), are the basis for binational spatial wet deposition maps. Starting in 2020, the global COVID-19 pandemic led to a prolonged period where many precipitation samples in Canada were collected but not analyzed due to the requirement for federal employees, including laboratory staff, to work from home. Analysis of these samples is underway, along with a quality control study to assess the impact of long-term sample storage. Collection and analysis of samples in the United States were less impacted by the pandemic due to generally shorter and state-specific public health measures; however, data from more sites than usual did not meet the completeness criteria to be included in annual reporting for the year 2020. Therefore, the most recent year of data presented here is for 2019.

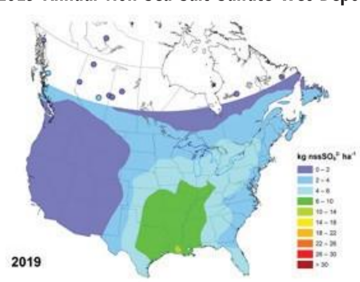
Figures 1 and 2 show the spatial patterns of annual wet sulfate deposition of non-sea-salt sulfate ($nssSO_4^{2-}$), which is measured sulfate with the contribution of sea salt sulfate removed, in 1990 and 2019, respectively, along with point values at sites in less densely measured regions. Figures 3 and 4 show the patterns of wet nitrate deposition for the same years. The lower Great Lakes region consistently received the highest wet deposition of both sulfate and nitrate in the 30-year period. Sulfate deposition in 1990 exceeded 26 kg $nssSO_4^{2-}$ ha^{-1} over a large area of eastern North America. In 2019, only a small area on the Gulf Coast exceeded 10 kg $nssSO_4^{2-}$ ha^{-1}. Similarly, nitrate deposition exceeded 19 kg NO_3^- ha^{-1} in many parts of the northeastern United States and southern Ontario and Quebec in 1990, and in 2019, nitrate deposition was less than 13 kg NO_3^- ha^{-1} throughout North America, except for a small area of eastern Lake Erie, which is still below 16 kg ha^{-1}. The steepest declines in nitrate wet deposition occurred after the year 2000 due to major NO_x emission reductions in both countries.

Figure 1. 1990 Annual Non-Sea-Salt Sulfate Wet Deposition



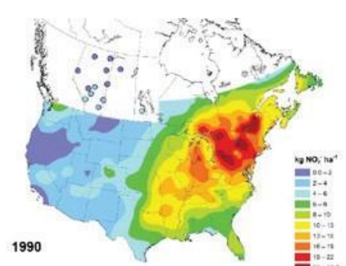
Source: The Canadian Air and Precipitation Monitoring Network, Alberta Precipitation Quality Monitoring Program (both at https://doi.org/10.18164/72bef1bc-709a-4d57-99ea-6969b9728335) and the United States National Atmospheric Deposition Program (http://nadp.slh.wisc.edu/).

Figure 2. 2019 Annual Non-Sea-Salt Sulfate Wet Deposition



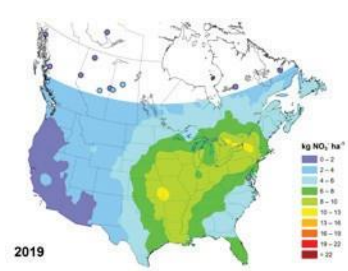
Source: The Canadian Air and Precipitation Monitoring Network, Alberta Precipitation Quality Monitoring Program (both at https://doi.org/10.18164/72bef1bc-709a-4d57-99ea-6969b9728335) and the United States National Atmospheric Deposition Program (http://nadp.slh.wisc.edu/).

Figure 3. 1990 Annual Nitrate Wet Deposition



Source: The Canadian Air and Precipitation Monitoring Network, Alberta Precipitation Quality Monitoring Program (both at https://doi.org/10.18164/72bef1bc-709a-4d57-99ea-6969b9728335) and the United States National Atmospheric Deposition Program (http://nadp.slh.wisc.edu/).

Figure 4. 2019 Annual Nitrate Wet Deposition



Source: The Canadian Air and Precipitation Monitoring Network, Alberta Precipitation Quality Monitoring Program (both at https://doi.org/10.18164/72bef1bc-709a-4d57-99ea-6969b9728335) and the United States National Atmospheric Deposition Program (http://nadp.slh.wisc.edu/).

ACID RAIN COMMITMENTS AND EMISSION REDUCTIONS

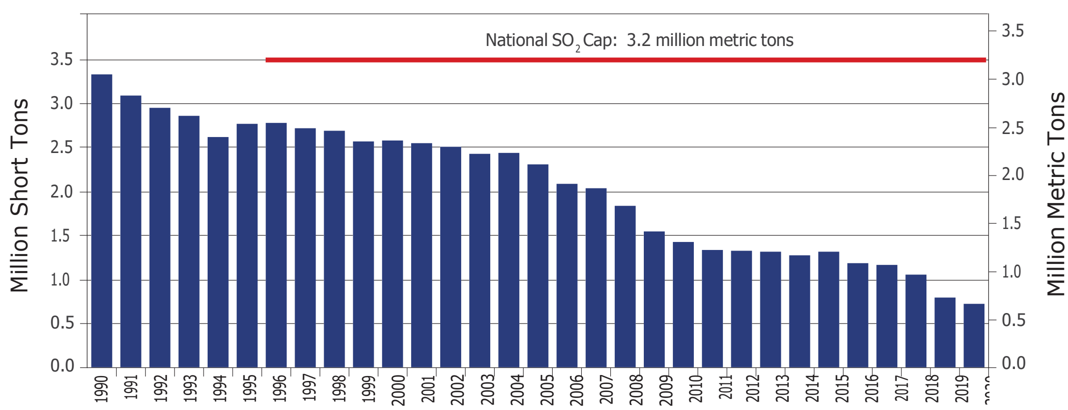
SO_2 Emission Reductions

CANADA

Actions driving SO_2 emission reductions include the implementation of the Canada-Wide Acid Rain Strategy for Post-2000, which serves as the framework for addressing the issues related to acid rain. The goal of the strategy is to ensure that the deposition of acidifying pollutants does not further deteriorate the environment in eastern Canada and that new acid rain problems do not occur elsewhere in Canada.

Canada has met its commitments to reduce SO_2 in the Agreement. In 2020[2], Canada's total SO_2 emissions were approximately 651 thousand metric tons (716 thousand short tons[3]), about 80 percent below the national cap of 3.2 million metric tons (3.5 million short tons). The 2020 emissions level also represents a 78 percent reduction from Canada's total SO_2 emissions of 3.0 million metric tons (3.3 million short tons) in 1990 [see Figure 5].

Figure 5. Total Canadian SO_2 Emissions, 1990-2020



Source: Environment and Climate Change Canada, 2022.

Three industrial sectors make up the largest contribution of SO_2 emissions in Canada: upstream oil and gas, which includes the exploration and production of crude oil; coal-fired electric power generation; and non-ferrous mining and smelting. These three sectors accounted for 70 percent of national SO_2 emissions in 2020. The majority of overall reductions in national SO_2 emission levels can be attributed to the SO_2 emission reductions from the non-ferrous refining and smelting industry, which had decreases in emissions in the early 1990s, and again, from 2008 to 2020. The decrease since 2008 can be attributed to preparation and implementation of pollution prevention plans by facilities, the installation of new technology or processes at facilities, phase-out of coal-fired electricity, switch to low-sulphur fuels, the closure of four major smelters in Manitoba, Ontario, Quebec and New Brunswick, and facilities achieving industrial emissions requirements through environmental performance agreements. These industrial emissions requirements are part of Canada's Air Quality Management System (AQMS).

[2] Emissions trends for Canada presented in this report are from Canada's 2022 Air Pollutant Emissions Inventory.

[3] One metric ton is equal to 1.1 short tons.

Although Canada has been successful in reducing these acidifying pollutants, many areas across Canada are still exposed to concentrations that exceed the capacity of the soils and surface waters to neutralize the acidic deposition, most notably in eastern Canada. Measures are being undertaken to reduce SO_2 and NO_x emissions from certain industrial sectors as part of Canada's AQMS, which will also reduce the impact of acidifying pollutants on soils and surface waters.

★ UNITED STATES

The United States has met its commitment to reduce SO_2 emissions. The national Acid Rain Program (ARP), the regional Clean Air Interstate Rule (CAIR), and the Cross-State Air Pollution Rule (CSAPR) were designed to reduce emissions of SO_2 (and NO_x) from the electric power sector. Since 1995, SO_2 emissions have fallen significantly under these programs. In addition, the Mercury and Air Toxics Standards (MATS), which went into effect in April 2015, achieved substantial SO_2 emissions reductions as an additional benefit to air toxics emissions reductions from the power sector. These reductions occurred while the demand for electricity increased and were the result of continued increases in efficiency, installation of state-of-the-art pollution controls, and the switch to lower emitting fuels. Most of the power sector emission reductions since 2005 were from early-reduction incentives and stricter emission cap levels under emission reduction programs developed to help attain and maintain National Ambient Air Quality Standards (NAAQS) for ozone and fine particulate matter ($PM_{2.5}$). The CAIR SO_2 emissions trading program began on January 1, 2010, and was replaced by the CSAPR SO_2 emissions trading program on January 1, 2015. More detailed information about the CSAPRs program can be found at www.epa.gov/csapr.

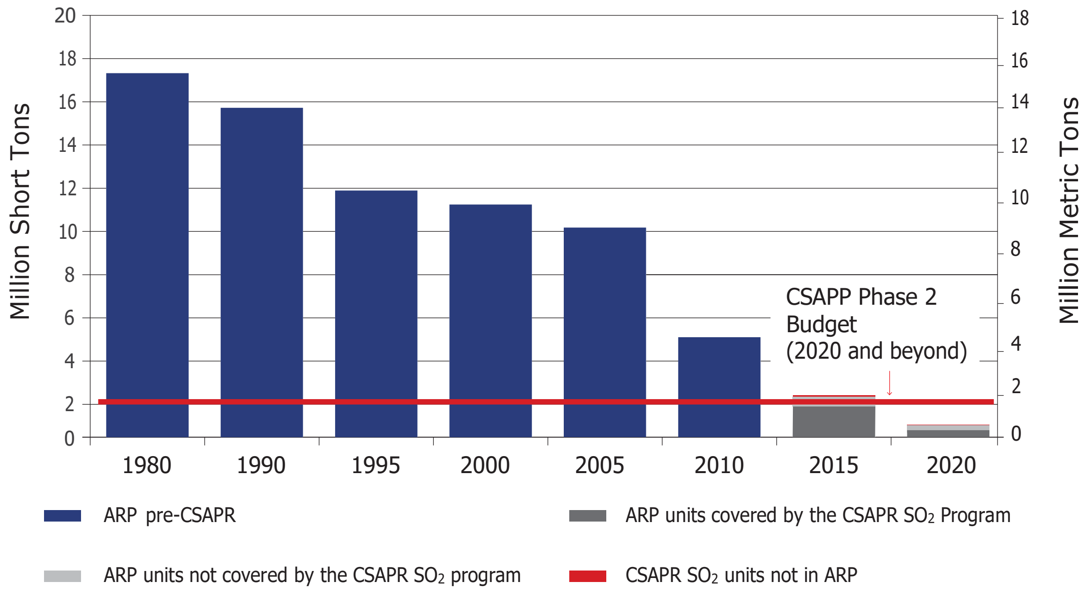
Electric generating units in the ARP emitted 778 thousand short tons (706 thousand metric tons) of SO_2 in 2020, well below the ARP's statutory annual cap of 8.95 million short tons (8.12 million metric tons). ARP sources reduced emissions by 15.0 million short tons (13.6 million metric tons, or 95 percent) from 1990 levels and 16.5 million short tons (15.0 million metric tons, or 95 percent) from 1980 levels [see Figure 6].

In 2020, sources in the CSAPR SO_2 program and the ARP collectively reduced SO_2 emissions by 10.4 million short tons (9.4 million metric tons, or 93 percent) from 2000 levels, and 9.5 million short tons (8.6 million metric tons), or 92 percent from 2005 levels (before implementation of CAIR and CSAPR). All ARP and CSAPR sources together emitted a total of 788 thousand short tons (715 thousand metric tons) of SO_2 in 2020.

Annual SO_2 emissions from sources in the regional CSAPR SO_2 program alone fell from 7.7 million short tons (7.0 million metric tons) in 2005 to 497 thousand short tons (451 thousand metric tons) in 2020, a 94 percent reduction. In 2020, SO_2 emissions were about 1.5 million short tons (1.3 million metric tons) below the regional CSAPR emission budget.

In addition to the electric power generation sector, emission reductions from other sources not affected by the ARP or CSAPR, including industrial and commercial boilers and refining operations, have contributed to an overall reduction in annual SO_2 emissions. National SO_2 emissions from all sources fell from 23.1 million short tons (20.9 million metric tons) in 1990 to 1.8 million short tons (1.6 million metric tons) in 2020, a reduction of 92 percent.

Figure 6. SO_2 Emissions from CSAPR and ARP Sources, 1980-2020



Notes: For CSAPR units not in the ARP, the 2015 annual SO_2 emissions were applied retroactively for each pre-CSAPR year following the year in which the unit began operating. There are a small number of sources in CSAPR but not in ARP. Emissions from these sources comprise about 1 percent of total emissions and are not easily visible on the full chart.

Sources: U.S. EPA, 2022.

NO_x Emission Reductions

CANADA

Canada has met its commitment to reduce NO_x emissions from power plants, major combustion sources, and metal smelting operations by 100,000 metric tons (110,000 short tons) below the forecasted level of 970,000 metric tons (1.1 million short tons). This commitment is based on a 1985 forecast of 2005 NO_x emissions.

Emissions of NO_x from industrial sources, including from electric power generating units, totaled 687 thousand[4] metric tons (756 thousand short tons) in 2020. Transportation and mobile equipment sources contributed 49 percent of total Canadian NO_x emissions in 2020, with the remainder produced by the upstream oil and gas industry (31 percent), electric power generating units (7 percent), and other sources. Canada continues to develop programs to further reduce NO_x emissions nationwide. Since 2016, Canada's *Multi-Sector Air Pollutants Regulations* have established mandatory national standards for NO_x emissions from industrial boilers, heaters, and stationary spark-ignition engines in major industrial facilities; and NO_x and SO_2 emissions from cement manufacturing facilities. The regulations will significantly reduce emissions that contribute to acid rain and smog. Environment and Climate Change Canada (ECCC) analysis predicts that the regulations will result in a reduction of 2.0 million metric tons (2.2 million short tons) of NO_x emissions in the first 19 years (equivalent to taking all passenger cars and trucks off the road for about 12 years). These regulations implement industrial emission requirements that are a key element of Canada's AQMS.

[4] Total includes NO_x emissions from the following sources: ore and mineral industry, oil and gas industry, electric power generation (utilities) and manufacturing.

Beginning in January 2020, cement manufacturing facilities must limit their emissions of NO_x and SO_2. NO_x emission intensity limits for new stationary gaseous fuel-fired engines (≥ 75 kW) came into force in 2016. The phased implementation of emission limits for existing stationary gaseous fuel-fired engines (≥ 250 kW) in oil and gas facilities started in 2021, with the final limits in force by 2026. The regulations provide multiple compliance options for regulated entities to achieve the limits. Finally, regulated limits were established for new and existing industrial gaseous fuel-fired boilers and heaters (≥ 10.5 GJ/h). As of June 2019, emission intensity limits are fully in force for modern and transitional boilers and heaters. Limits for pre-existing boilers and heaters are phased in based on their current classification. The higher and high NO_x emitting equipment must meet the limits by 2026 and by 2036, respectively. Most regulated facilities have fulfilled the regulatory obligations required to date, including submitting the required annual reports.

★ UNITED STATES

The United States has met its commitment to reduce NO_x emissions. To address NO_x emissions, the ARP NO_x program requires emission reductions through a rate-based approach on certain coal-fired power plants, while CSAPR achieves emission reductions through a market-based, emission trading program from fossil fuel-fired power plants.

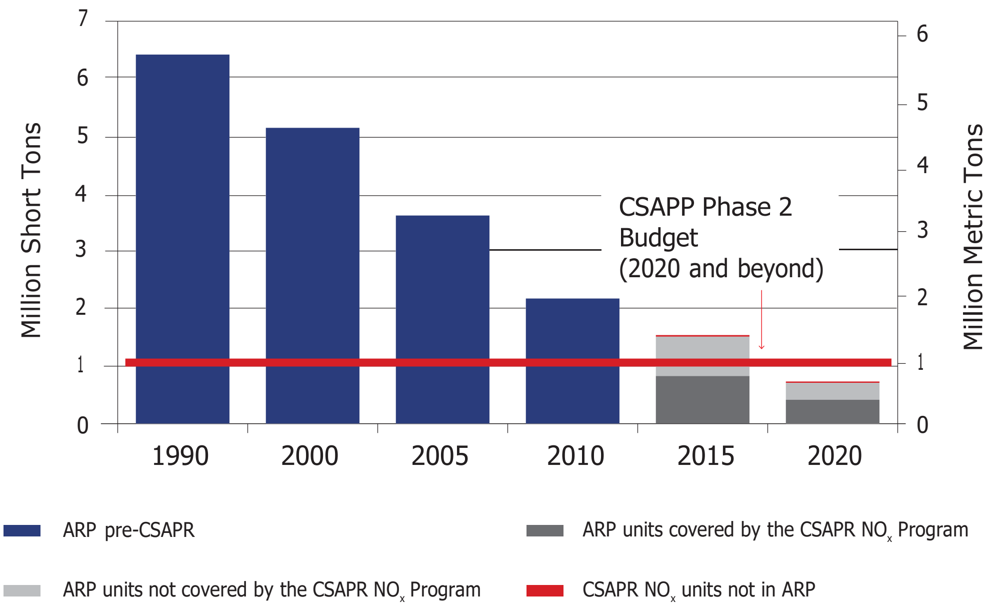
Overall, NO_x emissions have declined dramatically under the ARP, the former NO_x Budget Trading Program (NBP), the CAIR NO_x program, and the CSAPR programs, with the majority of reductions coming from coal-fired units. Other programs—such as regional and state NO_x emission control programs—also contributed significantly to the annual NO_x emission reductions achieved by sources in 2020.

In 2020, sources in both the CSAPR NO_x programs and the ARP reduced NO_x emissions by 5.7 million short tons (5.2 million metric tons) or 89 percent from 1990 levels, 4.4 million short tons (4.0 million metric tons) or 86 percent from 2000 levels, and 2.9 million short tons (2.6 million metric tons) or 80 percent from 2005 levels. Together, all ARP and CSAPR sources emitted a total of 737 thousand short tons (669 thousand metric tons) of NO_x in 2020 [see Figure 7].

Annual NO_x emissions from sources in the CSAPR NO_x programs alone fell from 2.3 million short tons (2.1 million metric tons) in 2005 to 405 thousand short tons (367 thousand metric tons) in 2020, an 81 percent reduction. This is 664 thousand tons (602 thousand metric tons), or 62 percent, below the CSAPR NOx annual program's 2020 regional budget of 1,069,256 tons (970 thousand metric tons). For more detailed information on the United States NO_x programs, see www.epa.gov/airmarkets.

In addition to ARP and CSAPR, other programs such as state and regional NO_x emission control programs, also contributed significantly to the NO_x reductions that sources achieved in 2020. Annual NO_x emissions from the power sector as well as all other sources fell from 25.2 million short tons (22.8 million metric tons) in 1990 to 8.0 million short tons (7.2 million metric tons) in 2020, a reduction of 68 percent.

Figure 7. Annual NO_x Emissions from ARP and CSAPR Sources, 1990-2020



Notes: For CSAPR units not in the ARP, the 2015 annual NO_x emissions were applied retroactively for each pre-CSAPR year following the year in which the unit began operating. There are a small number of sources in CSAPR but not in ARP. Emissions from these sources comprise about 1 percent of total emissions and are not easily visible on the full chart.

Source: U.S. EPA, 2022.

Preventing Air Quality Deterioration and Protecting Visibility

CANADA

Canada has continued to address the commitment to prevent air quality deterioration and ensure visibility protection by implementing the *Canadian Environmental Protection Act, 1999* (CEPA 1999) and the *Impact Assessment Act, 2019* and by following the principles of "continuous improvement" and "keeping clean areas clean". These principles underpin Canada's AQMS and the associated Canadian Ambient Air Quality Standards (CAAQS).

The British Columbia Visibility Coordinating Committee (BCVCC) continues to work towards completing a visibility management framework for the Lower Fraser Valley (LFV) in southwest British Columbia. Membership of the committee includes all air management agencies with responsibilities in that region. The BCVCC is currently preparing a summary of the regional visibility pilot project. The summary will inform the development of a quantitative visibility goal for the region as well as future efforts to develop visibility programs in other areas of British Columbia and Canada. The pilot project report is expected to be completed in 2023 and will be posted on the Clear Air BC website (www.clearairbc.ca/Pages/default.aspx) when complete.

A near real time visibility index for four sites in the region is available to the public through the Clear Air BC website. In 2021, the Fraser Valley Regional District adopted a new Air Quality Management Plan (2021 09 24 AQMP - Final reduced.pdf (fvrd.ca)) that includes achieving excellent visual air quality as one of its four main goals that are the drivers for air quality action in that portion of the LFV. Also in 2021, Metro Vancouver's Clean Air Plan (www.metrovancouver.org/services/air-quality/AirQualityPublications/Clean-Air-Plan-2021.pdf) renewed that area's commitment to a visibility goal – increasing the amount of time that has excellent visual air quality.

UNITED STATES

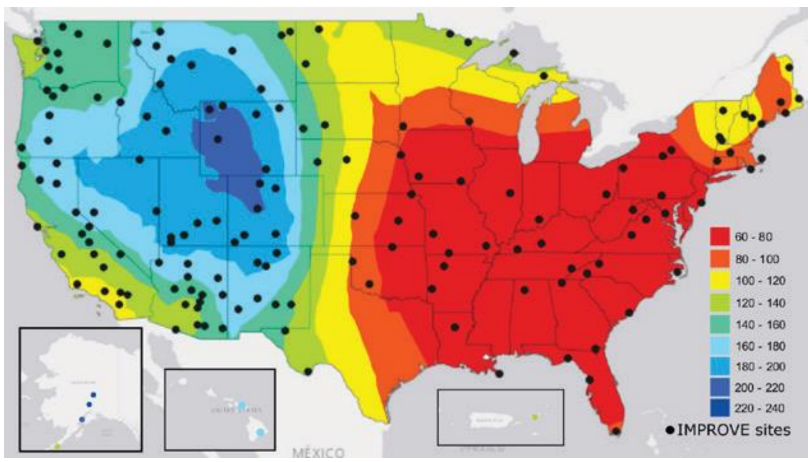
The United States continues to address its commitment to air quality and visibility protection through several Clean Air Act programs, including New Source Review (NSR) and the Regional Haze Program. The NSR program requires that new or modified sources obtain pre-construction permits in areas that meet the National Ambient Air Quality Standards (NAAQS) (i.e., attainment areas) and in areas that exceed the NAAQS (i.e., nonattainment areas). Nonattainment NSR permits for major sources require the source to apply air pollution controls that represent the lowest achievable emission rate (LAER) and obtain emissions offsets. Emissions offsets are actual emission reductions, generally obtained from sources in the vicinity of a proposed source or modification, that offset the proposed emissions increase from the proposed new or modified source and provide a net air quality benefit.

NSR permits for major sources in attainment areas are known as prevention of significant deterioration (PSD) permits and require the source to apply air pollution controls that represent the best available control technology (BACT), and demonstrate that the project's emissions will not cause or contribute to a violation of any NAAQS or PSD increments. PSD permits also require protections of the air quality and visibility in Class I areas (i.e., national parks exceeding 6,000 acres and wilderness areas exceeding 5,000 acres) and an assessment of the impacts on soils, vegetation, and visibility caused by pollution and growth resulting from the source or modification. The NSR program requires pre-construction permits for smaller sources of air pollution by way of the minor NSR program. Requirements for getting a minor NSR permit are generally less prescriptive than the requirements for a major NSR permit.

The Clean Air Act established the goal of improving visibility in the nation's 156 Class I areas and returning these areas to visibility conditions that existed before human-caused air pollution. In January 2017, the U.S. Environmental Protection Agency (EPA) issued a final rule updating the Regional Haze Program, including revising portions of the visibility protection rule promulgated in 1980 and the Regional Haze Rule promulgated in 1999. The Regional Haze Program is divided into iterative 10-year implementation periods with the goal of achieving natural conditions. The CAA requires states to develop a long-term strategy for making "reasonable progress" toward the national visibility goal. The first required plans, due in 2007, had to primarily address a one-time best available retrofit technology (BART) requirement that applied to certain older, larger stationary sources of visibility impairing pollutants. In addition, the first and subsequent plans (2nd implementation period plans were due in 2021) must include measures necessary to make reasonable progress toward the national goal. Additional information on EPA's Regional Haze Program can be found at www.epa.gov/visibility.

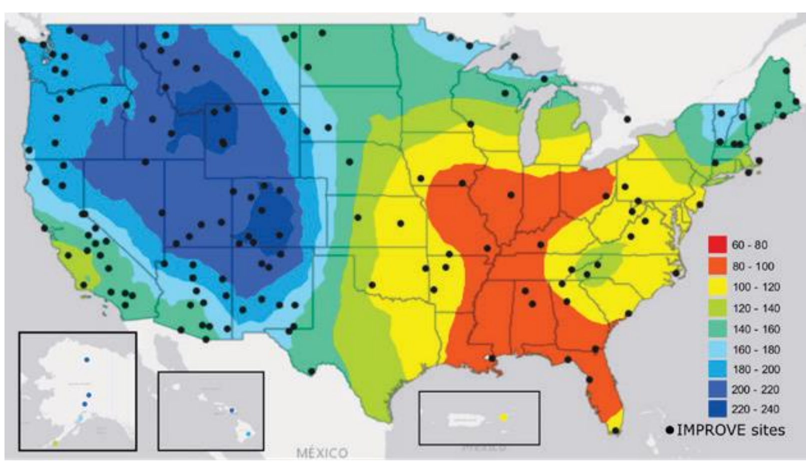
Figures 8 and 9 show the annual average "standard visual range" (the farthest distance a large, dark object can be seen during daylight hours) within the United States for the period 2000-2004 and 2016-2020, respectively. This distance is calculated using fine and coarse particle data from the Interagency Monitoring of Protected Visual Environments (IMPROVE) network. Increased particle pollution reduces the visual range. Between 2000-2004 and 2016-2020, the visual range increased throughout the United States with the largest increase occurring in the eastern United States. The visual range under naturally occurring conditions without human-caused pollution in the United States is typically 50–90 miles (80–140 kilometers [km]) in the east and 110–150 miles (180–240 km) in the west. Additional information on the IMPROVE program and visibility in U.S. National Parks can be found at www.vista.cira.colostate.edu/improve/.

Figure 8. Annual Average Standard Visual Range (km) 2000-2004



Source: U.S. NPS, 2022 (data from IMPROVE website: http://vista.cira.colostate.edu/improve/).

Figure 9. Annual Average Standard Visual Range (km) 2016-2020



Source: U.S. NPS, 2022 (data from IMPROVE website: http://vista.cira.colostate.edu/improve/).

Emissions/Compliance Monitoring

Commitments in the Agreement require Canada and the United States to apply continuous emissions monitoring or methods of comparable effectiveness to certain electric utility units. Both countries meet these commitments by using continuous emissions monitoring systems (CEMS) and rigorous reporting programs. Canada and the United States each monitor more than 90 percent of eligible SO_2 emissions with CEMS.

CANADA

Canada continues to meet its commitment to monitor and estimate emissions of NO_x and SO_2 from new and existing electric utility units with a capacity rating greater than 25 megawatts. CEMS, or other comparable monitoring methods, have had widespread use in Canada's electric utility sector since the late 1990s. Currently, a majority of new and existing base-load fossil steam plants and natural gas turbines with high emission rates operate CEMS technology. Approximately 27 coal or coal to natural gas converted generating units are currently operating in Canada. Together they represent the largest source of emissions from this sector. Out of these 27 units, 23 units have SO_2 and NO_x CEMS installed. In addition, under Canada's National Pollutant Release Inventory, a mandatory reporting program, electric power generating facilities are required to report their air pollutant emissions (including NO_x and SO_2) annually. CEMS also serves as a recognized monitoring approach to demonstrate compliance with several aspects of the *Multi-Sector Air Pollutants Regulations*.

UNITED STATES

EPA has developed detailed procedures to ensure that source owners or operators monitor and report emissions with a high degree of precision, accuracy, reliability, and consistency. Most emissions of SO_2, carbon dioxide, and NO_x are measured with continuous emissions monitoring systems (CEMS), which monitor important information such as the amount of pollution emitted from a smokestack (pollutant concentration) and some emission flow rates, i.e., how fast the emissions occur, are monitored using continuous emission rate monitoring systems (CERMS). In 2020, CEMS monitored over 99 percent of SO_2 emissions from CSAPR sources, including 100 percent from coal-fired units.

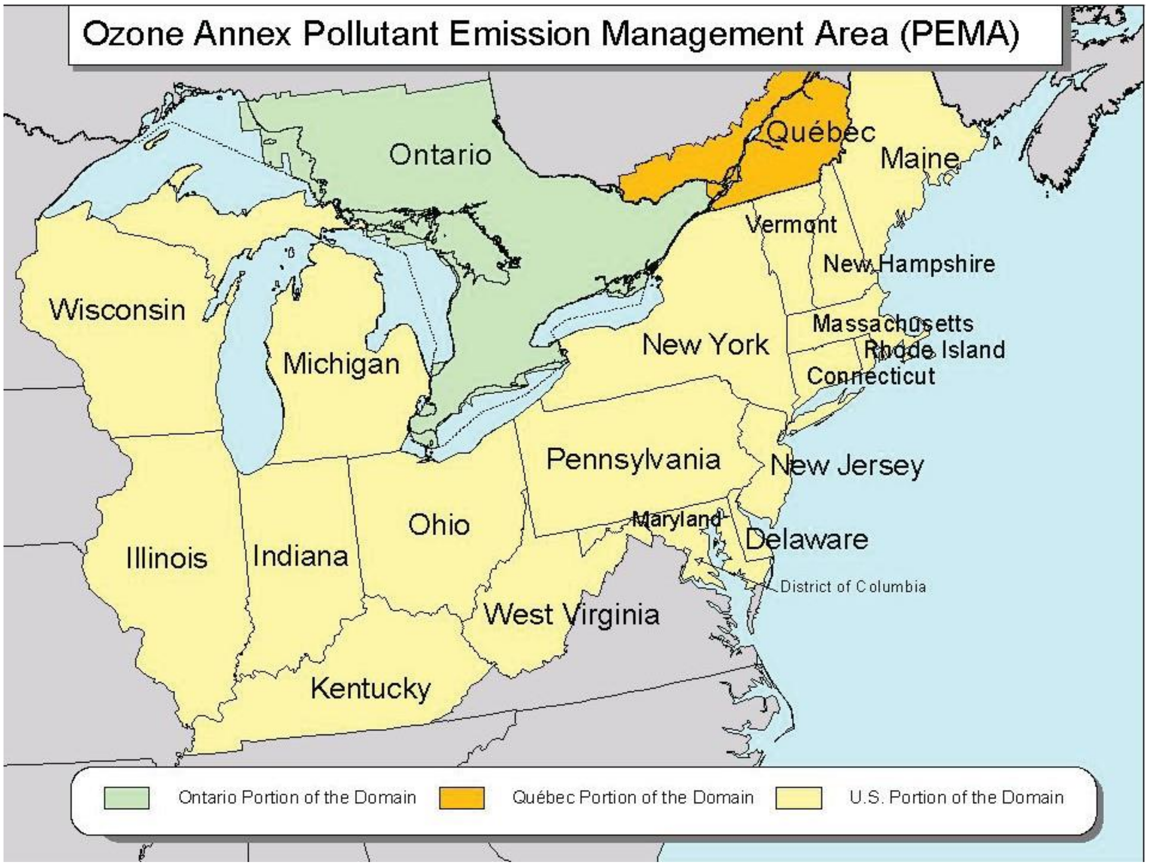
Additionally, certain large emission sources that are subject to rules promulgated before 1990 and that are equipped with pollution control devices to meet emission limitations or standards without CEMS monitoring must comply with the requirements under the Compliance Assurance Monitoring (CAM) rule. The CAM rule includes criteria that define the monitoring, reporting, and record keeping that must be conducted by a source to provide a reasonable assurance of compliance with emission limitations and standards. Rules promulgated after 1990 are to contain monitoring that provides a reasonable assurance of compliance with emission limitations and standards. EPA requires owners or operators of CEMS and CERMS to rigorously check and report on the completeness, quality, and integrity of monitoring data. In addition to electronic audits, EPA conducts targeted field audits on sources that report suspect data.

OZONE ANNEX

Ground-level ozone is a pollutant that forms when emissions of NO_x and VOCs and other pollutants react in the atmosphere in the presence of sunlight. Cars, trucks, buses, engines, industries, power plants and products such as solvents and paints are among the major man-made sources of ozone-forming emissions. A key component of smog, ground-level ozone, can cause or exacerbate respiratory illnesses, and is especially harmful to young children, the elderly, and those suffering from chronic asthma and/or bronchitis. Exposure to ground-level ozone can damage vegetation, reduce growth, and have other harmful effects on plants and trees. This can make them more susceptible to attack from insects and diseases and reduce their ability to withstand droughts, windstorms, and man-made stresses such as acid rain.

The Ozone Annex, added to the Agreement in 2000, commits the United States and Canada to address transboundary ground-level ozone by reducing emissions of NO_x and VOCs, the precursors to ozone, from stationary and mobile sources and from solvents, paints, and consumer products. The commitments apply to a defined region in both countries known as the Pollutant Emission Management Area (PEMA), which includes central and southern Ontario, southern Quebec, 18 states, and the District of Columbia, where emission reductions are most important for reducing transboundary ozone [see Figure 10].

Figure 10. Ozone Annex Pollutant Emission Management Area (PEMA)



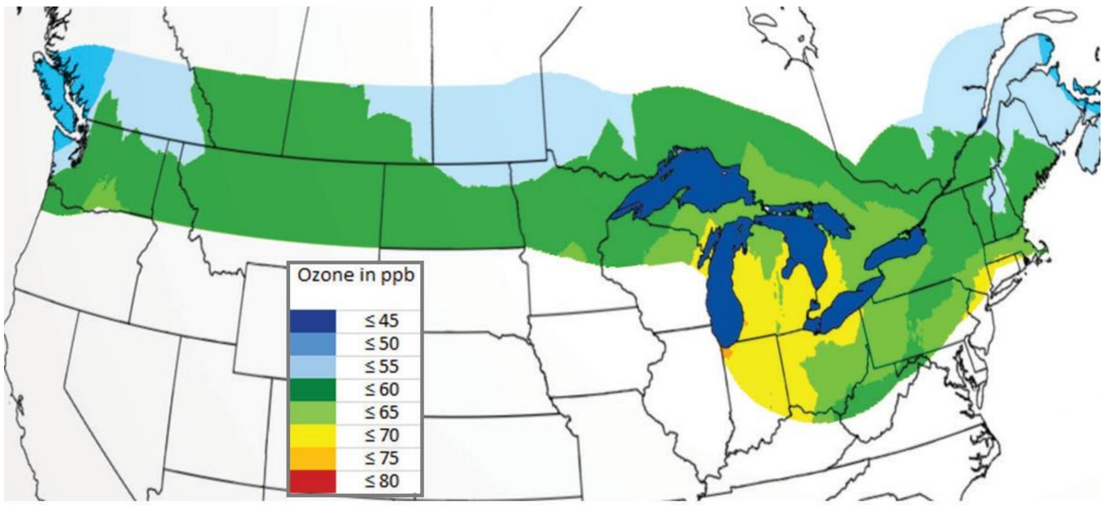
AMBIENT LEVELS OF OZONE IN THE BORDER REGION

Ozone concentrations or ambient levels in the PEMA have gradually decreased since 1995. Similarly decreasing trends in concentrations are found for both NO_x and VOCs. Regulatory and non-regulatory programs designed to meet emissions commitments in the Ozone Annex, as well as programs designed to meet air quality management goals for Canada and the United States individually, have contributed to the reductions in ozone concentrations.

Figure 11 illustrates ozone concentrations in the border region within 500 km (310 miles) of the United States–Canada border. The figure shows that higher ozone levels occur near the Great Lakes and along the United States eastern coast. The lowest values are generally found in western and eastern Canada. Levels are generally higher within and downwind of urban areas. The figure illustrates the regional pattern of ozone concentrations. Ozone is depicted in this figure as a three year average (2018-2020) of the annual fourth-highest daily maximum 8-hour concentration, in parts per billion (ppb), by volume. Only sites that met data completeness requirements (based upon 75 percent or more of all possible daily values during the EPA-designated ozone monitoring seasons) were used to develop this map.

Figure 12 shows the trend of ozone concentrations reported as the annual average fourth-highest daily maximum 8-hour ozone concentration for sites within 500 km of the United States-Canada Border for 2001-2020. Trends of NO_x and VOC concentrations for the same time period are shown in Figures 13 and 14. Ambient concentrations of NO_x and VOCs reflect the significant reductions in emissions of these ozone precursors. Ozone concentrations reflect not only precursor concentrations, but also meteorological conditions for ozone formation. While some of the lowest ozone concentration levels are associated with cool, rainy summers (2004, 2009, 2014), ozone concentration levels are mainly due to the emission reductions programs described in this report.

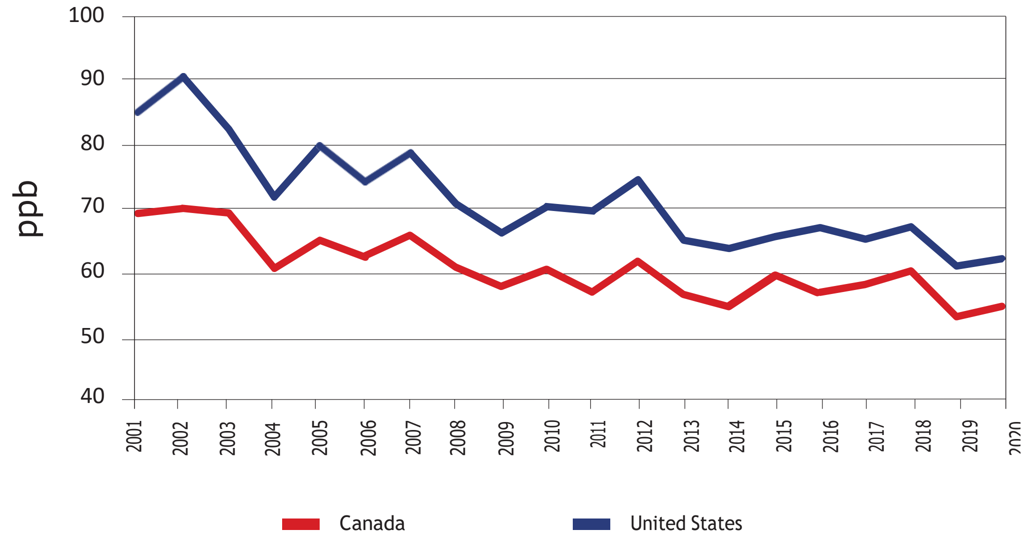
Figure 11. Ozone Concentrations along the United States–Canada Border (Three-Year Average of the Fourth-highest Daily Maximum 8-hour Concentration), 2018-2020



Note: Data are the 2018-2020 averages of annual fourth-highest daily values, where the daily value is the highest running 8-hour average for the day.

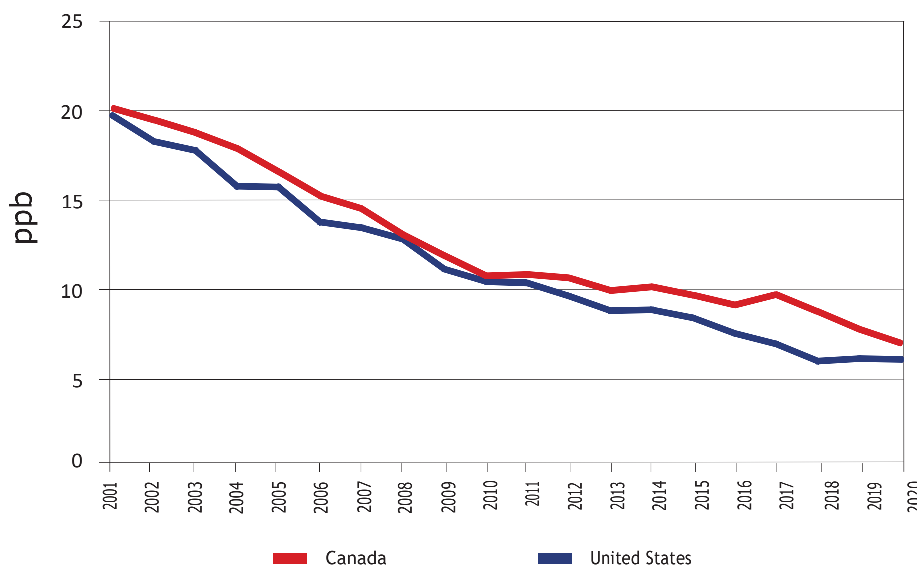
Sources: Environment and Climate Canada NAPS Network Canada-wide Database, 2022; (http://data.ec.gc.ca/data/air/monitor/national-air-pollution-surveillance-naps-program/). U.S. EPA Air Quality System (AQS) Data Mart (www.epa.gov/airdata).

Figure 12. Annual Average Fourth-Highest Daily Maximum 8-hour Ozone Concentration for Sites within 500 km of the United States-Canada Border, 2001-2020



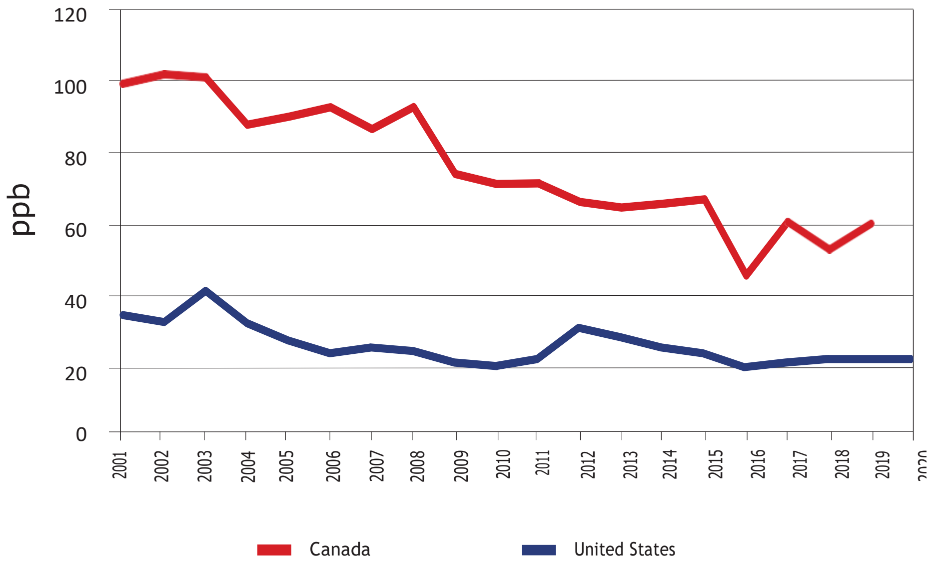
Source: U.S. EPA and Environment and Climate Change Canada, 2022.

Figure 13. Average Ozone Season (May-September) 1-hour NO_x Concentrations for Sites within 500 km of the United States-Canada Border, 2001-2020



Source: U.S. EPA and Environment and Climate Change Canada, 2022.

Figure 14. Average Ozone Season (May-September) 24-hour VOC Concentrations for Sites within 500 km of the United States-Canada Border, 2001-2020



Note: Canadian VOC data for 2020 is not yet available due to delays associated with COVID lockdowns.

Source: U.S. EPA and Environment and Climate Change Canada, 2022.

EMISSIONS AND EMISSION TRENDS IN THE PEMA

Table 1 shows 2020 Canadian and United States emissions in the PEMA. In the Canadian PEMA, the sectors that contribute the most to the area's annual NO_x emissions are on-road and non-road transportation. The sectors that contribute the most to NO_x in both the Canadian PEMA and the United States PEMA are transportation and industrial sources. The predominant sectors that contribute to annual VOC emissions in the Canadian PEMA are solvent utilization processes and non-industrial fuel combustion. Transportation and solvent utilization are the predominant sectors for VOC emissions in the United States PEMA.

Table 1. PEMA Emissions, 2020

Emissions Category	2020 Annual				2020 Ozone Season			
	NO_x		VOCs		NO_x		VOCs	
	1000 Short Tons	1000 Metric Tons	1000 Short Tons	1000 Metric Tons	1000 Short Tons	1000 Metric Tons	1000 Short Tons	1000 Metric Tons
Canadian PEMA Region: Annual and Ozone Season Emissions								
Industrial Sources	59	53	69	62	28	26	29	27
Non-industrial Fuel Combustion	40	36	66	60	12	10	9	8
Electric Power Generation	5	5	0	0	2	2	0	0
On-road Transportation	136	123	52	47	54	49	21	19
Non-road Transportation	113	103	64	58	56	51	25	23
Solvent Utilization	0	0	161	146	0	0	69	62
Other Anthropogenic Sources	3	3	80	73	2	1	41	37
Forest Fires	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biogenic Emissions	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TOTALS	**355**	**322**	**492**	**446**	**153**	**139**	**194**	**176**
TOTALS without Forest Fires and Biogenics	**355**	**322**	**492**	**446**	**153**	**139**	**194**	**176**
U.S. PEMA States: Annual and Ozone Season Emissions								
Industrial Sources	464	421	490	445	193	175	204	185
Non-industrial Fuel Combustion	271	246	146	132	113	103	61	55
Electric Power Generation	222	201	10	9	93	84	4	4
On-road Transportation	699	634	425	386	291	264	177	161
Non-road Transportation	535	485	364	330	223	202	152	138
Solvent Utilization	0	0	1,073	973	0	0	447	406
Other Anthropogenic Sources	50	45	392	356	21	19	163	148
Forest Fires	3	3	42	38	1	1	18	16
Biogenic Emissions	189	171	3,778	3,427	114	103	3,171	2,877
TOTALS	**2,433**	**2,206**	**6,720**	**6,096**	**1,049**	**951**	**4,397**	**3,990**
TOTALS without Forest Fires and Biogenics	**2,241**	**2,032**	**2,900**	**2,631**	**934**	**847**	**1,208**	**1,097**

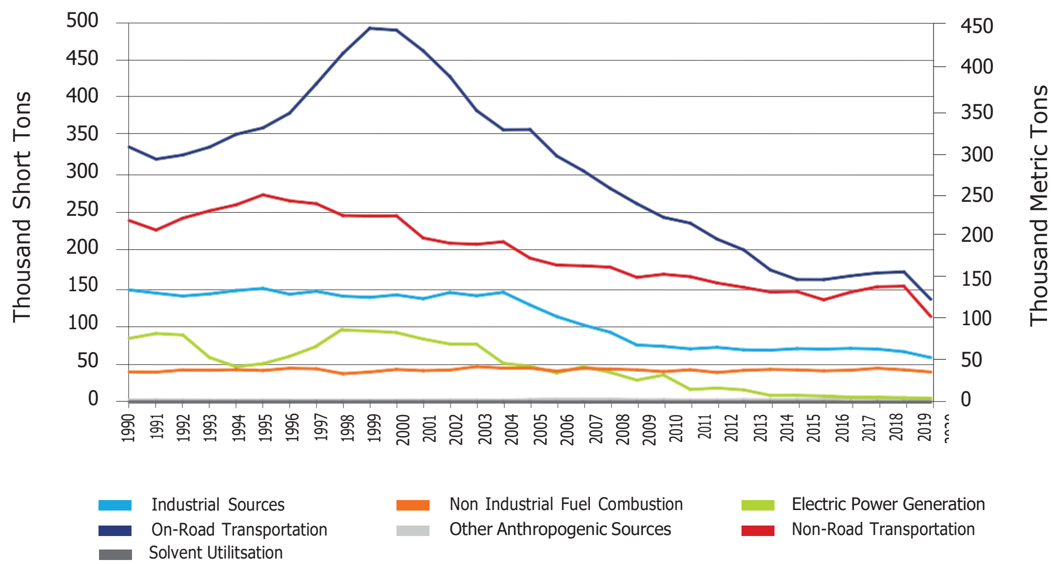
Note: Short tons and metric tons are rounded to the nearest thousand. Totals in rows may not equal the sum of the individual columns.

Source: Environment and Climate Change Canada and U.S. EPA, 2022.

Figures 15 and 16 show Canadian NO_x and VOC PEMA emission trends for the years 1990 through 2020. NO_x and VOC emissions have decreased in the PEMA over this period. The percent decrease in emissions from 1990 to 2020 for NO_x is 58 percent and for VOCs is 61 percent. For NO_x, nearly all source categories show an overall decrease in emissions with the greatest reductions originating from electric power generation, followed by industrial sources and on-road transportation. On-road and non-road transportation contributed to the greatest portion of NO_x PEMA emissions in 2020, followed by industrial sources and non-industrial fuel combustion.

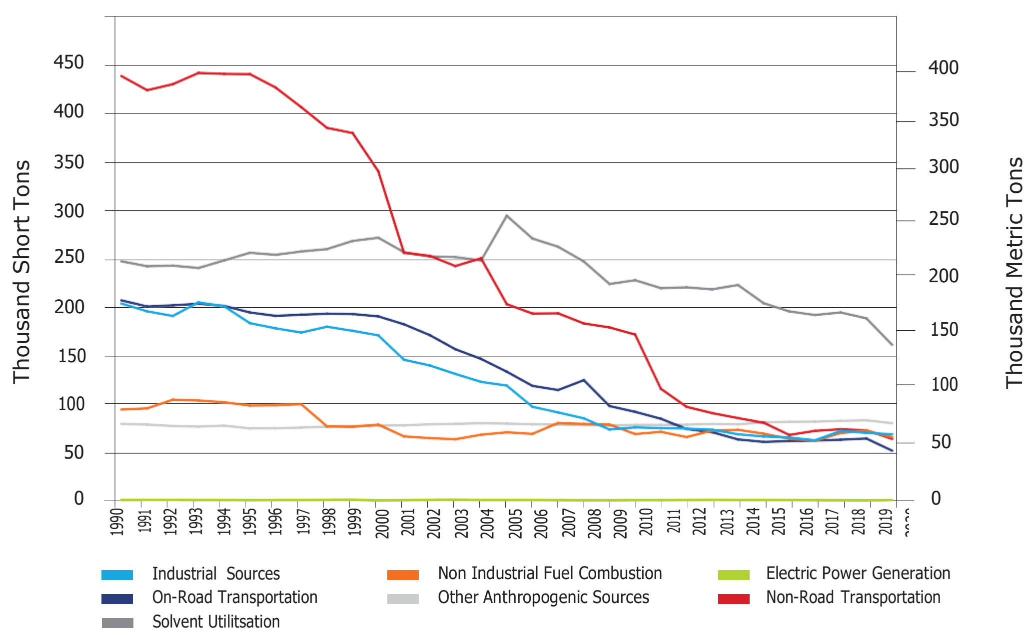
Over the same time period, each category of VOC sources shows an overall decrease with most of the reductions coming from non-road transportation sources, on-road transportation sources and industrial sources. Solvent utilization accounted for the greatest portion of VOC PEMA emissions in 2020 followed by other anthropogenic sources and industrial sources.

Figure 15. Canada NO_x Emission Trends in the PEMA Region, 1990-2020



Source: Environment and Climate Change Canada, 2022.

Figure 16. Canada VOC Emission Trends in the PEMA Region, 1990-2020

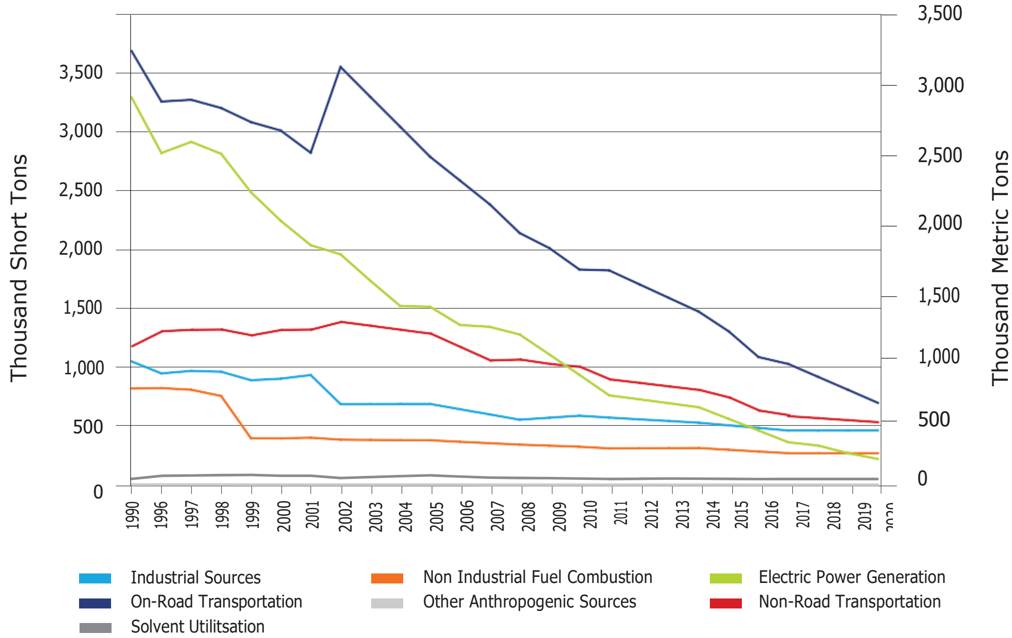


Source: Environment and Climate Change Canada, 2022

Figures 17 and 18 show United States PEMA emission trends for 1990 through 2020. There has been an overall trend of emission reductions for NO_x and VOCs. The percent decrease in emissions from 1990 to 2020 for NO_x is 78 percent and for VOCs is 68 percent. For NO_x emissions, the on-road and non-road transportation sources account for the greatest portion of the emissions in 2020, followed by fuel combustion for electrical power generation and industrial and non-industrial boilers. The largest NO_x emission reductions from these sources have occurred over the last 15 years.The sharp increase in NO_x emissions for on-road transportation in 2002 is due to a different estimation method beginning with that year.

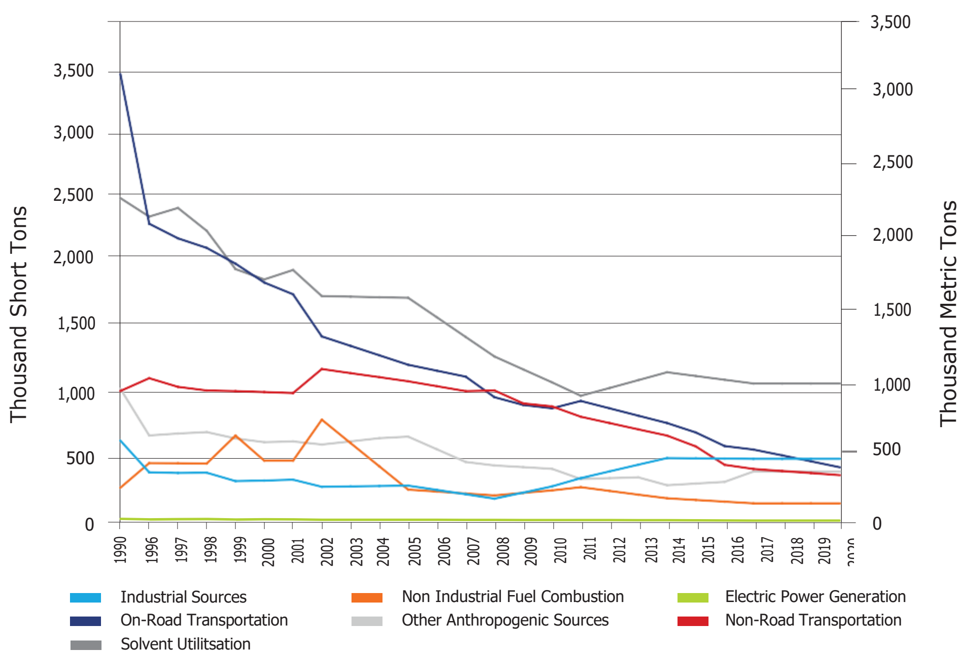
The greatest contributions of VOC emissions since 2012 are predominantly from solvent utilization and transportation sources. Over the period shown in Figure 18, the largest VOC emission reductions have occurred in on-road mobile sources and solvent utilization. While there is an overall decrease in VOC emissions, there have been some increases for petroleum and related industries, including oil and gas production. Emission estimation methods and reporting for these sources have also improved significantly in recent years.

Figure 17. U.S. NO_x Emission Trends in PEMA States, 1990-2020



Source: U.S. EPA, 2022.

Figure 18. U.S. VOC Emission Trends in PEMA States, 1990-2020



Source: U.S. EPA, 2022.

ACTIONS TO ADDRESS OZONE

Canada and the United States continue to implement programs designed to reduce emissions of NO_x and VOCs. Emissions from power plants, vehicles and engines remain a focus of these programs.

CANADA

Canada is implementing a series of regulations to align Canadian emission standards for vehicles, engines, and fuels with corresponding standards in the United States.

Four regulations which set emission performance standards for air pollutant emissions from on-road and off-road vehicles are in effect. They include:

- *On-Road Vehicle and Engine Emission Regulations*;
- *Off-Road Small Spark-Ignition Engine Emission Regulations*;
- *Off-Road Compression-Ignition (Mobile and Stationary) and Large Spark-Ignition Engine Emission Regulations*; and,
- *Marine Spark-Ignition Engine, Vessel, and Off-Road Recreational Vehicle Emission Regulations*.

Regulations that have been subject to recent amendments are set out below.

Canada continues to work synergistically with the United States in administering and enforcing its vehicle and engine emission regulations. Highlighting progress from prior reports, ECCC has aligned its regulations with the latest EPA Tier 3 standards for certain on-road vehicles as well as EPA Phase 3 emission standards for the control of both exhaust and evaporative emissions from small spark-ignition engines. ECCC also adopted the Marine Spark-Ignition Engine, Vessel and Off-Road Recreational Vehicle Emission Regulations. These emission regulations apply to outboard engines, inboard engines, personal watercraft, snowmobiles, off-road motorcycles and all-terrain vehicles. The standards align with corresponding U.S. EPA rules.

Regulatory initiatives for gasoline include *Sulphur in Gasoline Regulations* and *Benzene in Gasoline Regulations*, which have limited the level of sulfur and benzene content in gasoline. In addition, *Sulphur in Diesel Fuel Regulations* set maximum limits for sulfur in diesel fuels. Sulfur in gasoline impairs the effectiveness of emission control systems and contributes to air pollution. Reducing the sulfur content in gasoline enables advanced emission controls and reduces air pollution.

In December 2020, ECCC published the *Off-road Compression-Ignition (Mobile and Stationary) and Large Spark-Ignition Engine Emission Regulations*. These regulations incorporate the EPA Tier 2 emission standards for large spark-ignition (LSI) engines, such as those used in forklifts and ice resurfacers, and the EPA Tier 4 emission standards for stationary diesel engines, such as those used in fire pumps and back-up generators. Prior to these regulations, LSI engines and stationary diesel engines were not subject to any emission standards in Canada. These regulations also repealed and replaced the *Off-Road Compression-Ignition Engine Emission Regulations*, and combined the previous mobile diesel engine standards together with new LSI engine and stationary diesel engine standards into one consistent framework. These regulations apply to LSI engines and stationary diesel engines manufactured on or after June 4, 2021 and mobile diesel engines of the 2006 and later model years must meet the applicable emissions standards in place at their time of manufacture. The regulations will work to reduce air pollutant emissions from all three types of off-road engines.

In October 2022, ECCC published the *Regulations Amending Certain Regulations Made Under the Canadian Environmental Protection Act, 1999*. The purpose of these amendments was to maintain alignment with the corresponding technical amendments made by the EPA in their final rule entitled Improvements for Heavy-Duty Engine and Vehicle Test Procedures, and Other Technical Amendments. Many changes made by the EPA were automatically adopted in Canadian vehicle and engine emission regulations due to incorporation by reference. However, some modifications were required in the Canadian context, such as modifying definitions and regulatory text and updating some references to the Code of Federal Regulations (CFR). The amendments made minor modifications to three of the vehicle and engine emission regulations under the *Canadian Environmental Protection*

Act, 1999: the *Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations*, the *On-Road Vehicle and Engine Emission Regulations*, and the *Marine Spark-Ignition Engine, Vessel and Off-road Recreational Vehicle Emission Regulations*. The amendments also made modifications to the *Off-road Compression-Ignition (Mobile and Stationary) and Large Spark-Ignition Engine Emission Regulations* to correct a regulatory misalignment with the EPA regulations, including definitions, labeling, and maintenance instructions for certain large spark-ignition engines. There were no changes made to the stringency of any emission standards that are currently in effect.

Currently, ECCC and the EPA are collaborating on initiatives to reduce emissions of air pollutants and greenhouses gases (GHGs) further from on-road vehicles, with a view of increasing zero-emission vehicle deployment in both countries. In February 2021, as part of the Roadmap for a Renewed Canada-U.S. Partnership, Canada's Prime Minister and the U.S. President agreed to take aligned and accelerated policy actions to achieve a zero-emission vehicle future.

In March 2022, the Government of Canada released its 2030 Emissions Reduction Plan that outlines how the Government proposes to set and achieve its climate targets. In order to support the switch to zero-emission on-road vehicles and ensure their affordability and accessibility, the Plan outlines the Government's commitment to:

- develop a regulated sales mandate to ensure that 100 percent of new passenger vehicles sold in Canada will be zero emission by 2035, with interim targets of at least 20 percent by 2026 and 60 percent by 2030.
- launch an integrated strategy to reduce emissions from medium-and heavy-duty vehicles with the aim of reaching 35 percent of total sales being zero-emission vehicles (ZEVs) by 2030; and
- develop a regulation that will require 100 percent medium- and heavy-duty vehicle sales to be ZEVs by 2040 for a subset of vehicle types based on feasibility, with interim 2030 regulated sales requirements that would vary for different vehicle categories based on feasibility, and explore interim targets for the mid-2020s.

The transition to ZEVs will result in significant reductions in emitted air pollutants as well as GHGs.

The federal government also continues to address VOC emissions through various regulations. The *Tetrachloroethylene (Use in Dry Cleaning and Reporting Requirements) Regulations* were published in March 2003 with the goal of reducing tetrachloroethylene (PERC) use in dry cleaning in Canada to less than 1,600 (1,760 short tons) metric tons per year. In 2019, dry cleaners reporting under the regulations used less than 300 metric tons (330 short tons) of PERC.

The *Solvent Degreasing Regulations*, which took effect in July 2003, required a 65 percent reduction in annual consumption of trichloroethylene (TCE) and PERC from affected facilities by 2007. This usage has continued to decline. Under the regulations, ECCC issues annual allowances (consumption units) for use of PERC or TCE to qualifying facilities. Consumption units issued for 2020 represented a reduction of 89 percent for TCE and 88 percent for PERC relative to the baseline.

ECCC has taken action to reduce VOC emissions from consumer and commercial products. The *Volatile Organic Compound (VOC) Concentration Limits for Automotive Refinishing Products Regulations and the Volatile Organic Compound (VOC) Concentration Limits for Architectural Coatings Regulations* were published in 2009. By 2016, these two regulations had contributed to an estimated reduction in VOC emissions from surface coatings of 43 percent, compared to 2004 levels.

In January 2022, the department published the *Volatile Organic Compound (VOC) Concentration Limits for Certain Products Regulations*. The Regulations establish maximum VOC concentration limits and emissions potential for the manufacture and import of over 130 categories and sub-categories of products, including personal care, automotive, and household maintenance products, adhesives, adhesive removers, sealants, and caulks and other miscellaneous products. Between 2024 and 2033, the Regulations are expected to result in 250,000 metric tons (275,000 short tons) of VOC emission reductions.

The *Code of Practice for the Reduction of Volatile Organic Compound (VOC) Emissions from Cutback and Emulsified Asphalt* came into effect in February 2017. The main objective of the Code has been to encourage the use of low VOC-emitting asphalt products. It is anticipated that compliance with the Code will result in annual VOC emission reductions of up to 5,000 metric tons (5,500 short tons) from the use of asphalt.

ECCC has taken action to put in place requirements to limit VOC emissions from industrial facilities. In April 2018, ECCC published *Regulations Respecting the Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas)* which came into effect January 2020. These regulations introduce operating and maintenance standards for the upstream oil and gas industry, ensuring that fugitive and venting emissions of hydrocarbon gas will be reduced at oil and gas extraction facilities. In November 2020, the Government of Canada finalized the *Reduction in the Release of Volatile Organic Compounds Regulations (Petroleum Sector)*, to reduce emissions of VOCs from refineries, upgraders, and certain petrochemical facilities. In May 2021, the Government of Canada published a discussion document proposing a regulatory approach to control VOC emissions from the storage and transfer of petroleum liquids. The proposed approach addresses emissions from large storage tanks, and from transfer racks at truck, rail and marine terminals and other bulk storage facilities. In March 2022, the Government of Canada published a discussion paper on further reducing methane emissions from Canada's oil and gas sector.

New CAAQS for fine particulate matter ($PM_{2.5}$) and ground-level ozone, effective for the years 2015 and 2020, were established as objectives under the CEPA 1999 by the federal government in 2013, having been approved by federal, provincial, and territorial Ministers of the Environment. In 2017 new standards were established for SO_2 and NO_x, effective for years 2020 and 2025. These health-and environment-based standards are regularly reviewed to ensure they are set at the appropriate level, reflecting the latest scientific information and technological advances. A review of the 2020 ozone standard was completed in 2019 resulting in a more stringent standard for 2025 being established in June 2019. A review of the $PM_{2.5}$ standards is ongoing. The CAAQS are objectives underpinned by four air quality management levels with thresholds that require increasingly more stringent action as the air quality in a given air zone approaches the level of the standard.

★ UNITED STATES

The U.S. EPA has established NAAQS for six principal pollutants shown to be harmful to public health and the environment, including ground-level ozone. In 2015, EPA revised the level of ozone NAAQS from 0.075 ppm to 0.070 ppm. When EPA establishes a new or revised NAAQS, the Clean Air Act directs EPA to designate all areas in the country as attainment, nonattainment, or unclassifiable (insufficient information to support a nonattainment or attainment designation). EPA completed initial designations for the revised NAAQS in 2018, with 52 areas designated as nonattainment. Nineteen of these nonattainment areas are fully or partially located in the ozone PEMA.

Ozone nonattainment areas are subject to planning and emission reduction requirements as specified in the Clean Air Act. The requirements and attainment dates vary according to the severity of the air quality levels in each area. State plans must provide for expeditious attainment of the NAAQS, taking into account existing national emission reduction programs (e.g., since 2000 EPA has finalized numerous emissions and fuel standards for cars, trucks, and nonroad engines); adoption of reasonably available control measures on local sources in the area; and regional emission reductions from programs designed to address interstate transport of air pollution that affects the ability of downwind states to meet and maintain the NAAQS.

EPA has addressed interstate transport of air pollution contributing to ozone nonattainment through successive multi-state programs designed to help downwind states attain and maintain ozone NAAQS (as well as other NAAQS): the NO_x State Implementation Plan (SIP) Call in 1998 (1979 1-hour ozone NAAQS), CAIR in 2005 (1997 8-hour ozone NAAQS), CSAPR in 2012 (1997 8-hour ozone NAAQS), CSAPR Update in 2016 (2008 ozone NAAQS), and Revised CSAPR Update in 2021 (2008 ozone NAAQS). The Revised Cross-State Air Pollution Rule (CSAPR) Update for the 2008 NAAQS, published in April 2021, requires additional NO_x emissions reductions relative to the CSAPR Update from power plants in 12 states. Specifically, beginning with the 2021 ozone season, emission reductions are required at power plants in these 12 states based on optimization of existing, already-installed selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) controls beginning in the 2021 ozone season, and installation or upgrade of state-of-the-art NO_x combustion controls beginning in the 2022 ozone season. Overall, these programs have addressed regional interstate transport of ozone by requiring identified states to make reductions in NO_x emissions that contribute to ozone pollution in downwind states. These programs have contributed significantly to the ozone season NO_x reductions, enhancing public health and environmental protections regionally and for local communities.

In 2020, the CSAPR NO_x ozone season program emissions were 31 percent below the regional emission budget of 337,677 tons (306,000 metric tons). Group 1 emissions totaled 24,041 tons (22,000 metric tons) and Group 2 emissions totaled 313,626 tons (285,000 metric tons).

In addition to implementing existing United States vehicle, non-road engine, and fuel quality rules to achieve both VOC and NO_x reductions, EPA continues implementation and updating of New Source Performance Standards to achieve VOC and NO_x reductions from new and modified sources. Reductions of NO_x emissions are also being achieved through rules on solid waste incineration units and guidelines that impact new and existing incineration units.

In August 2021, President Biden issued Executive Order 14,037 on Strengthening American Leadership in Clean Cars and Trucks. This Executive Order (EO) sets a goal that 50 percent of all new passenger cars and light trucks sold in 2030 be zero-emission vehicles. In addition, it directs EPA to consider beginning work on new multi-pollutant emissions standards, including for greenhouse gas (GHG) emissions, for light and medium duty vehicles beginning with model year 2027 and extending through and including at least model year 2030. It also directs EPA to consider beginning work on a rulemaking under the Clean Air Act to establish new NO_x standards for heavy-duty engines and vehicles beginning with model year 2027 and extending through and including at least model year 2030, and new GHG standards for these vehicles beginning as soon as model 2030. In line with the President's EO, on March 28, 2022, EPA published a proposed rule that would set new, more stringent standards to reduce pollution from heavy-duty vehicles and engines starting in model year 2027. The proposed standards would significantly reduce emissions of smog-and soot-forming NO_x from heavy-duty gasoline and diesel engines and set more stringent GHG standards for certain commercial vehicle categories.

SCIENTIFIC AND TECHNICAL COOPERATION AND RESEARCH

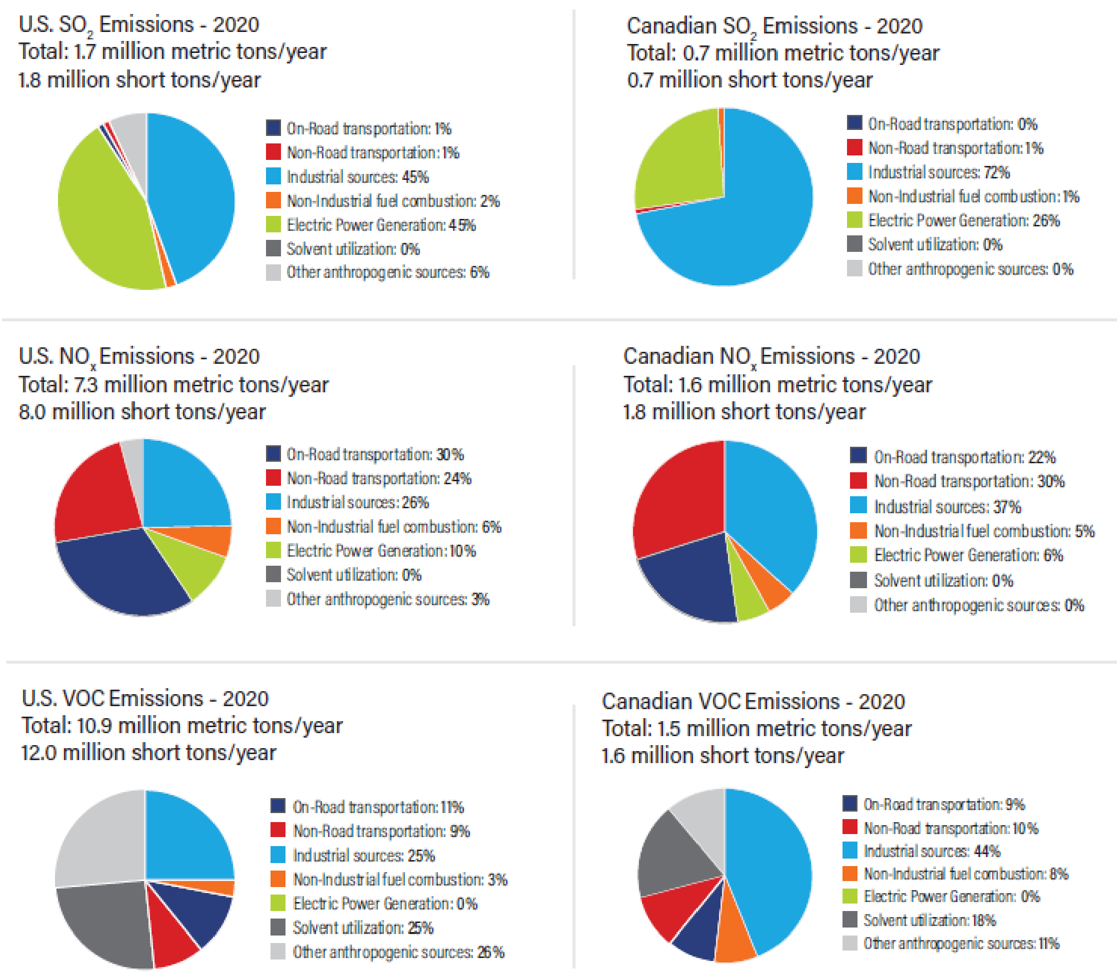
EMISSION INVENTORIES AND TRENDS

The United States and Canada have updated and improved their emission inventories and projections for a number of important pollutants, including particulate matter less than or equal to 10 microns (PM_{10}), $PM_{2.5}$, VOCs, NO_x, and SO_2, to reflect the latest information available. In Canada, the emissions inventory data are for the year 2020, as published in Canada's 2022 Air Pollutant Emissions Inventory. The United States emissions data are based on national and state-level trend information from the 2017 National Emission Inventory (www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data).

Figure 19 shows the distribution of emissions by source category grouping for SO_2, NO_x, and VOCs.

- Canadian SO_2 emissions originate mostly from the industrial sources such as the non-ferrous refining and smelting industry and the upstream oil and gas industry, and coal-fired electric power generation. The relative contribution from electric power generation utilities is lower in Canada due to the large hydroelectric and nuclear capacity in place.
- SO_2 emissions in the United States originate primarily from coal-fired combustion in the electric power sector and from industrial boilers.
- In Canada, non-road and on-road transportation sources account for the greatest portion of NO_x emissions, followed by industrial sources such as the upstream oil and gas industry.
- Similarly, in the United States non-road and on-road vehicles account for the greatest portion of NO_x emissions, followed by industrial sources.
- Solvent utilization and industrial sources contribute more than half the total VOC emissions in both Canada and the United States.

Figure 19. U.S. and Canadian National Emissions by Sector for Selected Pollutants, 2020



Notes: Emissions exclude natural sources (biogenics and forest fires).
Percentages may not add up to 100 due to rounding.

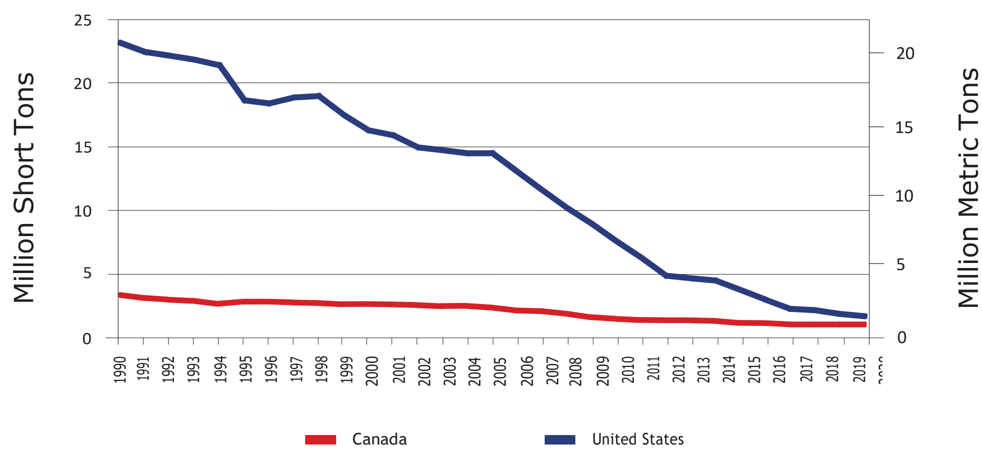
Source: Environment and Climate Change Canada, 2022; U.S. EPA, 2022.

Figures 20, 21, and 22 show emissions trends from 1990 through 2020 in Canada and the United States, for SO_2, NO_x, and VOCs, respectively. Both countries have seen major reductions in emissions.

In Canada, the reductions in SO_2 emissions came from the non-ferrous smelting and refining industry, coal-fired electric power generation, and the oil and gas industry. For NO_x, the reductions were from coal-fired electric power generation and transportation-related sources. The VOC reductions came from transportation-related sources such as off-road and on-road vehicles and the manufacturing industry.

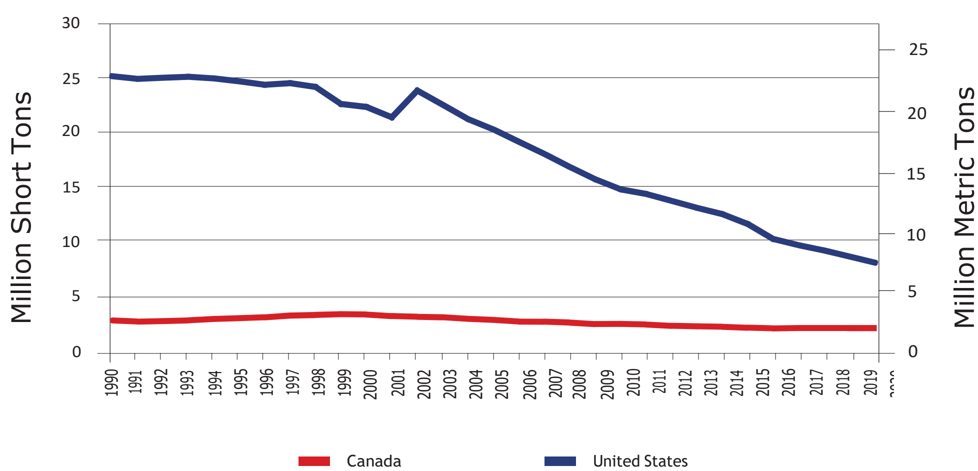
In the United States, the reductions in SO_2 emissions came in all source categories, especially electric power generation and industrial sources. Reductions in NO_x emissions came from transportation and electric power generation. Reductions in VOC emissions came from transportation as well as non-industrial fuel combustion.

Figure 20. National SO_2 Emissions in the United States and Canada from All Sources, 1990-2020



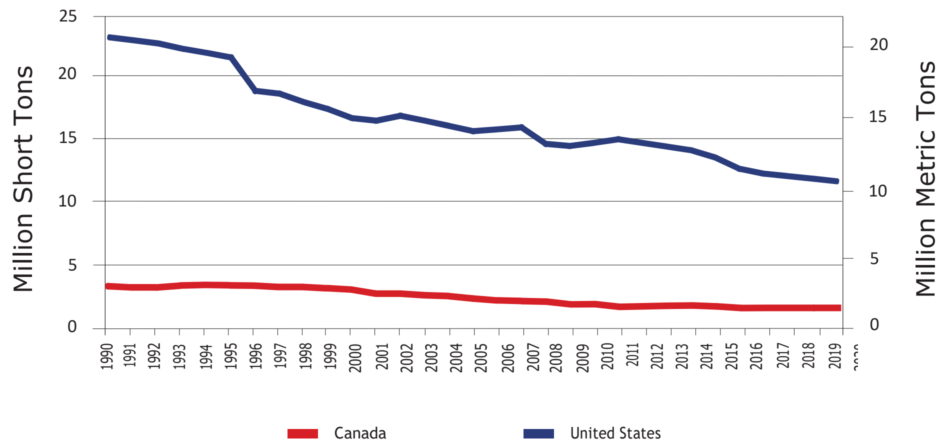
Source: U.S. EPA and Environment and Climate Change Canada, 2022.

Figure 21. National NO_x Emissions in the United States and Canada from All Sources, 1990-2020



Source: U.S. EPA and Environment and Climate Change Canada, 2022.

Figure 22. National VOC Emissions in the United States and Canada from All Sources, 1990-2020



Source: U.S. EPA and Environment and Climate Change Canada, 2022.

SCIENTIFIC COOPERATION

In addition to emissions reductions and ozone goals, the United States and Canada have committed to numerous areas of scientific cooperation. Many of these projects are longstanding and have promoted mutual learning on important topics. Projects that are highlighted in this report include: the Air Quality Model Evaluation International Initiative (AQMEII), collaborative projects on nitrogen and sulfur deposition, science information exchange workshops, cooperation on mobile transportation sources, and cooperation on oil and gas sector emissions.

Air Quality Model Evaluation International Initiative

Since its start in 2008, the Air Quality Model Evaluation International Initiative (AQMEII) has been coordinated by the European-Commission Joint Research Center (JRC) and the EPA. The primary goal of this project is to promote the collaboration of the European and North American regional scale air quality modeling communities on evaluation of air quality models. The key elements driving the AQMEII process are regular, dedicated workshops; the organization of international model evaluation studies; and the dissemination of findings from these studies in the peer-reviewed literature.

To date, AQMEII has completed three phases of collaborative model evaluation and intercomparison activities and the fourth phase is currently underway. These collaborations involved a total of 37 groups from 17 countries. Besides co-chairing AQMEII with the JRC, EPA also contributes Community Multiscale Air Quality Modeling (CMAQ) simulations to these collaborative activities, allowing comparison of various aspects of CMAQ to other state-of-science regional air quality models used by the North American and European modeling communities. ECCC has contributed simulations using its AURAMS (AQMEII-1 and GEM-MACH models (AQMEII-2, AQMEII-4)), as well as contributing to the design of the study protocols through participation in the AQMEII steering committees.

In the first phase of AQMEII (2010-2012), chemical transport models were applied by different groups over the North American and European continents and extensively evaluated based on the comprehensive model evaluation framework presented by Dennis et al.[5] This framework promotes a gradual and fit-for-purpose multi-stage evaluation process that includes operational, diagnostic, dynamic, and probabilistic (i.e., uncertainty) evaluation. While all these model evaluation modes were employed in Phase 1, most of the contributions focused on operational and probabilistic evaluation as noted in Schere et al.[6], who reflected on lessons learned from that activity.

Phase 2 of AQMEII (2012-2014) focused on applying and evaluating on-line coupled or integrated chemistry transport models and meteorological models. Such modeling systems attempt to close some or all of the feedback loops that exist between atmospheric dynamics and composition. A key feature of AQMEII-2 was a detailed evaluation of the impacts of air pollution on weather and the skill of fully coupled models on weather forecasts[7, 8]. The model evaluation framework presented by Dennis et al.[9] also formed the basis for the work under AQMEII Phase 2. Compared to Phase 1, contributions covered a fuller range of this framework, most notably diagnostic evaluation as well as some aspects of dynamic and probabilistic evaluation.

Some of the key findings from Phase 2 of AQMEII included:

- It is important to include interactions between meteorology and chemistry (especially aerosols and ozone) in online coupled models;
- Aerosol indirect and direct effects often counteract each other - direct effects are weaker on the annual scale;
- The aerosol indirect effect (cloud microphysics implementation) is a prime cause of model differences;
- The representation of aerosol indirect effects needs to be further developed and improved in online coupled models; and
- Inter-model variability typically is greater than the feedback effects simulated with a given model. This last finding implies that factors other than feedback effects such as emissions, boundary conditions, and process representations of chemistry and/or transport remain the key determinants for overall model performance.

Phase 3 of AQMEII (2014-2018) was aimed at applying and comparing modeling techniques to provide information on the impact of long-range transport on regional air quality. Modeling this phenomenon requires representing relevant processes at hemispheric-to-regional scales, either by using global or linked global-regional scale modeling systems. AQMEII contributed to coordinated modeling exercises to apply and intercompare these modeling approaches in partnership with the Task Force on Hemispheric Transport of Air Pollution (HTAP) and the Model Intercomparison Study for Asia (MICS-Asia). Results were published in the journal Atmospheric Chemistry and Physics in a special issue entitled "Global and regional assessment of intercontinental transport of air pollution: results from HTAP, AQMEII and MICS".[10] The special issue contains publications that investigate various aspects of modeling intercontinental transport of air pollution such as publications evaluating the joint HTAP, AQMEII and MICS modeling experiments, publications developing new methodologies to assess intercontinental transport or air pollution, and publications describing and evaluating observational and emission data sets used to study intercontinental transport.

---

[5] Dennis, R., Fox, T., Fuentes, M. *et al*. A framework for evaluating regional-scale numerical photochemical modeling systems. *Environ. Fluid Mech*. **10**, 471–489 (2010). https://doi.org/10.1007/s10652-009-9163-2

[6] Schere, K., Vautard, R., Solazzo, E., Hogrefe, C., and Galmarini, S. Results and Lessons Learned from Phase 1 of the Air Quality Model Evaluation International Initiative (AQMEII). EM (Pittsburg, Pa). **July**, 30-37, (2012): 30-37, (2012).

[7] Makar, P.A., Gong, W., Milbrandt, J., *et al*. Feedbacks between air pollution and weather, part 1: Effects on weather. *Atmos. Environ*., 11**5**, 442-469, (2015). https://doi.org/10.1016/j.atmosenv.2014.12.003

[8] Makar, P.A., Gong, W., Hogrefe, C., *et al*. Feedbacks between air pollution and weather, part 2: Effects on chemistry. *Atmos. Environ*. 11**5**, 499-526, (2015). https://doi.org/10.1016/j.atmosenv.2014.10.021

[9] Dennis, R., Fox, T., Fuentes, M. *et al*. A framework for evaluating regional-scale numerical photochemical modeling systems. *Environ. Fluid Mech*. **10**, 471–489 (2010). https://doi.org/10.1007/s10652-009-9163-2

[10] Available at http://www.atmos-chem-phys.net/special_issue390.html

Phase 4 of AQMEII focuses on performing systematic intercomparisons of atmospheric deposition estimates from a variety of modeling systems used in the U.S. and Europe. A Steering Committee was formed in 2018 and has conducted an analysis of the aspects to be considered in the planned evaluation activities. The Steering Committee included representatives from ECCC and EPA. The analysis performed by the Steering Committee included a harmonization of the nomenclatures (for example, making sure that a specific definition of a resistance or conductance would comprise the same processes across different models, since no common nomenclature exists in general and across schemes), a harmonization of the reported land use categories to make sure that sophisticated land descriptions could be comparable with less sophisticated ones, and a determination of variables and parameters which can be used to represent equivalent deposition-related pathways across models with different deposition formulations. Study protocols were released in the summer of 2019, and most but not all model simulations were completed by the summer of 2021. Analysis of these simulations has been initiated and a few additional simulations are still being performed and will be included in the final analysis. To complement the grid model intercomparison, AQMEII4 also includes a box model intercomparison of ozone dry deposition schemes at the location of eight flux measurement sites. Detailed observational data to drive and evaluate the box models at these sites has been obtained and shared with participating groups. A technical note describing the AQMEII4 grid model intercomparison has been published[11] in a dedicated special issue[12] and additional manuscripts describing results of both the grid model and complementary box model analyses are expected to be submitted to this special issue. Both ECCC and EPA are contributing simulations and analyses to the grid and box model intercomparison aspects of AQMEII4. It is anticipated that results from this activity will help more robustly characterize the uncertainties in current estimates of deposition fluxes, identify key knowledge gaps, and study implications for the use of these estimates for ecological assessments.

Collaborative Projects on Nitrogen and Sulfur Deposition

The atmospheric deposition of nitrogen, sulfur, and other chemical species to underlying surfaces is an important exposure pathway that can contribute or lead to the degradation of air, land, and water quality as well as reductions in the benefits humans may derive from ecosystems. Understanding the processes and outcomes associated with atmospheric deposition is needed to characterize progress toward meeting targeted reductions in deposition in the U.S. and Canada.

Scientists at the U.S. EPA and ECCC actively participate in the National Atmospheric Deposition Program's (NADP) Total Deposition (TDep) Science Committee. The mission of TDep is to improve estimates of atmospheric deposition by advancing the science of measuring and modeling atmospheric wet, dry, and total deposition of species such as sulfur, nitrogen, and mercury. TDep provides a forum for the exchange of information on current and emerging issues within a broad multi-organization context including atmospheric scientists, ecosystem scientists, resource managers, and policy makers. One of the goals of the NADP's TDEp Science Committee is to provide estimates of total sulfur and nitrogen deposition for use in critical loads and other ecological assessments.

In 2019, TDep members and collaborators issued a white paper – *Science Needs for Continued Development of Total Nitrogen Deposition Budgets in the United-States*[13]. This document describes the current state of the science and remaining knowledge and data gaps related to improving measurements and models of reactive nitrogen deposition and better understanding sources of reactive nitrogen to support review of the U.S. secondary NAAQS and further develop critical loads as a framework for managing deposition of nutrients and acidity. Though focused on the U.S., this document can serve as a roadmap for researchers and policy makers across North America.

---

[11] Galmarini, S., Makar, P., Clifton, O. E., *et al*. Technical note: AQMEII4 Activity 1: evaluation of wet and dry deposition schemes as an integral part of regional-scale air quality models, *Atmos. Chem. Phys.*, **21**, 15663–15697, https://doi.org/10.5194/acp-21-15663-2021, 2021.

[12] Available at www.atmos-chem-phys.net/special issue1130.html.

[13] Available at https://nadp.slh.wisc.edu/white-paper/

EPA and ECCC scientists are continuing to collaborate on projects that combine network measurement data and air quality models to estimate total deposition. A comparison of the U.S. product from TDep with results from the Canadian project ADAGIO (Atmospheric Deposition Analysis Generated by optimal Interpolation from Observations) is planned. This comparison will support the goal of combining the results from the two approaches to obtain one set of deposition maps for North America. The measurement-model fusion approaches used by the U.S. and Canada, as well as Sweden, are now leading the way for the use of measurement-model fusion on a global scale. Scientists from the TDep and ADAGIO projects are members of the steering committee for a Measurement-Model Fusion for Global Total Atmospheric Deposition initiative sponsored by the World Meteorological Organization (WMO) and jointly contributed to a recent publication outlining the initiative[14]. EPA and ECCC scientists also collaborate as members of the WMO Science Advisory Group for Total Atmospheric Deposition (SAG-TAD). Over the next few years, this SAG will focus on developing documentation to guide WMO in better characterizing dry deposition of nitrogen, sulfur, and ozone for global measurement-model fusion.

Much of the collaborative work discussed above was summarized in an article titled, *Ongoing U.S.-Canada Collaboration on Nitrogen and Sulfur Deposition* in the Air and Waste Management Association's EM magazine[15]. This article, co-authored by Canadian and U.S. scientists, was included in the June 2019 special issue highlighting cross-border environmental issues highlighting. It provided an overview of the past, current and planned activities related to deposition, such as monitoring network and modelling intercomparison studies, cooperation on measurement-model fusion projects as described above and sharing data to improve satellite estimates of reactive nitrogen dry deposition.

Science Information Exchange Workshops

Recognizing and building from successful Canadian/U.S. scientific collaborations, Subcommittee 2 (Scientific Cooperation) of the U.S-Canada Air Quality Committee initiated a pilot series of science information exchange workshops in 2021. The goals of these workshops were to share knowledge about new developments and key advances in science topics of common interest, to enhance scientific collaborations, and strengthen connections with Subcommittee 1 (Program Monitoring and Reporting/Policy).

Three workshops were held in 2021 focused on: (1) impacts of the COVID-19 pandemic on air quality; (2) wildland fires; and (3) emerging pollutants/sources of increased interest. Specific technical, policy, and managerial staff were invited to listen to brief presentations provided by U.S. EPA, ECCC, and Health Canada staff and to engage in focused discussions recognizing the common air quality-related challenges that the U.S. and Canada face.

The pilot science information exchange workshops received positive feedback and continued in 2022. The second year of workshops will focus on expanding the discussions between both the technical and policy staffs in a follow-up workshop on wildland fires as well as one on a new topic – ammonia.

[14] Fu, J.S., Carmichael, G.R., Dentener, F., *et al.* Improving Estimates of Sulfur, Nitrogen, and Ozone Total Deposition through Multi-Model and Measurement-Model Fusion Approaches. *Environ. Sci. Technol.* **56**, 2134-2142 (2022). https://doi.org/10.1021/acs.est.1c05929

[15] Schwede, D.; Cole, A.; Vet, R.; Lear, G. Ongoing US-Canada collaborations on nitrogen and sulfur deposition. EM (Pittsburgh, Pa.), **June**, 1-5 (2019) www.ncbi.nlm.nih.gov/pmc/articles/PMC7923747/.

COOPERATION ON MOBILE TRANSPORTATION SOURCES

There is a long history of collaboration between ECCC and the EPA to reduce transportation emissions, largely fostered by the framework of the Agreement. ECCC and the EPA have jointly developed a work plan supporting this ongoing collaboration. Canada has historically aligned federal regulations, emission standards and test procedures with those of the EPA for the transportation sector. This approach provides efficiencies for regulators and industry while supporting the competitiveness of Canadian manufacturers given the highly integrated nature of the North American market. This aligned regulatory approach also ensures long-term regulatory certainty for industry, while minimizing regulatory burden on organizations.

The resulting alignment enables Canada and the U.S. to collaborate further on compliance programs to maximize efficiencies in administration of the programs in both countries. For instance, the EPA and ECCC share information and closely coordinate vehicle and engine compliance verification testing programs between their laboratories in Ann Arbor, Michigan and Ottawa, Ontario.

The EPA and ECCC also coordinate research and testing projects to inform regulatory development. This collaboration minimizes testing overlap and improves the breadth of compliance monitoring, resulting in program efficiencies in both organizations. The two agencies are currently working on initiatives to further reduce emissions from the on-road sector, with an aim to increase the deployment of ZEVs in both countries. ECCC recognizes the importance of regulatory alignment and will continue to work closely with the EPA to align emission standards and coordinate their implementation.

Moreover, Canada-U.S. cooperation continues on the international stage, specifically as part of the World Forum for the Harmonization of Vehicle Regulations (WP.29). ECCC and the EPA continue to share information and consolidate resources to bring a North American perspective to the global standards-setting process for emissions. This collaboration also expands to work within the Transport Task Group, an international working group of G20 countries and their neighbors that participate in information sharing on best practices to reduce emissions and improve energy efficiency in the transport sector. Canada is also a member of the ZEV Transition Council that is currently co-chaired by the U.S. and the United Kingdom.

COOPERATION ON OIL AND GAS SECTOR EMISSIONS

In November 2015, a work plan between the EPA and ECCC was approved under the Agreement to support collaboration on oil and gas sector emissions. The oil and gas work plan has facilitated ongoing technical discussions between the two countries on a range of oil and gas issues, including developing equipment standards, addressing regulatory requirements and emissions associated with venting and flaring, designing leak detection and repair programs, fence-line monitoring at refineries, and the sharing of information through webinar discussions on our respective GHG inventory and reporting programs. The work plan also served as the foundation for developing joint commitments to reduce methane emissions from the oil and gas sector.

CONCLUSION

Canada and the United States continue to meet their commitments in the 1991 Agreement. Since the establishment of the Agreement, both countries have made significant progress in reducing acid rain and controlling ozone in the transboundary region.

Despite the results achieved under the Agreement, the pollutants covered by the Agreement (SO_2, NO_x, VOCs) remain a concern and continue to have significant impacts on human health and the environment in both countries. Continued bilateral efforts are needed to reduce the transboundary impact of these pollutants and to ensure that transboundary air pollution does not affect each country's ability to attain and maintain its ambient air quality standards for pollutants such as ozone and $PM_{2.5}$ or to protect the health and environment of its residents.

Canada and the United States are currently undertaking a review and assessment of the Agreement to assess: if the Agreement is meeting its current objectives; whether the commitments, including emission reduction targets and measures in the Agreement remain appropriate for Canadian and United States policy and science needs; and determine if new commitments or measures would be appropriate. Based on the results of the review and assessment, both countries may consider modification of the Agreement and associated policies, programs, or measures.

The Agreement provides a formal yet flexible vehicle for addressing transboundary air pollution and as such provides a framework under which the two countries continue to cooperate to address ongoing, emerging, and future air quality issues.

APPENDIX A: LIST OF ABBREVIATIONS AND ACRONYMS

ADAGIO	Atmospheric Deposition Analysis Generated by optimal Interpolation from Observations
ARP	Acid Rain Program
Agreement	Air Quality Agreement
AQMEII	Air Quality Model Evaluation International Initiative
AQMS	(Canada) Air Quality Management System
BACT	Best Available Control Technology
BART	Best Available Retrofit Technology
BCVCC	British Columbia Visibility Coordinating Committee
CAM	Compliance Assurance Monitoring
CAAQS	Canadian Ambient Air Quality Standards
CAIR	Clean Air Interstate Rule
CEM	Continuous Emissions Monitoring
CEPA 1999	*Canadian Environmental Protection Act*, 1999
CERMS	Continuous Emission Rate Monitoring System
CFR	Code of Federal Regulations
CMAQ	Community Multiscale Air Quality Model
CSAPR	Cross-State Air Pollution Rule
ECCC	Environment and Climate Change Canada
EO	Executive Order
EPA	Environmental Protection Agency
GHG	greenhouse gas
IMPROVE	Interagency Monitoring of Protected Visual Environments
JRC	European Commission Joint Research Centre
kg ha^{-1}	kilograms per hectare
kW	kilowatts
LAER	Lowest Achievable Emission Rate
LFV	Lower Fraser Valley
LSI	large spark-ignition engine
MATS	Mercury and Air Toxics Standards
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NAPS	National Air Pollution Surveillance
NBP	NO_x Budget Trading Program
NO_2	nitrogen dioxide

NO_{3^-}	nitrate
NO_x	nitrogen oxides
NO_x SIP	NO_x State Implementation Plan
$nssSO_4^{2-}$	non-sea-salt sulfate
NPS	National Park Service
NSR	New Source Review
PEMA	Pollutant Emission Management Area
PERC	tetrachloroethylene
$PM_{2.5}$	particulate matter less than or equal to 2.5 microns, known as fine particles
PM_{10}	particulate matter less than or equal to 10 microns
ppb	parts per billion
ppm	parts per million
PSD	Prevention of Significant Deterioration
SAG-TAD	Science Advisory Group for Total Atmospheric Deposition
SCR	selective catalytic reduction
SNCR	selective non-catalytic reduction
SO_x	sulfur oxides
SO_2	sulfur dioxide
SO_4^{2-}	sulfate
TDep	National Atmospheric Deposition Program) Total Deposition Science Committee
TCE	trichloroethylene
VOCs	volatile organic compounds
WMO	World Meteorological Organization
ZEV	zero-emission vehicle