POWER SECTOR PROGRAMS PROGRESS REPORT

2021

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- Affected Units
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- Emission Controls & Monitoring
- Program Compliance
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- Air Quality
- Affected Communities
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Executive Summary

Part 1, *Program Implementation, Compliance, and Emissions Trends*, released in July, 2022, covers program basics, and provides annual updates on pollution controls, monitoring methods, and changes in emissions. Part 2, *Environmental Results and Affected Communities*, covers the air quality and ecosystem response to these reductions, and also features a new section on community impacts.

Under the Clean Air Act, EPA implements regulations to reduce emissions from power plants, including the Acid Rain Program (ARP), the Cross-State Air Pollution Rule (CSAPR), the CSAPR Update, the Revised CSAPR Update, and the Mercury and Air Toxics Standards (MATS). These programs require fossil fuel-fired electric generating units to reduce emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and hazardous air pollutants including mercury (Hg) to protect human health and the environment. This reporting year marks the seventh year of CSAPR implementation, the fifth year of the CSAPR Update implementation, the first year of Revised CSAPR Update implementation, the twenty-seventh year of the ARP, and the fifth year of MATS implementation. This report summarizes annual progress through 2021, highlighting data that EPA systematically collects on emissions for all power plant programs and on compliance for the ARP and the CSAPR programs. Commitment to transparency and data availability is a hallmark of these programs and a cornerstone of their success.

SO_2, NO_x, and hazardous air pollutants (HAPs), including mercury, are fossil fuel combustion byproducts that affect public health and the environment. SO_2 and NO_x, and their sulfate and nitrate byproducts, are transported downwind and deposited as acid rain which can be harmful to sensitive ecosystems in many areas of the country. These pollutants also contribute to the formation of fine particles (sulfates and nitrates) and ground-level ozone that are associated with significant human health effects and regional haze. Atmospheric mercury deposition accumulates in fish to levels of concern for human health and the health of fish-eating wildlife.

The ARP, CSAPR, CSAPR Update, Revised CSAPR Update, and MATS have delivered substantial reductions in power sector emissions of SO_2, NO_x, and hazardous air pollutants, along with significant improvements in air quality and the environment. In addition to the requirement of the power sector emission control programs described in this report, a variety of power industry trends have contributed to further declines of SO_2, NO_x, and hazardous air pollutant emissions.

EPA data in this report are current as of March 2023 and reflects 2021 data. Data may differ from past or future reports because of data resubmissions by sources and ongoing data quality assurance activities.

2021 Program Implementation, Compliance, and Emissions Trends at a Glance

- **Annual SO_2 emissions:**
  CSAPR – 592,000 tons (93 percent below 2005)
  ARP – 936,000 tons (94 percent below 1990)
- **Annual NO_X emissions:**
  CSAPR – 440,000 tons (80 percent below 2005)
  ARP – 763,000 tons (85 percent below 2000)
- **CSAPR ozone season NO_X emissions:** 242,000 tons (46 percent below 2015)
- **Compliance:** 100 percent compliance for in the market-based ARP and CSAPR emissions trading programs
- **Emissions reported under MATS:**
  Mercury – 3.0 tons (90 percent below 2010)

2021 Environmental Results at a Glance

- **Ambient particulate sulfate concentrations:** The eastern United States has shown substantial improvement, decreasing 76 to 79 percent from 2000-2002 to 2019–2021.
- **Ozone NAAQS attainment:** Based on 2019-2021 data, 19 of the 22 areas in the East originally designated as nonattainment for the 2008 ozone NAAQS are now meeting the standard, while the remaining three areas have shown improvement.
- **$PM_{2.5}$ NAAQS attainment:** Based on 2019-2021 data, all 16 areas in the East originally designated as nonattainment for the 2006 24-hour $PM_{2.5}$ NAAQS are now meeting the standard.
- **Affected communities:** Program evaluation through an environmental justice lens shows more disadvantaged people living near power plants with higher emissions, and a greater overall emission reduction trend in areas of potential environmental justice concern.
- **Wet sulfate deposition:** All areas of the eastern U.S. have shown significant improvement with an overall 71 percent reduction in wet sulfate deposition from 2000-2002 to 2019–2021.
- **Levels of acid neutralizing capacity (ANC):** This indicator of aquatic ecosystem recovery improved (i.e., increased) significantly from 1990 levels at lake and stream monitoring sites in the Adirondack region, New England, and the Catskill mountains.

Contents

Chapter 1: Program Basics

The Acid Rain Program (ARP), the Cross-State Air Pollution Rule (CSAPR), the CSAPR Update, and the Revised CSAPR Update are implemented through trading programs[1] designed to reduce emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) from power plants. Established under Title IV of the 1990 Clean Air Act Amendments, the ARP was a landmark nationwide emissions trading program, with a goal of reducing the emissions that cause acid rain. The success of the program in achieving significant emission reductions in a cost-effective manner led to the application of the market-based emissions trading tool for other regional environmental problems, namely interstate air pollution transport, or pollution from upwind emission sources that impacts air quality in downwind areas. The interstate transport of pollution makes it difficult for downwind states to meet health-based air quality standards for regional pollutants, particularly fine particulates ($PM_{2.5}$) and ozone. EPA first employed trading to address regional pollution in the NO_X Budget Trading Program (NBP), which helped northeastern states address the interstate transport of NO_X emissions causing ozone pollution in northeastern states. Next, the NBP was effectively replaced by the ozone season NO_X program under the Clean Air Interstate Rule (CAIR), which required further summertime NO_X emission reductions from the power sector, and also required annual reductions of NO_X and SO_2 emissions to address $PM_{2.5}$ transport. In response to a court decision on CAIR, CSAPR replaced CAIR beginning in 2015 and continued to reduce annual SO_2 and NO_X emissions, as well as ozone season NO_X emissions, to facilitate attainment of the 1997 annual $PM_{2.5,}$ the 2006 24-hour $PM_{2.5}$, and the 1997 8-hour ozone National Ambient Air Quality Standards (NAAQS). Implementation of the CSAPR Update began in 2017. The CSAPR Update further reduces ozone season NO_X emissions to help states attain and maintain a newer ozone NAAQS established in 2008. Implementation of the Revised CSAPR Update began in 2021 and resolves 21 states' outstanding interstate transport obligations for the 2008 ozone NAAQS. Most recently, in February 2022, the EPA proposed additional reductions in ozone-forming emissions of NO_X to facilitate attainment and maintenance of the more stringent 2015 ozone NAAQS.

The Mercury and Air Toxics Standards (MATS) set limits on emissions of hazardous air pollutants from power plants. EPA published the final standards in February 2012, and the compliance requirements generally went into effect in April 2015, with extensions for some plants until April 2016 and a small number until April 2017. As such, 2021 is the fifth full year for which most sources covered by MATS have reported emissions data to the EPA.

Highlights

Acid Rain Program (ARP): 1995 - present

- The ARP began in 1995 and covers fossil fuel-fired power plants across the contiguous United States. The ARP was established under Title IV of the 1990 Clean Air Act Amendments and is designed to reduce SO_2 and NO_X emissions, the primary precursors of acid rain.

[1] These emissions trading programs are also known as "allowance trading programs" or "cap-and-trade" programs.

- The ARP's market-based SO_2 emissions trading program sets an annual cap on the total amount of SO_2 that may be emitted by power plants throughout the contiguous U.S. The final annual SO_2 emissions cap was set at 8.95 million tons in 2010, a level of about one-half of the emissions from the power sector in 1980.
- NO_X reductions under the ARP are achieved through a rate-based approach that applies to a subset of coal-fired power plants.

Cross-State Air Pollution Rule (CSAPR): 2015 - present

- CSAPR addresses regional interstate transport of fine particle ($PM_{2.5}$) and ozone pollution for the 1997 ozone and $PM_{2.5}$ NAAQS and the 2006 $PM_{2.5}$ NAAQS. In 2015, CSAPR required reductions in annual emissions of SO_2 and NO_X from power plants in 23 eastern states and reductions of NO_X emissions during the ozone season from power plants in 25 eastern states, covering 28 states in all.
- CSAPR includes four separate emissions trading programs to achieve these reductions: the CSAPR SO_2 Group 1 and Group 2 trading programs, the CSAPR NO_X Annual trading program, and the CSAPR NO_X Ozone Season Group 1 trading program.

Cross-State Air Pollution Rule Update (CSAPR Update): 2017 - present

- The CSAPR Update was developed to address regional interstate transport for the 2008 ozone NAAQS and to respond to the July 2015 court remand of certain CSAPR ozone season requirements.
- As of May 2017, the CSAPR Update began further reducing ozone season NO_X emissions from power plants in 22 states in the eastern U.S.
- The CSAPR Update achieves these reductions through the CSAPR NO_X Ozone Season Group 2 trading program.

Revised Cross-State Air Pollution Rule Update (Revised CSAPR Update): 2021 – present

- The Revised CSAPR Update was developed to resolve 21 states' outstanding interstate transport obligations for the 2008 ozone NAAQS and to respond to the September 2019 court remand of the 2016 CSAPR Update.
- Beginning in June 2021, further emission reductions were required at power plants in 12 of the 21 states for which the CSAPR Update was previously found to be only a partial remedy. These reductions are 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 enhanced NO_X combustion controls beginning in the 2022 ozone season. EPA will also adjust these 12 states' ozone season emission budgets through 2024 to incentivize the continued use of these control technologies.
- The Revised CSAPR Update achieves these reductions through the CSAPR NO_X Ozone Season Group 3 trading program.

CSAPR, CSAPR Update, and Revised CSAPR Update Budgets

- The total CSAPR, CSAPR Update, and Revised CSAPR Update budget for each of the six trading programs equals the sum of the individual state budgets for those states affected by each program. The CSAPR Update replaced the original CSAPR ozone season NO_X program for most states. Most recently, the Revised CSAPR Update replaced the CSAPR Update ozone season NO_X program for twelve states. The total budget for each program was set at the following level in 2021:
    - SO_2 Group 1 – 1,372,631 tons
    - SO_2 Group 2 – 597,579 tons
    - NO_X Annual – 1,069,256 tons
    - NO_X Ozone Season Group 1 – 24,041 tons[2]
    - NO_X Ozone Season Group 2 – 143,408 tons[3]
    - NO_X Ozone Season Group 3 – 131,430 tons

Mercury and Air Toxics Standards (MATS)

- EPA announced standards to limit mercury, acid gases, and other toxic pollution from power plants in December 2011 (published in February 2012). EPA provided the maximum 3-year compliance period, so sources were generally required to comply no later than April 16, 2015. Some sources obtained a one-year extension from their state permitting authority, allowed under the CAA, and so were required to comply with the final rule by April 16, 2016.
- Units subject to MATS must comply with emission rate limits for certain hazardous air pollutants (or surrogates). There are several ways to demonstrate compliance, including the use of continuous monitoring or through periodic measurement of emissions. Some units may choose to demonstrate compliance through periodic performance tests.
- This progress report only provides data from affected sources that submitted hourly emissions data in 2021. Mercury emissions data are not available for 79 low emitting electric generating units.

Background Information

Power Sector Trends

The widespread and dramatic emission reductions in the power sector over the last few decades have come about from several factors, including changes in markets for fuels and electricity as well as regulatory programs.[4] While most coal-fired electricity generation comes from sources with state-of-the-art emission controls, broad industry shifts from coal-fired generation to gas-fired generation, as well as increases in zero-emitting generation sources, also have reduced power sector emissions. Market factors, modest demand growth, and policy and regulatory efforts have resulted in a notable

[2] Since the start of CSAPR Update in 2017, the CSAPR NO_X Ozone Season Group 1 program applies only to sources in Georgia.
[3] Since the start of Revised CSAPR Update in 2021, the CSAPR Update Group 2 program applies only to sources in ten states.
[4] EIA, Annual Energy Outlook 2022.

change in the last decade to the country's overall generation mix as natural gas and renewable energy generation increased while coal-fired generation decreased.

While the current and near-term expectations for natural gas prices are higher than recent historical levels, the price of natural gas is expected to decline to lower levels in the medium and long term.[3] In addition, the existing fleet of coal-fired power plants continues to age. With a continued (but reduced) tax credit and declining capital costs, solar capacity is projected to grow through 2050, while tax credits that phase out for plants entering service through 2023 provide incentives for new wind capacity in the near-term.[5] Some power generators have announced that they expect to continue to change their generation mix away from coal-fired generation and toward natural-gas fired generation, renewables, and more deployment of energy efficiency measures.[6] All these factors, in total, have resulted in declining power sector emissions in recent years, a trend that is expected to continue.

Acid Rain Program

Title IV of the 1990 Clean Air Act Amendments established the ARP to address acid deposition nationwide by reducing annual SO_2 and NO_X emissions from fossil fuel-fired power plants. In contrast to traditional command and control regulatory methods that establish specific emissions limitations, the ARP SO_2 program introduced a landmark emissions trading system that harnessed the economic incentives of the market to reduce pollution. This market-based emissions trading program was implemented in two phases. Phase I began in 1995 and affected the most polluting units, largely coal-fired, in 21 eastern and midwestern states. Phase II began in 2000 and expanded the program to include other units fired by coal, oil, and gas in the contiguous U.S. Under Phase II, Congress also tightened the annual SO_2 emissions cap with a permanent annual cap set at 8.95 million allowances starting in 2010. The NO_X program has a similar results-oriented approach and ensures program integrity through measurement and reporting. However, it does not cap NO_X emissions, nor does it utilize an emissions trading system. Instead, the ARP NO_X program provisions apply boiler-specific NO_X emission limits – or rates – in pounds per million British thermal units (lb/mmBtu) on certain coal-fired boilers. There is a degree of flexibility, however. Units under common control, which are owned or operated by the same company, can comply using emission rate averaging plans, subject to requirements ensuring that the total mass emissions from the units in an averaging plan do not exceed the total mass emissions the units would have emitted at their individual emission rate limits.

NO_X Budget Trading Program

The NBP was a market-based emissions trading program created to reduce NO_X emissions from power plants and other large stationary combustion sources during the summer ozone season to address regional air pollution transport that contributes to the formation of ozone in the eastern United States. The program, which operated during the ozone seasons from 2003 to 2008, was a central component of the NO_X State Implementation Plan (SIP) Call, promulgated in 1998, to help states attain the 1979 ozone NAAQS. All 21 jurisdictions (20 states plus Washington, D.C.) covered by the NO_X SIP Call opted to

[3] EIA, Annual Energy Outlook 2022.
[5] EIA, Annual Energy Outlook 2021.
[6] EIA, "Corporate Goal Case Using Annual Energy Outlook 2021".

participate in the NBP. In 2009, the CAIR's NO_X ozone season program began, effectively replacing the NBP to continue achieving ozone season NO_X emission reductions from the power sector.

Clean Air Interstate Rule

CAIR required 25 eastern jurisdictions (24 states plus Washington, D.C.) to limit annual power sector emissions of SO_2 and NO_X to address regional interstate transport of air pollution that contributes to the formation of fine particulates. It also required 26 jurisdictions (25 states plus Washington, D.C.) to limit power sector ozone season NO_X emissions to address regional interstate transport of air pollution that contributes to the formation of ozone during the ozone season. CAIR used three separate market-based emissions trading programs to achieve emission reductions and to help states meet the 1997 ozone and fine particle NAAQS.

EPA issued CAIR on May 12, 2005, and the CAIR federal implementation plans (FIPs) on April 26, 2006. In 2008, the U.S. Court of Appeals for the DC Circuit remanded CAIR to the Agency, leaving the existing CAIR programs in place while directing EPA to replace them as rapidly as possible with a new rule consistent with the Clean Air Act. The CAIR NO_X ozone season and NO_X annual programs began in 2009, while the CAIR SO_2 program began in 2010. As discussed below, CAIR was replaced by CSAPR in 2015.

Cross-State Air Pollution Rule

EPA issued CSAPR in July 2011, requiring 28 states in the eastern half of the U.S. to significantly improve air quality by reducing power plant emissions that travel across state lines and contribute to fine particle and summertime ozone pollution in downwind states. CSAPR required 23 states to reduce annual SO_2 and NO_X emissions to help downwind areas attain the 2006 24-hour $PM_{2.5}$ NAAQS and/or the 1997 annual $PM_{2.5}$ NAAQS. CSAPR also required 25 states to reduce ozone season NO_X emissions to help downwind areas attain the 1997 ozone NAAQS. CSAPR divides the states required to reduce SO_2 emissions into two groups (Group 1 and Group 2). Both groups were required to reduce their SO_2 emissions in Phase I. All Group 1 states, as well as some Group 2 states, were required to make additional reductions in SO_2 emissions in Phase II in order to eliminate their significant contribution to air quality problems in downwind areas.

CSAPR was scheduled to replace CAIR starting on January 1, 2012. However, the timing of CSAPR's implementation was affected by D.C. Circuit actions that stayed and then vacated CSAPR before implementation. On April 29, 2014, the U.S. Supreme Court reversed the D.C. Circuit's vacatur, and on October 23, 2014, the D.C. Circuit granted EPA's motion to lift the stay and shift the CSAPR compliance deadlines by three years. Accordingly, CSAPR Phase I implementation began on January 1, 2015, replacing CAIR, and CSAPR Phase II began January 1, 2017.

Cross-State Air Pollution Rule Update

On September 7, 2016, EPA finalized an update to the CSAPR ozone season program by issuing the CSAPR Update. This rule addressed summertime ozone pollution in the eastern U.S. that crosses state lines in order to help downwind states and communities meet and maintain the 2008 ozone NAAQS. In May 2017, the CSAPR Update began further reducing ozone season NO_X emissions from power plants in 22 states in the eastern U.S. When issuing the CSAPR Update, EPA found that while the rule would result in meaningful, near-term reductions in ozone pollution that crosses state lines, the rule might not be sufficient to fully address all covered states' good neighbor obligations[7] with respect to the 2008 ozone NAAQS. In December 2018, based on additional analysis conducted after issuance of the rule, EPA published a determination that the emission reductions required by the CSAPR Update in fact would fully address all covered states' good neighbor obligations with respect to this NAAQS.

In September 2019, the D.C. Circuit upheld the CSAPR Update in most respects but remanded the rule to EPA to address the court's holding that the rule unlawfully allowed upwind states' significant contribution to downwind air quality problems to continue beyond downwind states' deadlines for attaining the NAAQS. Relatedly, in October 2019, the court vacated EPA's December 2018 determination that the CSAPR Update fully addressed covered states' good neighbor obligations with respect to the 2008 ozone NAAQS.

Revised Cross-State Air Pollution Rule Update

On March 15, 2021, EPA finalized the Revised CSAPR Update to resolve 21 states' outstanding interstate transport obligations for the 2008 ozone NAAQS. Based on EPA's analysis, the Agency determined that additional emission reductions relative to the CSAPR Update were necessary for 12 of the 21 states. These reductions were based on optimization of existing, already-installed 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. This rulemaking also adjusted these 12 states' ozone season emission budgets through 2024 to incentivize the continued use of these control technologies. The rule became effective on June 29, 2021.

Mercury and Air Toxics Standards

On December 16, 2011, the EPA announced final standards to reduce emissions of toxic air pollutants from new and existing coal- and oil-fired power plants in all 50 states and U.S. territories. MATS established technology-based emission rate standards that reflect the level of hazardous air pollutant (HAP) emissions that had been achieved by the best-performing sources. These HAPs include mercury (Hg), non-mercury metals (such as arsenic (As), chromium (Cr), and nickel (Ni)), and acid gases, including hydrochloric acid (HCl) and hydrofluoric acid (HF). EPA provided the maximum 3-year compliance period, so sources were generally required to comply no later than April 16, 2015. Some sources obtained a one-year extension from their state permitting authority, as allowed under the CAA, and thus were required to comply with the final rule by April 16, 2016.

More Information

- Acid Rain Program (ARP) https://www.epa.gov/acidrain/acid-rain-program
- Interstate Air Pollution Transport https://www.epa.gov/interstate-air-pollution-transport
- Cross-State Air Pollution Rule (CSAPR) https://www.epa.gov/csapr
- Cross-State Air Pollution Rule Update (CSAPR Update) https://www.epa.gov/airmarkets/final-cross-state-air-pollution-rule-update

[7] "Good neighbor" obligations refer to provisions in the Clean Air Act that require upwind states to reduce the emissions that affect downwind states' ability to attain or maintain NAAQS.

- Revised CSAPR Update https://www.epa.gov/csapr/revised-cross-state-air-pollution-rule-update
- Clean Air Interstate Rule (CAIR) https://archive.epa.gov/airmarkets/programs/cair/web/html/index.html
- NO_X Budget Trading Program (NBP) / NO_X SIP Call https://www.epa.gov/airmarkets/nox-budget-trading-program
- National Ambient Air Quality Standards (NAAQS) https://www.epa.gov/criteria-air-pollutants
- EPA's Clean Air Market Programs https://www.epa.gov/airmarkets/programs
- Emissions Trading https://www.epa.gov/emissions-trading-resources
- Mercury and Air Toxics Standards (MATS) https://www.epa.gov/stationary-sources-air-pollution/mercury-and-air-toxics-standards
- EIA Annual Energy Outlook https://www.eia.gov/outlooks/aeo
- Corporate Goal Case Using Annual Energy Outlook 2021 https://www.eia.gov/outlooks/aeo/corporate_goal/

Figures

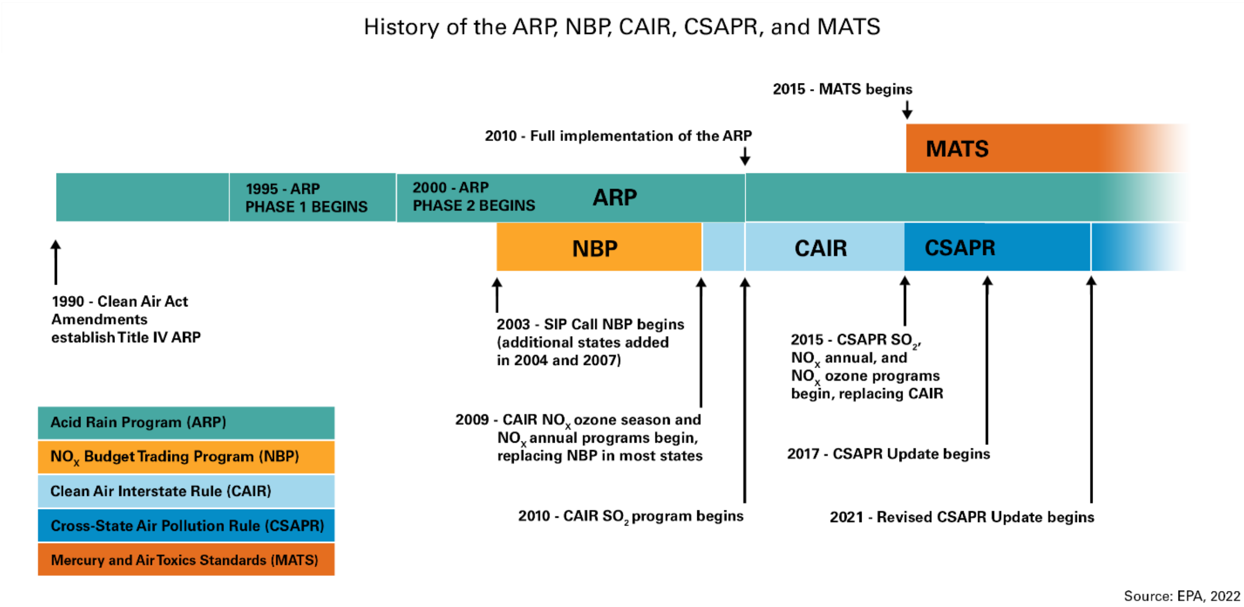

Figure 1. History of the ARP, NBP, CAIR, CSAPR, and MATS

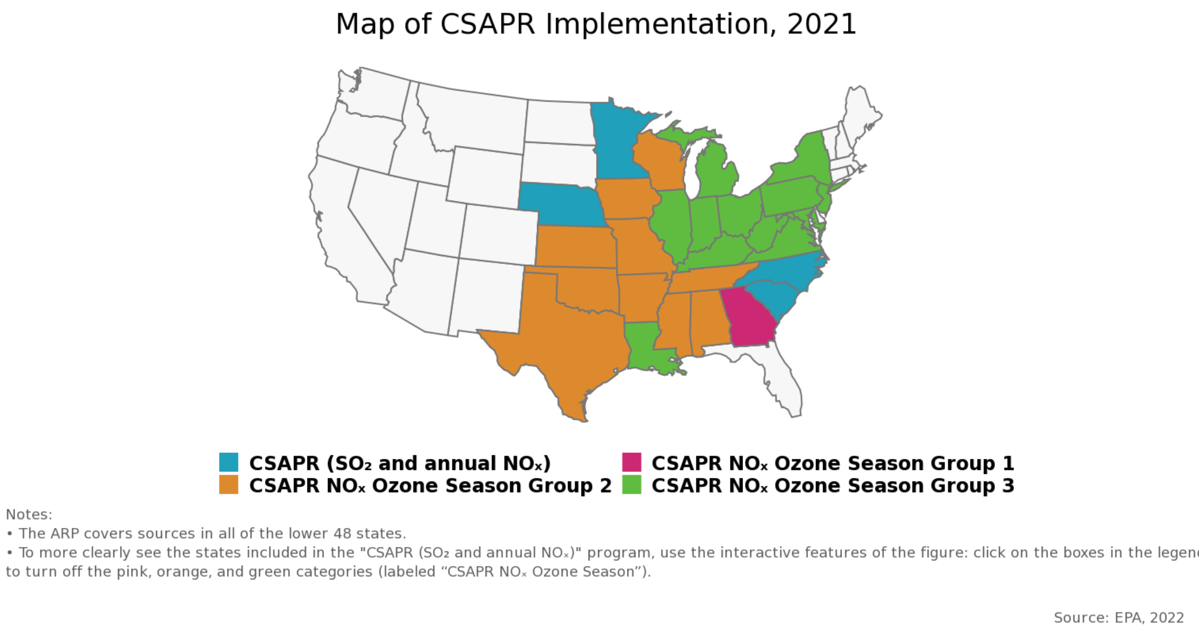

Figure 2. Map of CSAPR Implementation for 2021

Notes:
- The ARP covers sources in all of the lower 48 states.
- To more clearly see the states included in the "CSAPR (SO_2 and annual NO_x)" program, use the interactive features of the figure: click on the boxes in the legend to turn off the pink, orange, and green categories (labeled "CSAPR NO_x Ozone Season").

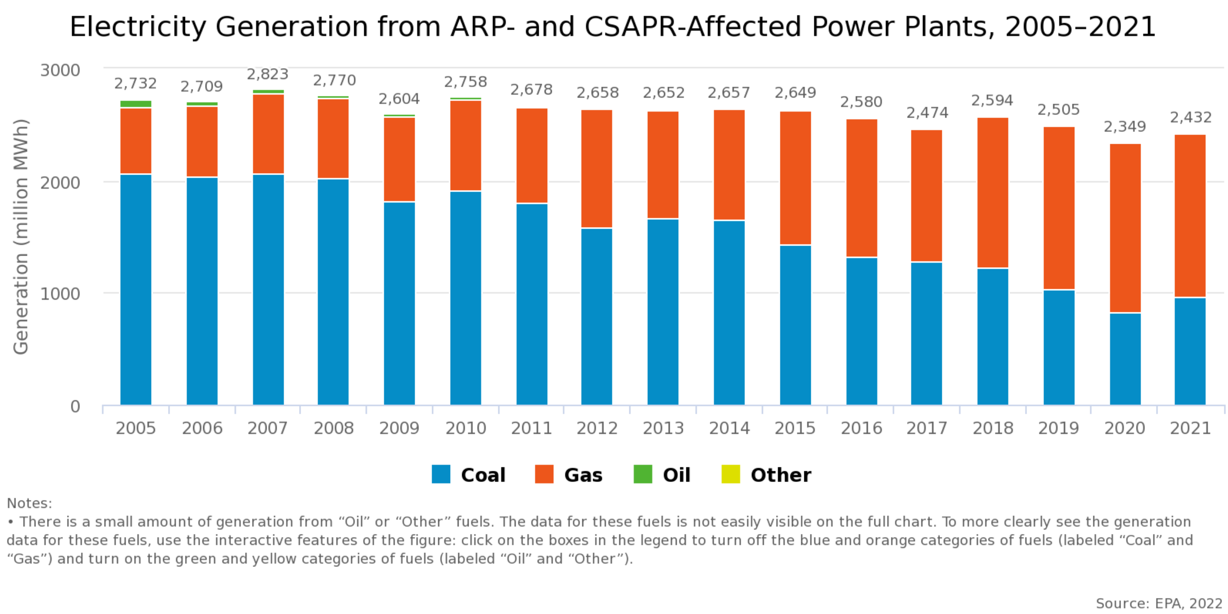

Figure 3. Electricity Generation from ARP- and CSAPR-Affected Power Plants, 2005–2021

Notes:
• There is a small amount of generation from "Oil" or "Other" fuels. The data for these fuels is not easily visible on the full chart. To more clearly see the generation data for these fuels, use the interactive features of the figure: click on the boxes in the legend to turn off the blue and orange categories of fuels (labeled "Coal" and "Gas") and turn on the green and yellow categories of fuels (labeled "Oil" and "Other").

Chapter 2: Regulated Emissions Sources

The Acid Rain Program (ARP) and the Cross-State Air Pollution Rule's (CSAPR)[1] sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emission reduction programs apply to large power plants that burn fossil fuels to generate electricity for sale. The Mercury and Air Toxics Standards (MATS) only cover large power plants that burn coal or oil to generate electricity for sale and excludes gas-fired units, resulting in fewer units in MATS than in the ARP and CSAPR.

Highlights

Acid Rain Program (ARP)

- In 2021, the ARP SO_2 requirements applied to 3,243 fossil fuel-fired units at 1,150 power plants across the country; 493 units at 227 power plants were subject to the ARP NO_X program.

Cross-State Air Pollution Rule (CSAPR)

- In 2021, there were 2,125 regulated emissions sources at 665 power plants in the CSAPR SO_2 programs. Of those, 1,713 (81 percent) were also covered by the ARP.
- In 2021, there were 2,125 regulated emissions sources at 665 power plants in the CSAPR NO_X annual program and 2,499 regulated emissions sources at 799 power plants in the CSAPR NO_X ozone season programs. Of those, 1,713 (81 percent) and 2,079 (83 percent), respectively, were also covered by the ARP.

Mercury and Air Toxics (MATS)

- The Mercury and Air Toxics Standards (MATS) set limits on the emissions of hazardous air pollutants from coal- and oil-fired electric utility steam generating units in all 50 states and U.S. territories. MATS was issued under section 112 of the Clean Air Act. EPA is including a summary of the mercury data submitted by affected sources in this report.
- In 2021, 406 units at 186 power plants reported hourly mercury emissions to EPA under MATS.

Background Information

In general, the ARP and CSAPR programs (CSAPR, CSAPR Update, and the Revised CSAPR Update) apply to large electricity generating units – boilers, turbines, and combined cycle units – that burn fossil fuel, serve generators with nameplate capacity greater than 25 megawatts, and produce electricity for sale. MATS applies only to coal- and oil-fired steam generating units (i.e., utility boilers). MATS does not apply to combustion turbines, combined cycle units, or to natural gas-fired utility boilers. The power plants affected by these programs include a range of unit types, including units that operate year-round to provide baseload power to the electric grid, as well as units that provide power only on peak demand days. The ARP NO_X program applies to a subset of these units that are older and historically coal-fired.

[1] CSAPR refers to the CSAPR, the CSAPR Update, and the Revised CSAPR Update programs.

More Information

- Acid Rain Program (ARP) https://www.epa.gov/acidrain/acid-rain-program
- Cross-State Air Pollution Rule (CSAPR) https://www.epa.gov/csapr
- Mercury and Air Toxics Standards (MATS) https://www.epa.gov/stationary-sources-air-pollution/mercury-and-air-toxics-standards

Figures

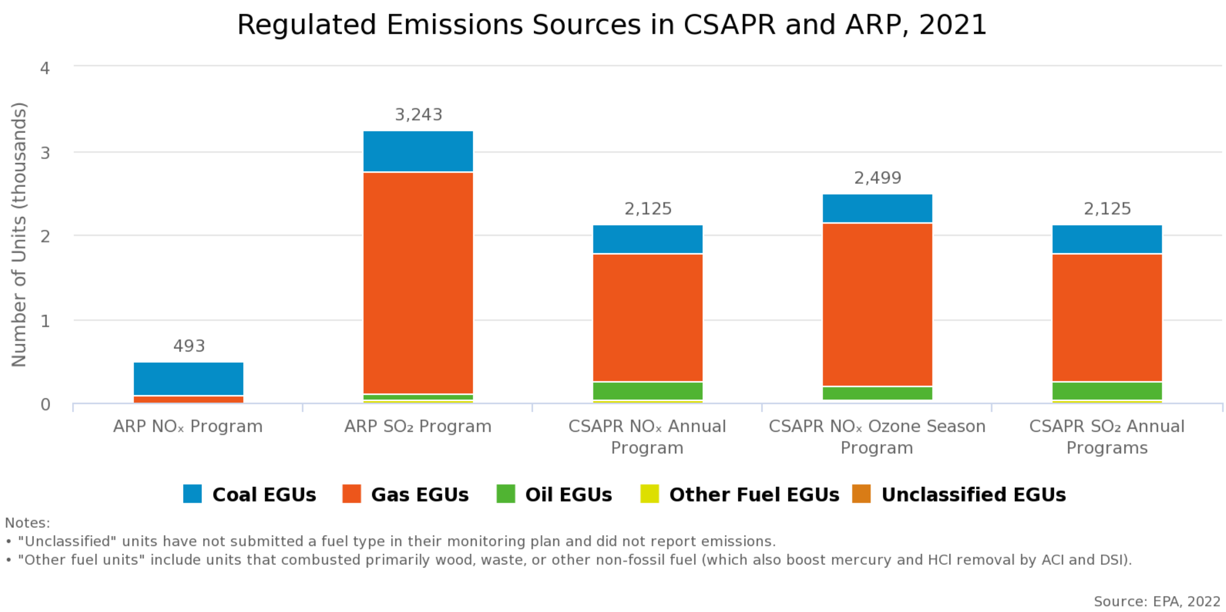

Figure 1. Regulated Emissions Sources in CSAPR and ARP, 2021

Notes:
• "Unclassified" units have not submitted a fuel type in their monitoring plan and did not report emissions.
• "Other fuel units" include units that combusted primarily wood, waste, or other non-fossil fuel (which also boost mercury and HCl removal by ACI and DSI).

Regulated Emissions Sources in CSAPR and ARP, 2021

Fuel	ARP NO_x	ARP SO_2	CSAPR Annual NO_x	CSAPR Ozone Season NO_x	CSAPR Annual SO_2
Coal EGUs	410	487	351	352	351
Gas EGUs	81	2,641	1,525	1,948	1,525
Oil EGUs	0	83	216	164	216
Other Fuel EGUs	2	27	33	24	33
Unclassified EGUs	0	5	0	11	0
Total Units	**493**	**3,243**	**2,125**	**2,499**	**2,125**

Notes:
• "Unclassified" units have not submitted a fuel type in their monitoring plan and did not report emissions.
• "Other fuel units" include units that combusted primarily wood, waste, or other non-fossil fuel (which also boost mercury and HCl removal by ACI and DSI).

Source: EPA, 2022
Last updated: 04/2022

Figure 2. Regulated Emissions Sources in CSAPR and ARP, 2021

Notes:
• "Unclassified" units have not submitted a fuel type in their monitoring plan and did not report emissions.
• "Other fuel units" include units that combusted primarily wood, waste, or other non-fossil fuel (which also boost mercury and HCl removal by ACI and DSI).

Chapter 3: Emission Reductions

The Acid Rain Program (ARP) and Cross-State Air Pollution Rule (CSAPR) programs[1] significantly reduced sulfur dioxide (SO_2), annual nitrogen oxides (NO_X), and ozone season NO_X emissions from power plants. The Mercury and Air Toxics Standards (MATS) set limits on the emissions of hazardous air pollutants from coal and oil burning power plants and have led to reductions in those emissions since 2010. This section covers changes in emissions at power plants affected by CSAPR, ARP, and MATS between 2021 and previous years.

Sulfur Dioxide (SO_2)

Highlights

Overall Results

- Under the ARP, CAIR, and CSAPR, power plants have significantly lowered SO_2 emissions while electricity generation from power plants in these programs has remained relatively stable since 2000.
- These emission reductions are a result of an overall increase in the environmental effectiveness at affected sources as electric generators installed controls, switched to lower emitting fuels, or otherwise reduced their SO_2 emissions. These trends are discussed further in Chapter 1.

SO_2 Emission Trends

- **ARP:** Units in the ARP emitted 936,000 tons of SO_2 in 2021, well below the ARP's statutory annual cap of 8.95 million tons. The ARP sources reduced emissions by 14.8 million tons (94 percent) from 1990 levels and 16.3 million tons (95 percent) from 1980 levels.
- **CSAPR and ARP:** In 2021, the seventh year of operation of the CSAPR SO_2 program, sources in both the CSAPR SO_2 annual programs and the ARP together reduced SO_2 emissions by 14.8 million tons (94 percent) from 1990 levels (before implementation of the ARP), 10.3 million tons (92 percent) from 2000 levels (ARP Phase II), and 9.3 million tons (91 percent) from 2005 levels (before implementation of the CAIR and the CSAPR). All ARP and CSAPR sources together emitted a total of 942,000 tons of SO_2 in 2021.
- **CSAPR:** Annual SO_2 emissions from sources in the CSAPR SO_2 programs fell from 7.7 million tons in 2005 to 592,000 tons in 2021 (93 percent). In 2021, SO_2 emissions were about 1.4 million tons below the regional CSAPR emission budgets (0.85 million in Group 1 and 0.52 million in Group 2); the CSAPR SO_2 annual programs' 2021 regional budgets are 1,372,631 and 597,579 tons for Group 1 and Group 2, respectively.

SO_2 State-by-State Emissions

- **CSAPR and ARP:** From 1990 to 2021, annual SO_2 emissions from sources in the ARP and the CSAPR SO_2 program dropped in 46 states plus Washington, D.C. by a total of 14.8 million tons. In

[1] CSAPR refers to the CSAPR, the CSAPR Update, and the Revised CSAPR Update programs.

contrast, annual SO_2 emissions increased in two states (Idaho and Vermont) by a combined total of 13 tons from 1990 to 2021.

- **CSAPR:** All 22 states (16 states in Group 1 and 6 states in Group 2) had emissions below their CSAPR allowance budgets, collectively by 1.4 million tons.

SO_2 Emission Rates

- The average SO_2 emission rate for units in the ARP or CSAPR SO_2 program fell to 0.09 pounds per million British thermal units (lb/mmBtu). This indicates an 88 percent reduction from 2005 rates, with most reductions coming from coal-fired units.
- Emissions have decreased dramatically since 2005, due in large part to greater use of control technology on coal-fired units and increased generation at natural gas-fired units that emit very little SO_2 emissions.

Background Information

SO_2 is a highly reactive gas that is generated primarily from coal-fired power plants. In addition to contributing to the formation of acid rain and fine particle ($PM_{2.5}$) pollution, SO_2 emissions are linked with a number of adverse effects to human health and ecosystems.

The states with the highest emitting sources in 1990 have generally seen the greatest SO_2 emission reductions under the ARP, and this trend continued under CAIR and CSAPR. Most of these states are in the Ohio River Valley and are upwind of the areas the ARP and CSAPR were designed to protect. Reductions under these programs have provided important environmental and health benefits over a large region.

More Information

- Power Plant Emission Trends https://www.epa.gov/airmarkets/power-plant-emission-trends
- Power Sector Emissions, Operations, and Environmental Data https://www.epa.gov/airmarkets/data-resources
- Acid Rain Program (ARP) https://www.epa.gov/acidrain/acid-rain-program
- Cross-State Air Pollution Rule (CSAPR) https://www.epa.gov/csapr
- Sulfur Dioxide (SO_2) Pollution https://www.epa.gov/so2-pollution
- Particulate Matter (PM) Pollution https://www.epa.gov/pm-pollution
- Power Profiler https://www.epa.gov/energy/power-profiler

Figures

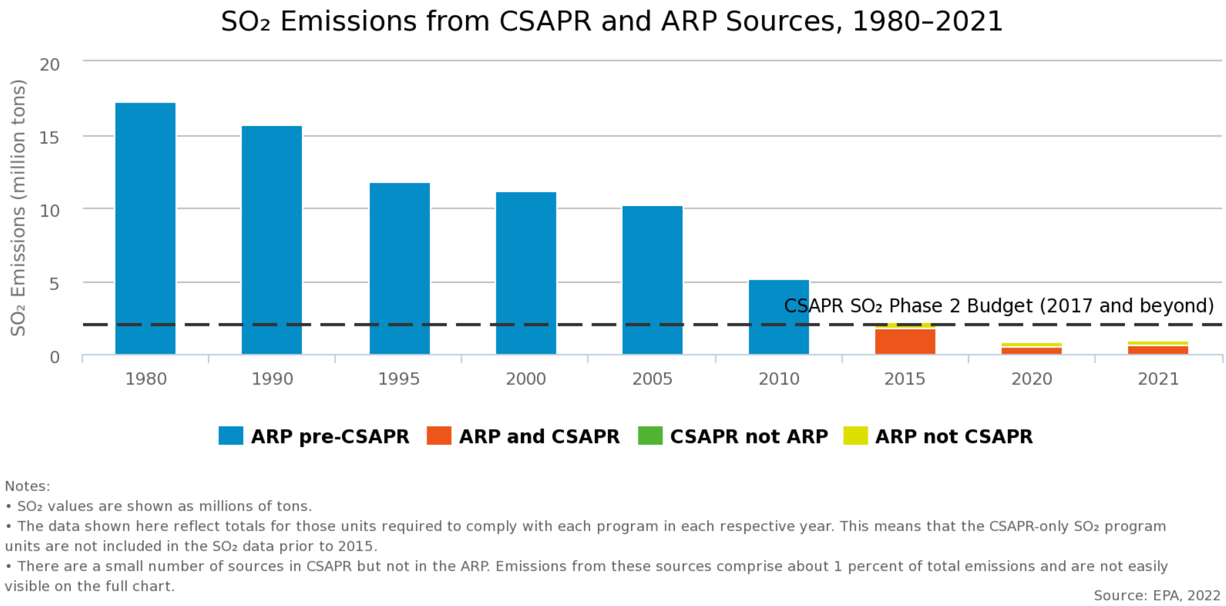

Figure 1. SO_2 Emissions from CSAPR and ARP Sources, 1980–2021

Notes:
• SO_2 values are shown as millions of tons.
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only SO_2 program units are not included in the SO_2 data prior to 2015.
• There are a small number of sources in CSAPR but not in the ARP. Emissions from these sources comprise about 1 percent of total emissions and are not easily visible on the full chart.

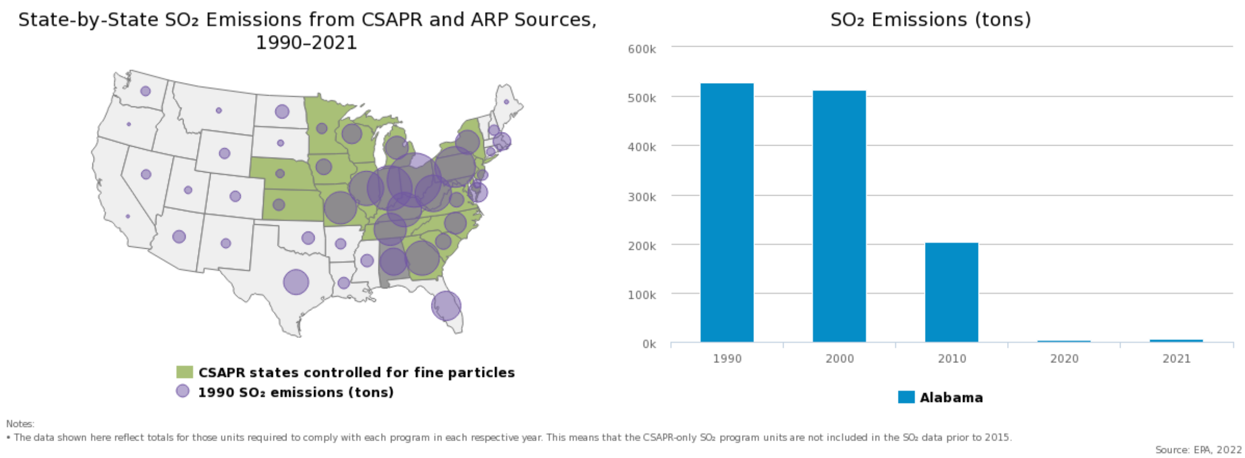

Figure 2. State-by-State SO_2 Emissions from CSAPR and ARP Sources, 1990–2021

Notes:
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only SO_2 program units are not included in the SO_2 data prior to 2015.

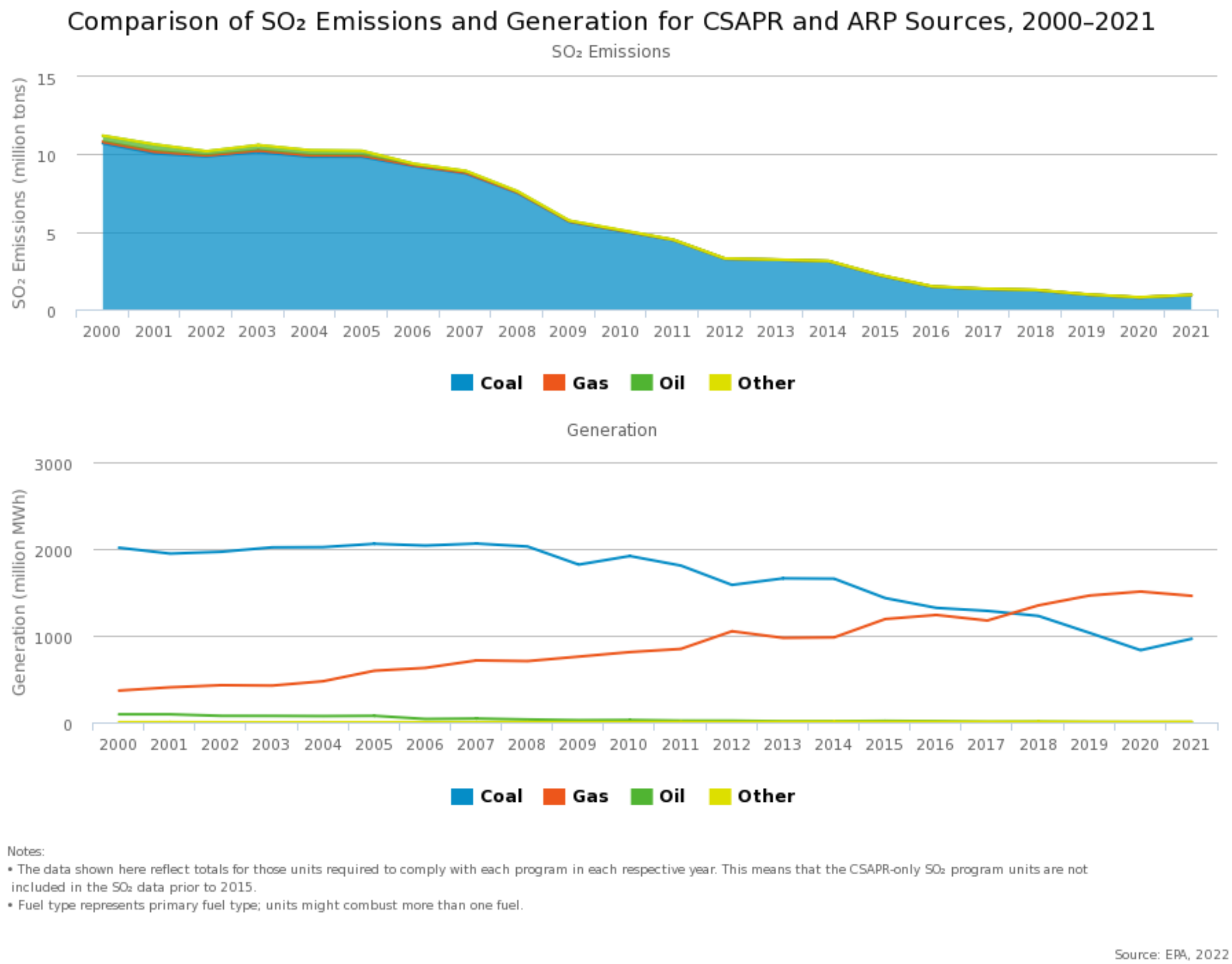

Figure 3. Comparison of SO_2 Emissions and Generation for CSAPR and ARP Sources, 2000–2021

Notes:
- The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only SO_2 program units are not included in the SO_2 data prior to 2015.
- Fuel type represents primary fuel type; units might combust more than one fuel.

CSAPR and ARP SO_2 Emissions Trends, 2021

	SO_2 Emissions (thousand tons)					SO_2 Rate (lb/mmBtu)				
Primary Fuel	**2000**	**2005**	**2010**	**2020**	**2021**	**2000**	**2005**	**2010**	**2020**	**2021**
Coal	10,708	9,835	5,052	788	927	1.04	0.95	0.53	0.18	0.19
Gas	108	91	19	5	8	0.06	0.03	0.01	0.00	0.00
Oil	384	292	28	1	1	0.73	0.70	0.19	0.04	0.06
Other	1	4	22	11	7	0.23	0.27	0.57	0.17	0.10
Total / Average	**11,201**	**10,222**	**5,120**	**788**	**942**	**0.88**	**0.75**	**0.39**	**0.08**	**0.09**

Notes:
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only SO_2 program units are not included in the SO_2 emissions data prior to 2015.
• Fuel type represents primary fuel type; units might combust more than one fuel.
• Totals may not reflect the sum of individual rows due to rounding.
• The emission rate reflects the emissions (pounds) per unit of heat input (mmBtu) for each fuel category. The total SO_2 emission rate in each column of the table is not cumulative and does not equal the arithmetic mean of the four fuel-specific rates. The total for each year indicates the average rate across all units in the program because each unit influences the annual emission rate in proportion to its heat input, and heat input is unevenly distributed across the fuel categories.

Source: EPA, 2022

Figure 4. CSAPR and ARP SO_2 Emissions Trends, 2000-2021

Notes:
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only SO_2 program units are not included in the SO_2 emissions data prior to 2015.
• Fuel type represents primary fuel type; units might combust more than one fuel.
• Totals may not reflect the sum of individual rows due to rounding.
• The emission rate reflects the emissions (pounds) per unit of heat input (mmBtu) for each fuel category. The total SO_2 emission rate in each column of the table is not cumulative and does not equal the arithmetic mean of the four fuel-specific rates. The total for each year indicates the average rate across all units in the program because each unit influences the annual emission rate in proportion to its heat input, and heat input is unevenly distributed across the fuel categories.

Annual Nitrogen Oxides

Highlights

Overall Results

- Annual NO_X emissions have declined dramatically under the ARP, CAIR, and CSAPR programs, with most reductions coming from coal-fired units. These reductions have occurred while electricity generation has remained relatively stable since 2000.
- These emission reductions are a result of an overall increase in the environmental efficiency at affected sources as power generators installed controls, ran their controls year-round, switched to lower emitting fuels, or otherwise reduced their NO_X emissions. These trends are discussed further in Chapter 1.
- 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 2021.

Annual NO_X Emissions Trends

- **ARP:** Units in the ARP NO_X program emitted 763,000 tons of NO_X emissions in 2021. Sources reduced emissions by 7.3 million tons from the projected level in 2000 without the ARP, over three times the program's NO_X emission reduction objective.
- **CSAPR and ARP:** In 2021, the seventh year of operation of the CSAPR NO_X annual program, sources in both the CSAPR NO_X annual program and the ARP together emitted 779,000 tons, a reduction of 5.6 million tons (88 percent reduction) from 1990 levels, 4.4 million tons (85 percent reduction) from 2000, and 2.9 million tons (79 percent reduction) from 2005 levels.
- **CSAPR:** Emissions from the CSAPR NO_X annual program sources were 440,000 tons in 2021. This is about 1.7 million tons (80 percent) lower than in 2005 and 629,000 tons (59 percent) below the CSAPR NO_X annual program's 2021 regional budget of 1,069,256 tons.

Annual NO_X State-by-State Emissions

- **CSAPR and ARP:** From 1990 to 2021, annual NO_X emissions in the ARP and the CSAPR NO_X program dropped in 47 states plus Washington, D.C. by a total of approximately 5.6 million tons. In contrast, annual emissions increased in one state (Idaho) by 428 tons from 1990 to 2021.
- **CSAPR:** 21 of 22 states had emissions below their CSAPR 2021 allowance budgets, collectively by 632,000 tons. One state (Missouri) exceeded its 2021 state level budget by 2,623 tons. For more information about Program Compliance, see the Program Compliance chapter.

Annual NO_X Emission Rates

- In 2021, the ARP and CSAPR average annual NO_X emission rate was 0.07 lb/mmBtu, a 73 percent reduction from 2005.
- Emissions have decreased dramatically since 2005, due in large part to greater use of control technology, primarily on coal-fired units, and increased generation at natural gas-fired units that emit less NO_X emissions per unit of electricity than coal-fired units.

Background Information

Nitrogen oxides (NO_X) are made up of a group of highly reactive gases that are emitted from power plants and motor vehicles, as well as other sources. NO_X emissions contribute to the formation of ground-level ozone and fine particle pollution, which cause a variety of adverse health effects.

More Information

- Power Plant Emission Trends https://www.epa.gov/airmarkets/power-plant-emission-trends
- Power Sector Emissions, Operations, and Environmental Data https://www.epa.gov/airmarkets/data-resources
- Acid Rain Program (ARP) https://www.epa.gov/acidrain/acid-rain-program
- Cross-State Air Pollution Rule (CSAPR) https://www.epa.gov/csapr
- Nitrogen Oxides (NO_X) Pollution https://www.epa.gov/no2-pollution
- Particulate Matter (PM) Pollution https://www.epa.gov/pm-pollution
- Power Profiler https://www.epa.gov/energy/power-profiler

Figures

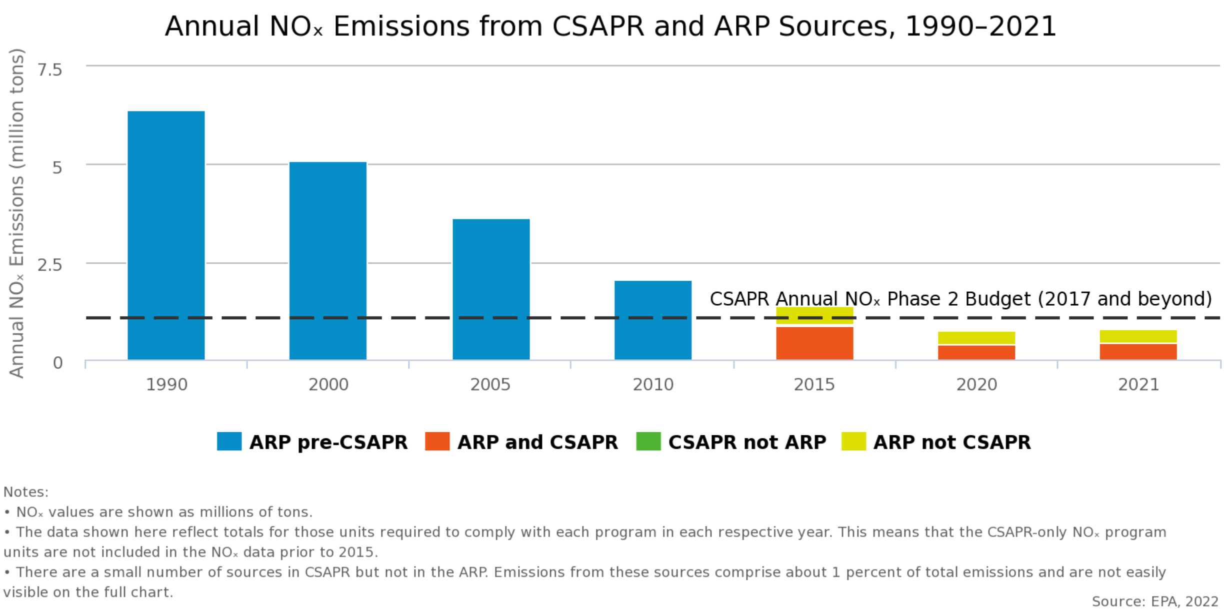

Figure 1. Annual NO_X Emissions from CSAPR and ARP Sources, 1990–2021

Notes:
• NO_x values are shown as millions of tons.
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only NO_x program units are not included in the NO_x data prior to 2015.
• There are a small number of sources in CSAPR but not in the ARP. Emissions from these sources comprise about 1 percent of total emissions and are not easily visible on the full chart.

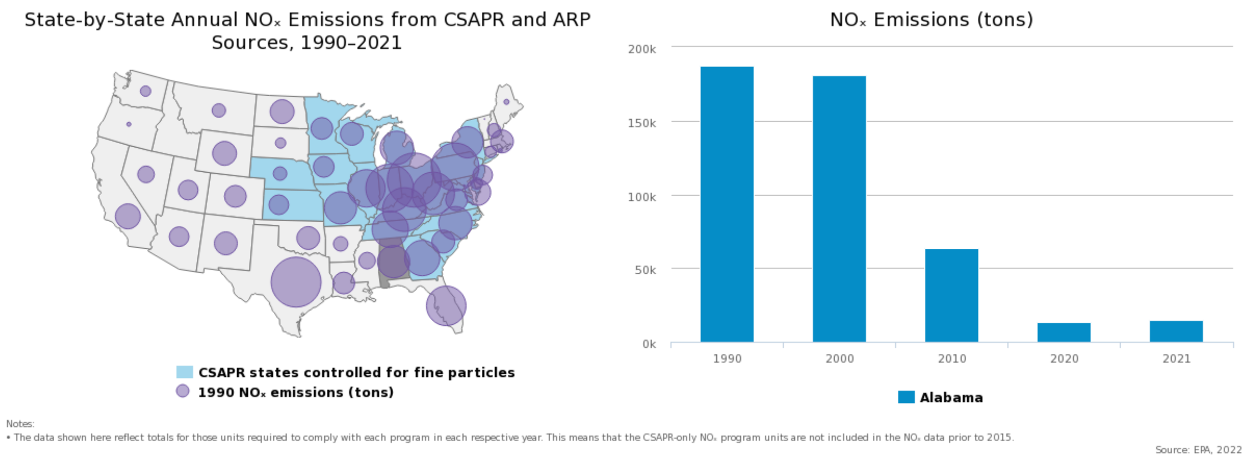

Figure 2. State-by-State Annual NO_X Emissions from CSAPR and ARP Sources, 1990–2021

Notes:
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only NO_x program units are not included in the NO_x data prior to 2015.

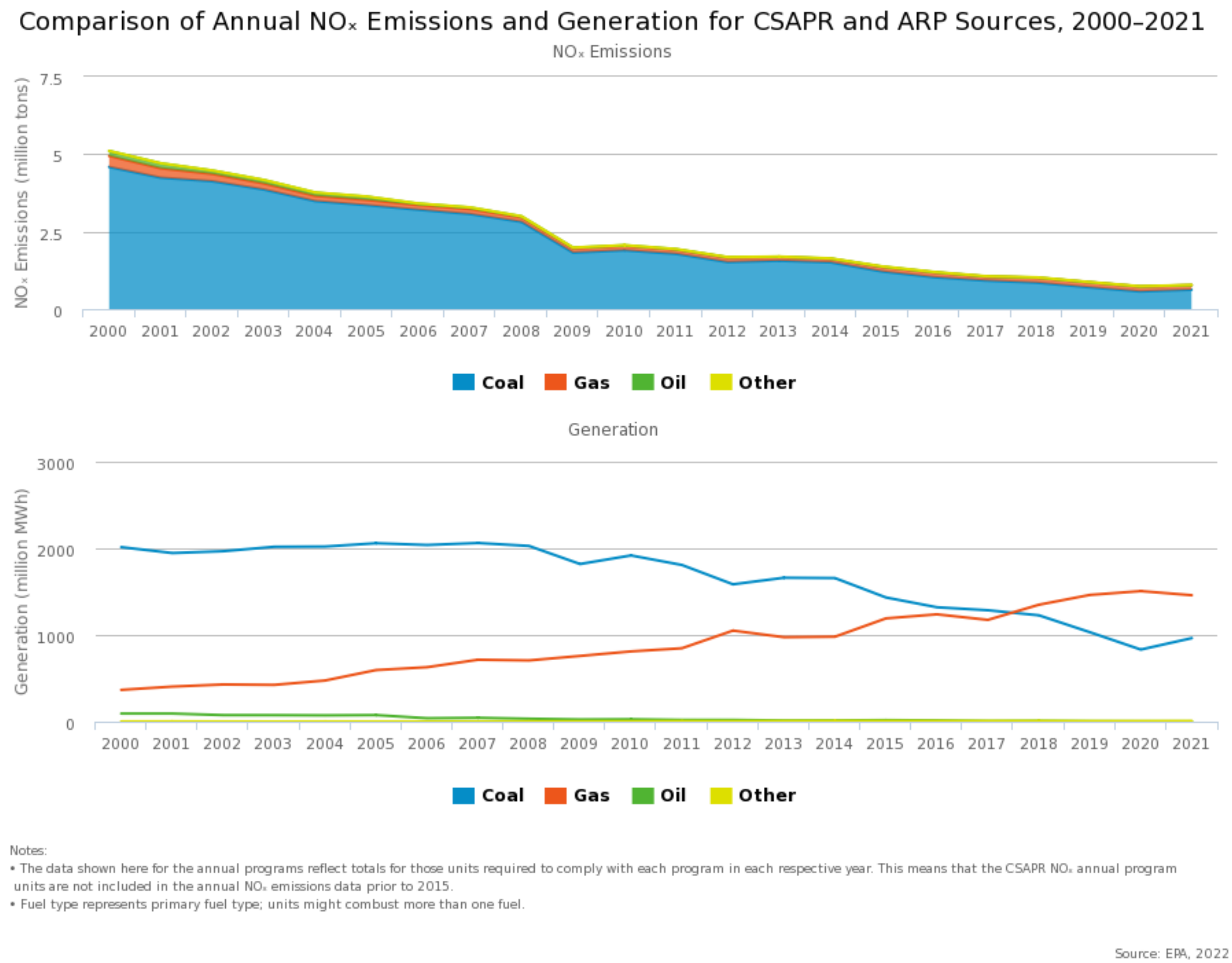

Figure 3. Comparison of Annual NO_X Emissions and Generation for CSAPR and ARP Sources, 2000–2021

Notes:
• The data shown here for the annual programs reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR NO_x annual program units are not included in the annual NO_x emissions data prior to 2015.
• Fuel type represents primary fuel type; units might combust more than one fuel.

CSAPR and ARP Annual NO_x Emissions Trends, 2021

	NO_x Emissions (thousand tons)					NO_x Rate (lb/mmBtu)				
Primary Fuel	**2000**	**2005**	**2010**	**2020**	**2021**	**2000**	**2005**	**2010**	**2020**	**2021**
Coal	4,587	3,356	1,896	569	624	0.44	0.32	0.20	0.14	0.13
Gas	355	167	142	160	146	0.18	0.06	0.04	0.03	0.03
Oil	162	104	20	2	3	0.31	0.25	0.13	0.10	0.20
Other	2	6	5	6	6	0.26	0.42	0.14	0.09	0.08
Total / Average	**5,104**	**3,633**	**2,063**	**737**	**779**	**0.40**	**0.27**	**0.16**	**0.07**	**0.07**

Notes:
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only annual NO_x program units are not included in the NO_x emissions data prior to 2015.
• Fuel type represents primary fuel type; units might combust more than one fuel.
• Totals may not reflect the sum of individual rows due to rounding.
• The emission rate reflects the emissions (pounds) per unit of heat input (mmBtu) for each fuel category. The total annual NO_x emission rate in each column of the table is not cumulative and does not equal the arithmetic mean of the four fuel-specific rates. The total for each year indicates the average rate across all units in the program because each unit influences the annual emission rate in proportion to its heat input, and heat input is unevenly distributed across the fuel categories.

Source: EPA, 2022

Figure 4. CSAPR and ARP Annual NO_X Emissions Trends, 2000-2021

Notes:
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only annual NO_x program units are not included in the NO_x emissions data prior to 2015.
• Fuel type represents primary fuel type; units might combust more than one fuel.
• Totals may not reflect the sum of individual rows due to rounding.
• The emission rate reflects the emissions (pounds) per unit of heat input (mmBtu) for each fuel category. The total annual NO_x emission rate in each column of the table is not cumulative and does not equal the arithmetic mean of the four fuel-specific rates. The total for each year indicates the average rate across all units in the program because each unit influences the annual emission rate in proportion to its heat input, and heat input is unevenly distributed across the fuel categories.

Ozone Season Nitrogen Oxides

Highlights

Overall Results

- Ozone season NO_X emissions have declined dramatically under the ARP, NBP, CAIR, and CSAPR programs.[1]
- States with the highest emitting sources of ozone season NO_X emissions in 2000 have seen the greatest reductions under the CSAPR NO_X ozone season programs. Most of these states are in the Ohio River Valley and are upwind of the areas CSAPR was designed to protect. Reductions by sources in these states have resulted in important environmental and human health benefits over a large region.
- These reductions have occurred while electricity generation has remained relatively stable since 2000. These trends are discussed further in Chapter 1.
- Other programs – such as regional and state NO_X emission control programs – also contributed significantly to the ozone season NO_X emission reductions achieved by sources in 2021.

Ozone Season NO_X Emissions Trends

- **ARP:** Units in the ARP program emitted 351,000 tons of ozone season NO_X emissions in 2021. Sources reduced emissions by 1.8 million tons (84 percent) from the 2000 ozone season and 920,000 tons (72 percent) from the 2005 ozone season.
- **CSAPR:** In 2021, units covered under the CSAPR NO_X ozone season programs (Groups 1, 2, and 3) emitted 242,000 tons, a reduction of 210,000 (46%) since 2015.
- In 2021, the CSAPR NO_X ozone season program emissions were 19 percent below the regional emission budget of 298,879 tons (24,041 tons for Group 1, 143,408 tons for Group 2, and 131,430 tons for Group 3).

Ozone Season NO_X State-by-State Emissions

- Between 2005 and 2021, ozone season NO_X emissions from the CSAPR sources fell in every state participating in the CSAPR NO_X ozone season program.
- 20 states had emissions below their CSAPR 2021 allowance budgets, collectively by about 62,000 tons. Three states (Illinois, Missouri, and Pennsylvania) exceeded their 2021 state level budgets by about 5,400 tons total.

Ozone Season NO_X Emission Rates

- In 2021, the average NO_X ozone season emission rate fell to 0.07 lb/mmBtu for the CSAPR ozone season program states and 0.07 lb/mmBtu nationally. This represents a 63 and 66 percent reduction, respectively, from 2005 emission rates, with the majority of reductions coming from coal-fired units.

[1] CSAPR refers to the CSAPR, the CSAPR Update, and the Revised CSAPR Update programs.

- Emissions have decreased dramatically since 2005, due in large part to greater use of control technology, primarily on coal-fired units, and increased generation at natural gas-fired units, which emit less NO_X emissions per unit of electricity than coal-fired units.

Background Information

Nitrogen oxides (NO_X) are made up of a group of highly reactive gases that are emitted from power plants and motor vehicles, as well as other sources. NO_X emissions contribute to the formation of ground-level ozone and fine particle pollution, which cause a variety of adverse human health effects.

The CSAPR NO_X ozone season program was established to reduce interstate transport of air pollution during the ozone season (May 1 – September 30), the warm summer months when ozone formation is highest, and to help eastern U.S. counties attain the 1997 ozone standard. The CSAPR Update NO_X ozone season program was similarly established to help eastern U.S. counties attain the 2008 ozone standard. On March 15, 2021, EPA finalized the Revised CSAPR Update to further reduce NO_X emissions from power plants in 12 states. The rule responded to a September 2019 ruling by the United States Court of Appeals for the D.C. Circuit, Wisconsin v. EPA, which remanded the 2016 CSAPR Update to EPA for failing to fully eliminate significant contribution to nonattainment and interference with maintenance of the 2008 ozone NAAQS from these states by downwind areas' attainment dates.

More Information

- Power Plant Emission Trends https://www.epa.gov/airmarkets/power-plant-emission-trends
- Power Sector Emissions, Operations, and Environmental Data https://www.epa.gov/airmarkets/data-resources
- Cross-State Air Pollution Rule (CSAPR) https://www.epa.gov/csapr
- Pollution from Nitrogen Oxides (NO_X) https://www.epa.gov/no2-pollution
- Pollution from Ozone https://www.epa.gov/ozone-pollution

Figures

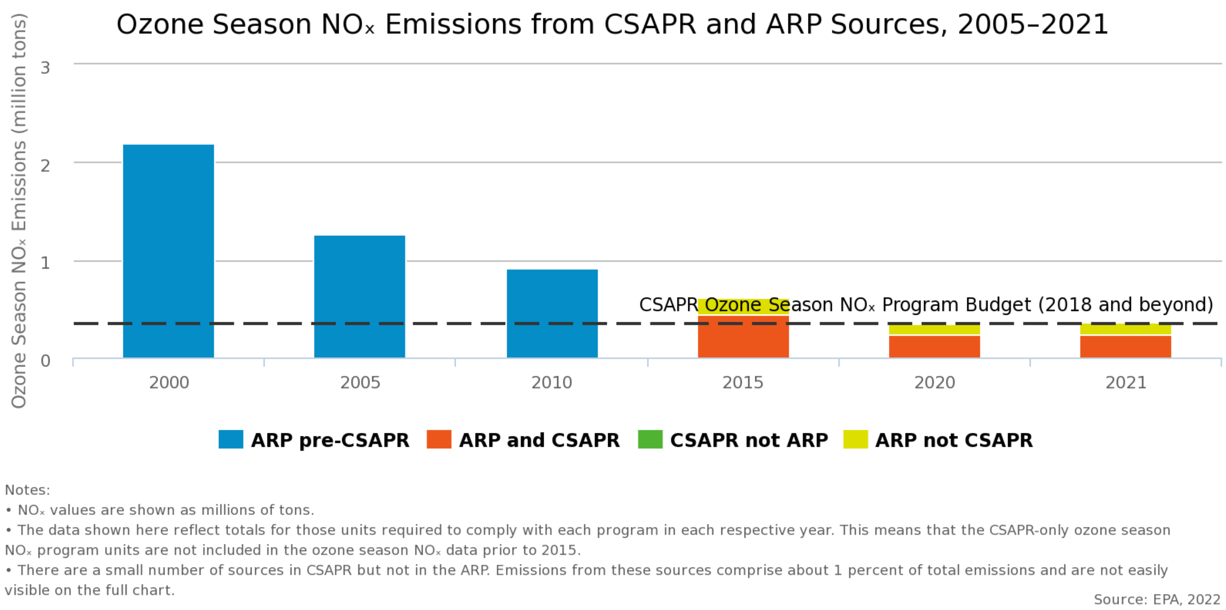

Figure 1. Ozone Season NO_X Emissions from CSAPR and ARP Sources, 2000–2021

Notes:
• NO_x values are shown as millions of tons.
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only ozone season NO_x program units are not included in the ozone season NO_x data prior to 2015.
• There are a small number of sources in CSAPR but not in the ARP. Emissions from these sources comprise about 1 percent of total emissions and are not easily visible on the full chart.

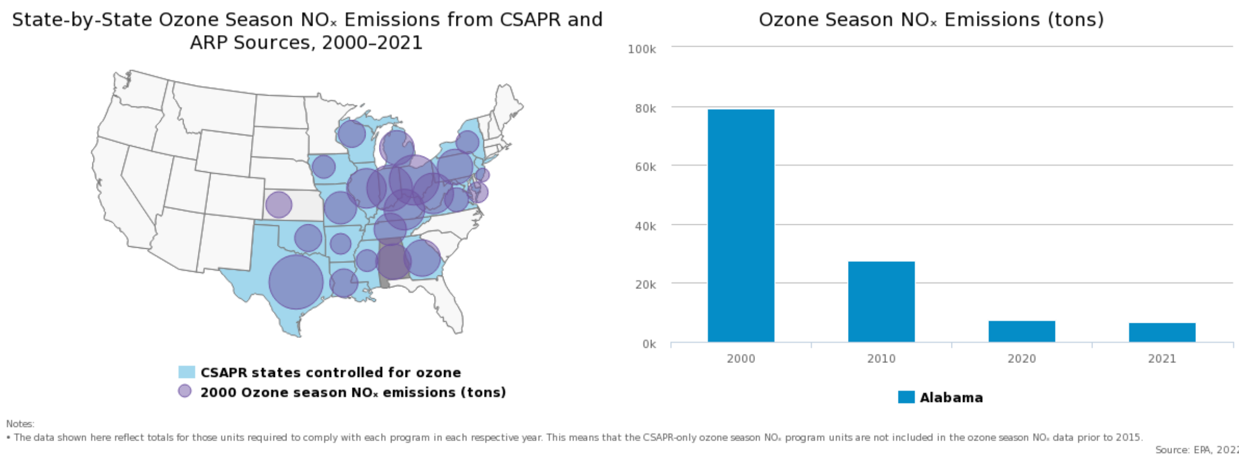

Figure 2. State-by-State Ozone Season NO_X Emissions from CSAPR and ARP Sources, 2000–2021

Notes:
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR-only ozone season NO_x program units are not included in the ozone season NO_x data prior to 2015.

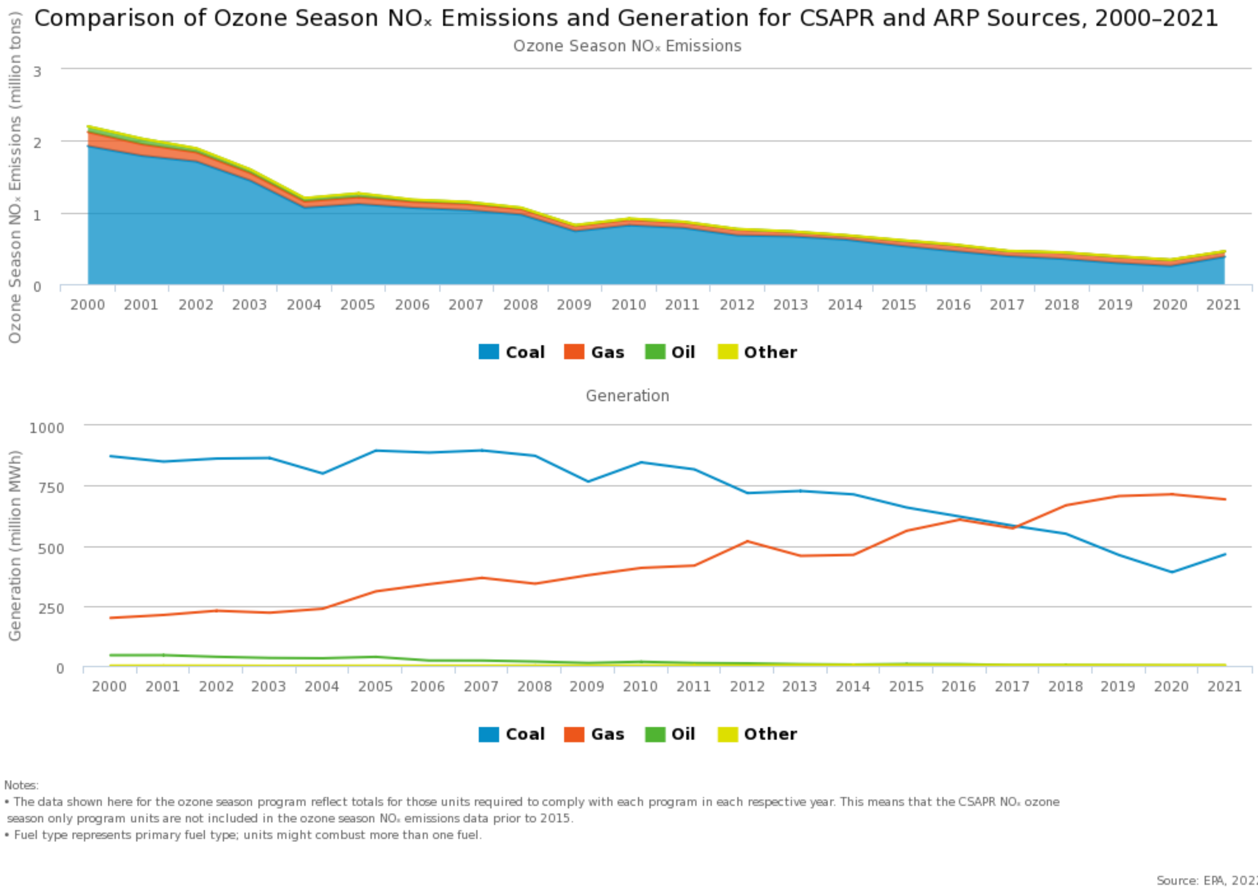

Figure 3. Comparison of Ozone Season NO_X Emissions and Generation for CSAPR and ARP Sources, 2000–2021

Notes:
• The data shown here for the ozone season program reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR NO_x ozone season only program units are not included in the ozone season NO_x emissions data prior to 2015.
• Fuel type represents primary fuel type; units might combust more than one fuel.

CSAPR and ARP Ozone Season NO_x Emissions Trends, 2021

	Ozone Season NO_x Emissions (thousand tons)					Ozone Season NO_x Rate (lb/mmBtu)				
Primary Fuel	**2000**	**2005**	**2010**	**2020**	**2021**	**2000**	**2005**	**2010**	**2020**	**2021**
Coal	1,926	1,117	821	253	282	0.43	0.25	0.19	0.13	0.12
Gas	196	96	79	85	73	0.19	0.07	0.04	0.03	0.03
Oil	78	52	12	1	1	0.31	0.25	0.13	0.09	0.13
Other	1	2	2	2	3	0.25	0.40	0.11	0.08	0.09
Total / Average	**2,201**	**1,267**	**914**	**341**	**359**	**0.38**	**0.20**	**0.15**	**0.07**	**0.07**

Notes:
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR NO_x ozone season only program units are not included in the ozone season NO_x emissions data prior to 2015.
• Fuel type represents primary fuel type; units might combust more than one fuel.
• Totals may not reflect the sum of individual rows due to rounding.
• The emission rate reflects the emissions (pounds) per unit of heat input (mmBtu) for each fuel category. The total NO_x ozone season emission rate in each column of the table is not cumulative and does not equal the arithmetic mean of the four fuel-specific rates. The total for each year indicates the average rate across all units in the program because each unit influences the annual emission rate in proportion to its heat input, and heat input is unevenly distributed across the fuel categories.

Source: EPA, 2022

Figure 4. CSAPR Ozone Season NO_X Emissions Trends, 2000-2021

Notes:
• The data shown here reflect totals for those units required to comply with each program in each respective year. This means that the CSAPR NO_x ozone season only program units are not included in the ozone season NO_x emissions data prior to 2015.
• Fuel type represents primary fuel type; units might combust more than one fuel.
• Totals may not reflect the sum of individual rows due to rounding.
• The emission rate reflects the emissions (pounds) per unit of heat input (mmBtu) for each fuel category. The total NO_x ozone season emission rate in each column of the table is not cumulative and does not equal the arithmetic mean of the four fuel-specific rates. The total for each year indicates the average rate across all units in the program because each unit influences the annual emission rate in proportion to its heat input, and heat input is unevenly distributed across the fuel categories.

Mercury

Highlights

Overall Results

- Mercury and other hazardous air pollutant (HAP) emissions have declined significantly since 2010 estimates. These emission reductions were driven by the installation of new pollution controls and enhancements of existing pollution controls that reduce multiple pollutants. Emissions have also decreased due to operational changes, such as fuel switching and increased generation at natural gas-fired units that emit very little mercury and other HAPs. These trends are discussed in Chapter 1.
- Other programs – such as regional and state SO_2 and NO_X emission control programs – also contributed to the mercury and other HAP emission reductions achieved by covered sources in 2021.

Mercury and Hazardous Air Pollutant Emission Trends

- Compared to 2010[1], units covered under MATS in 2021 emitted 26 fewer tons of mercury (90% reduction).

Background Information

Hazardous air pollutants (HAPs) emitted by power plants include mercury, acid gases (e.g., hydrochloric acid, hydrofluoric acid), non-mercury metallic toxics (e.g., arsenic, nickel, and chromium), and organic HAPs (e.g., formaldehyde, dioxin/furan). Exposure to these pollutants at certain concentrations and durations can increase chances of neurological and developmental effects, cancer, and reproductive, respiratory, and other health problems.

In 2011, EPA issued MATS, establishing national emission standards for mercury and other hazardous air pollutants for new and existing coal- and oil-fired power plants. The standards were finalized under section 112 of the Clean Air Act. The MATS emission standards were established using data from a 2010 information collection request that was sent to selected coal and oil burning power plants.

More Information

- Power Sector Emissions, Operations, and Environmental Data https://www.epa.gov/airmarkets/data-resources
- Mercury and Air Toxics Standards (MATS) https://www.epa.gov/stationary-sources-air-pollution/mercury-and-air-toxics-standards
- Hazardous Air Pollutants (HAPs) https://www.epa.gov/haps

[1] Emissions from 2010 are estimated as described in *Memorandum: Emissions Overview: Hazardous Air Pollutants in Support of the Final Mercury and Air Toxics Standard.* EPA-454/R-11-014. November 2011; Docket ID No. EPA-HQ-OAR-2009-0234-19914.

Figures

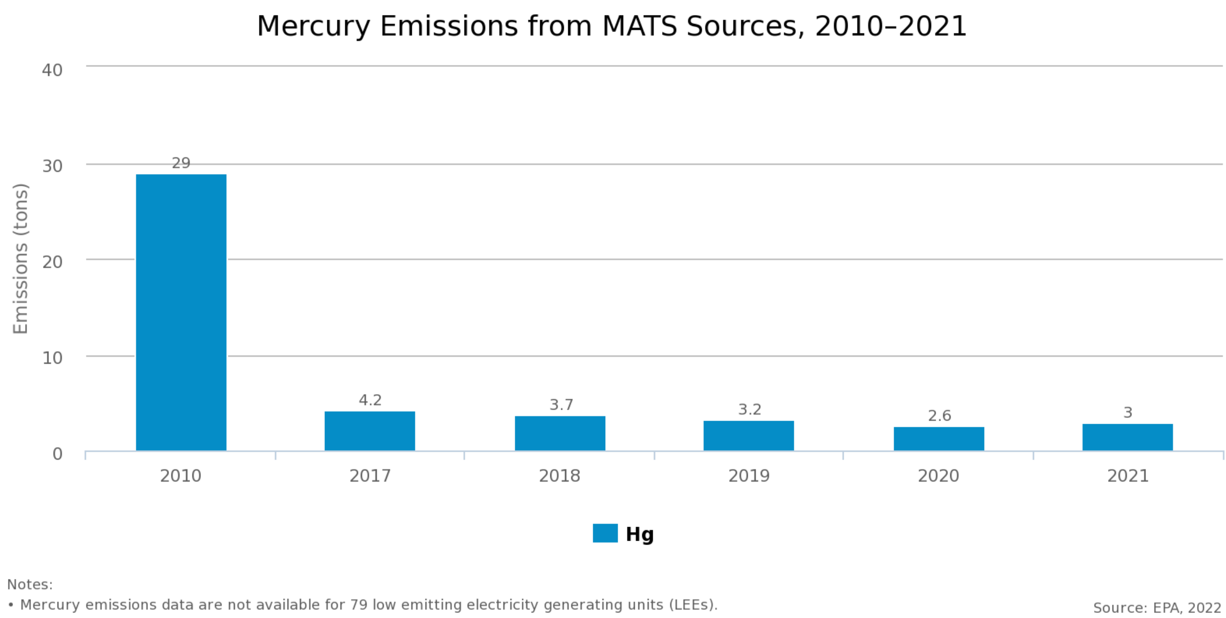

Figure 1. Mercury Emissions from MATS Sources, 2010–2021

Notes:
• Mercury emissions data are not available for 79 low emitting electricity generating units (LEEs).

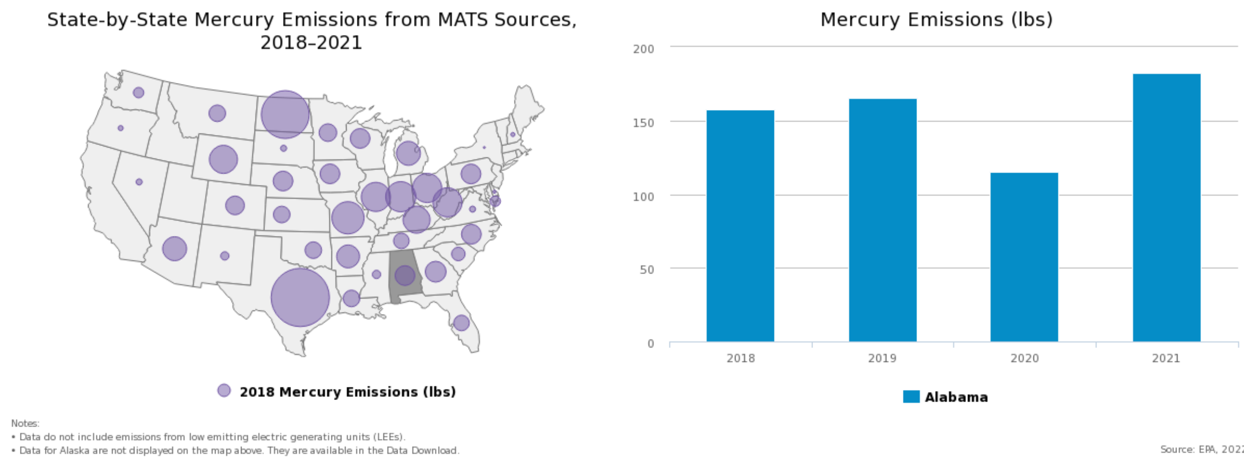

Figure 2. State-by-State Mercury Emissions from MATS Sources, 2021

Notes:

- Data do not include emissions from low emitting electric generating units (LEEs).
- Data for Alaska are not displayed on the map above. They are available in the Data Download.

Chapter 4: Emission Controls and Monitoring

Many sources opted to install control technologies to meet the Acid Rain Program (ARP) and Cross-State Air Pollution Rule (CSAPR) emission reduction targets.[1] A wide range of controls is available to help reduce emissions. Affected units under the Mercury and Air Toxics Standards (MATS) also have several options for reducing hazardous air pollutants and have some flexibility in how they monitor emissions. These programs hold sources to high standards of accountability for emissions. Accurate and consistent emissions monitoring data are critical to ensure program results and accountability. Most emissions from affected sources are measured by continuous emission monitoring systems (CEMS).

Highlights

ARP and CSAPR SO_2 Program Controls and Monitoring

- Units with advanced flue gas desulfurization (FGD) controls (also known as scrubbers) accounted for 71 percent of coal-fired units and 81 percent of coal-fired electricity generation, measured in megawatt hours, or MWh, in 2021.
- In 2021, 20 percent of the CSAPR units (including 100 percent of coal-fired units) monitored SO_2 emissions using CEMS. Ninety-nine percent of SO_2 emissions were measured by CEMS.

CSAPR NO_X Annual Program Controls and Monitoring

- Eighty-one percent of fossil fuel-fired generation was produced by units with advanced add-on controls (either selective catalytic reduction [SCR] or selective non-catalytic reduction [SNCR]).
- In 2021, the 236 coal-fired units with advanced add-on controls (either SCRs or SNCRs) generated 78 percent of coal-fired electricity. At oil- and natural gas-fired units, SCR- and SNCR-controlled units produced 84 percent of electricity generation.
- In 2021, 67 percent of the CSAPR units (including 100 percent of coal-fired units) monitored NO_X emissions using CEMS. Ninety-seven percent of NO_X emissions were measured by CEMS.

CSAPR NO_X Ozone Season Program Controls and Monitoring

- Seventy-three percent of all the fossil fuel-fired generation was produced by units with advanced add-on controls (either SCRs or SNCRs).
- In 2021, 213 units with advanced add-on controls (either SCR or SNCR) accounted for 71 percent of coal-fired electricity generation. At oil- and natural gas-fired units, SCR- and SNCR-controlled units produced 75 percent of electricity generation.
- In 2021, 73 percent of the CSAPR units (including 100 percent of coal-fired units) monitored ozone season NO_X emissions using CEMS. Ninety-seven percent of ozone season NO_X emissions were measured by CEMS.

[1] CSAPR refers to the CSAPR, the CSAPR Update, and the Revised CSAPR Update programs.

MATS Controls and Monitoring

- In 2021, forty-six percent of the MATS units reporting mercury emissions and 52 percent of the electricity generation at the MATS reporting units used activated carbon injection (ACI), a mercury-specific pollution control method to reduce mercury emissions and SO_2.
- About 81 percent of units that reported continuous mercury emissions data (or 82 percent of the total electricity generation from units that reported data) reported the use of advanced controls, such as wet scrubbers, dry scrubbers, or ACI, to reduce hazardous air pollutant emissions in 2021. These controls also reduce other pollutants, including SO_2. Some oil-fired units can meet the MATS emission limits through the use of particulate matter (PM) controls such as electrostatic precipitators (ESPs) or fabric filters (FFs).

Background Information

Continuous Emission Monitoring Systems (CEMS)

EPA has developed detailed procedures codified in federal regulations (40 CFR Part 75) to ensure that sources monitor and report emissions with a high degree of precision, reliability, accuracy, and timeliness. Sources are required to use CEMS or other approved methods to record and report pollutant emissions data. Sources conduct stringent quality assurance tests of their monitoring systems to ensure the accuracy of emissions data and to provide assurance to market participants that a quantity of emissions measured at one facility is equivalent to the same quantity measured at a different facility. EPA conducts comprehensive electronic and desk data audits to validate the reported data. While some units with low levels of SO_2 or NO_X emissions are allowed to use other approved monitoring methods, the vast majority of SO_2 and NO_X emissions are measured by CEMS.

Affected units have a variety of monitoring options, but most use either CEMS or sorbent traps for mercury (Hg). Some qualifying units with low emissions can conduct periodic stack tests in lieu of continuous monitoring.

SO_2 Emission Controls

Sources in the ARP or the CSAPR SO_2 programs have a number of SO_2 emission control options available. These include switching to low sulfur coal or natural gas, employing various types of FGDs, or, in the case of fluidized bed boilers, injecting limestone into the furnace. FGDs on coal-fired electricity generating units are the principal means of controlling SO_2 emissions and tend to be present on the highest generating coal-fired units.

NO_X Emission Controls

Sources in the ARP or the CSAPR NO_X annual and ozone season programs have a variety of options by which to reduce NO_X emissions, including advanced add-on controls such as SCR or SNCR, and combustion controls, such as low NO_X burners.

Hazardous Air Pollutant Controls

Sources in MATS have a number of options available to reduce hazardous air pollutants (HAPs), including mercury, PM (a surrogate for toxic non-mercury metals), HCl, HF, and other acid gases. Sources can improve operation of existing controls, add pollution controls, and switch fuels (including coal blending).

Specific pollution control devices that reduce mercury and HCl include wet FGDs, activated carbon injection (ACI), dry sorbent injection (DSI), and fabric filters.

More Information

- Power Plant Emission Trends https://www.epa.gov/airmarkets/power-plant-emission-trends
- Power Sector Emissions, Operations, and Environmental Data https://www.epa.gov/airmarkets/data-resources
- Emissions Monitoring https://www.epa.gov/airmarkets/emissions-monitoring-and-reporting
- Plain English guide to 40 CFR Part 75 https://www.epa.gov/airmarkets/plain-english-guide-part-75-rule
- Continuous Emission Monitoring Systems (CEMS) https://www.epa.gov/emc/emc-continuous-emission-monitoring-systems

Figures

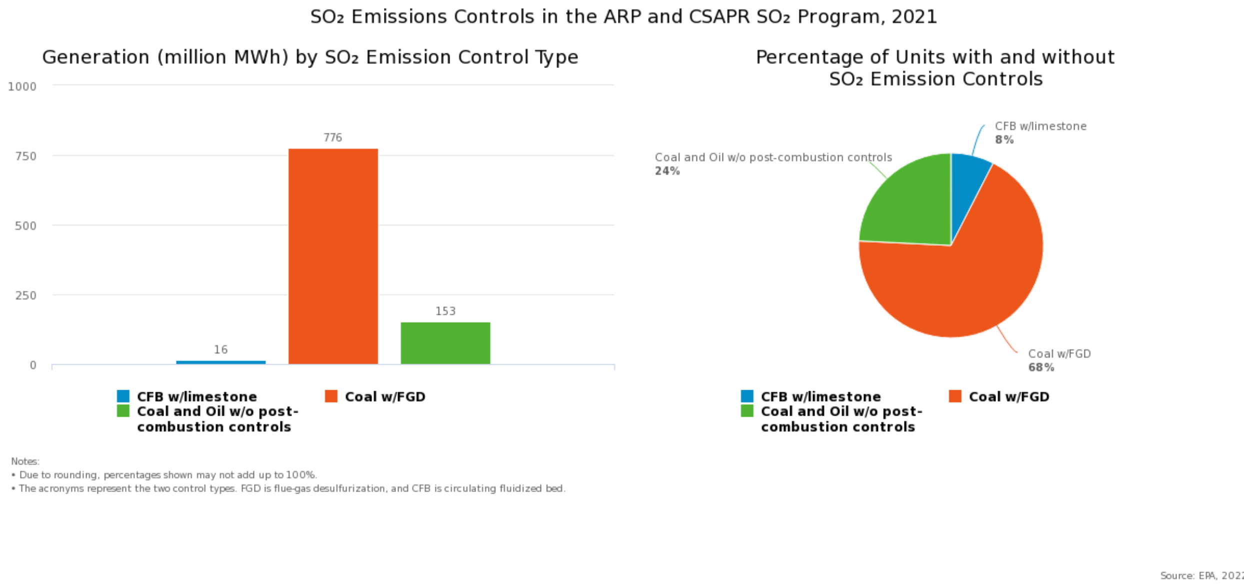

Figure 1. SO_2 Emissions Controls in the ARP and CSAPR SO_2 Program, 2021

Notes:
- Due to rounding, percentages shown may not add up to 100%.
- The acronyms represent the two control types. FGD is flue-gas desulfurization, and CFB is circulating fluidized bed.

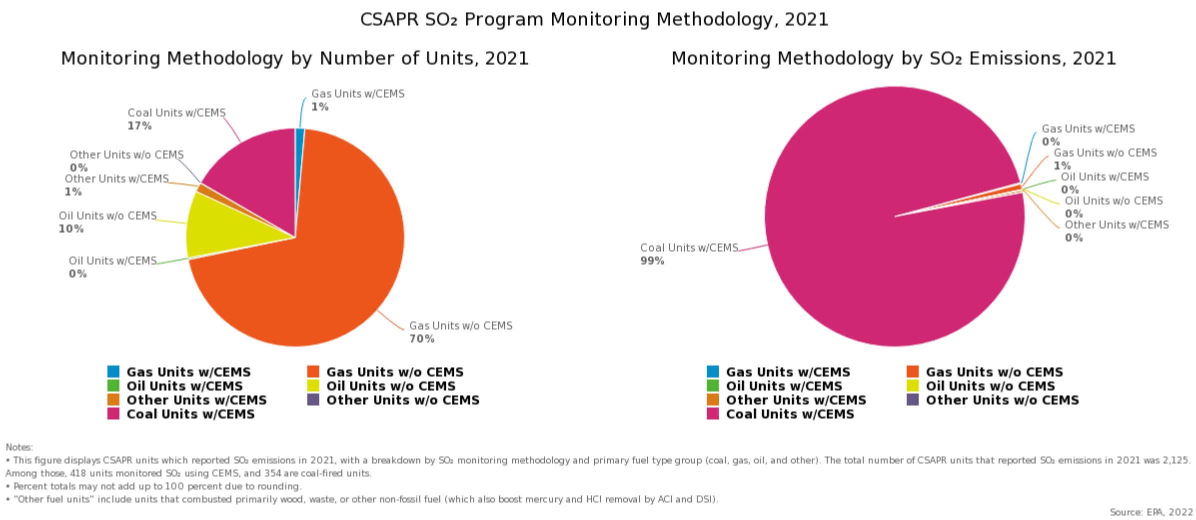

Figure 2. CSAPR SO_2 Program Monitoring Methodology, 2021

Notes:

- This figure displays CSAPR units which reported SO_2 emissions in 2021, with a breakdown by SO_2 monitoring methodology and primary fuel type group (coal, gas, oil, and other). The total number of CSAPR units that reported SO_2 emissions in 2021 was 2,125. Among those, 418 units monitored SO_2 using CEMS, and 354 are coal-fired units.
- Percent totals may not add up to 100 percent due to rounding.
- "Other fuel units" include units that combusted primarily wood, waste, or other non-fossil fuel (which also boost mercury and HCl removal by ACI and DSI).

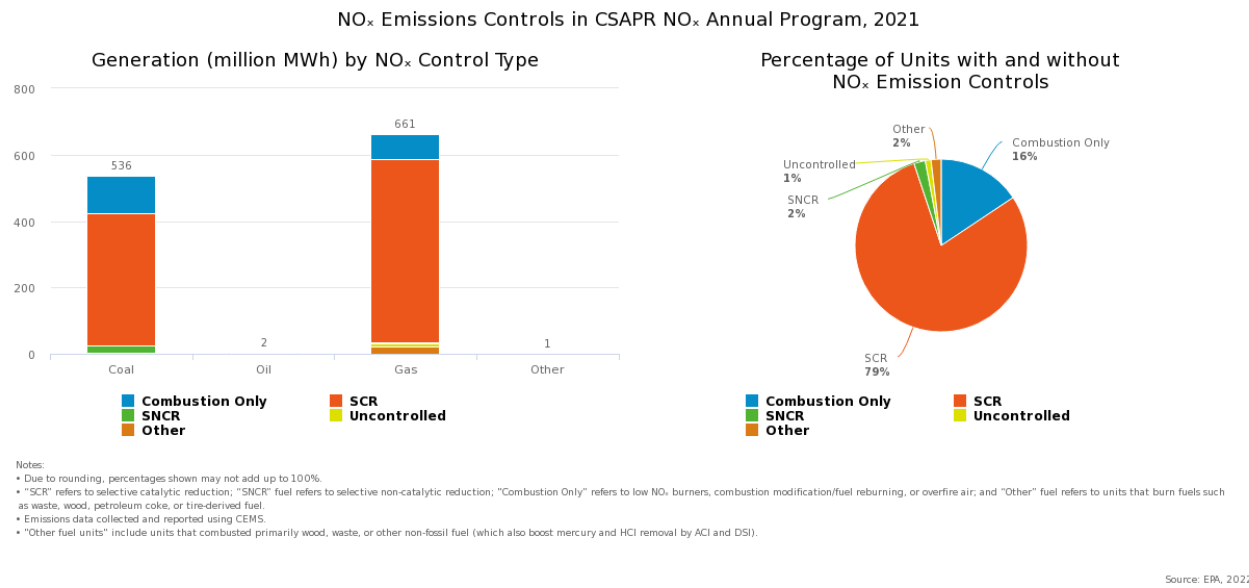

Figure 3. NO_X Emissions Controls in CSAPR NO_X Annual Program, 2021

Notes:
• Due to rounding, percentages shown may not add up to 100%.
• "SCR" refers to selective catalytic reduction; "SNCR" fuel refers to selective non-catalytic reduction; "Combustion Only" refers to low NO_x burners, combustion modification/fuel reburning, and/or overfire air; and "Other" fuel refers to units that burn fuels such as waste, wood, petroleum coke, or tire-derived fuel.
• "Other fuel units" include units that combusted primarily wood, waste, or other non-fossil fuel (which also boost mercury and HCl removal by ACI and DSI).

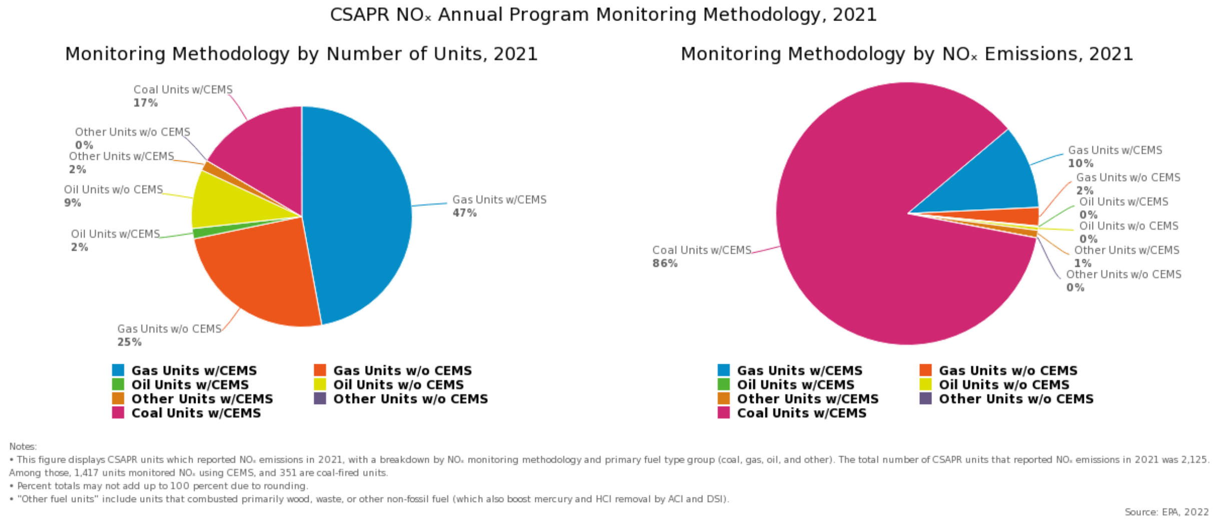

Figure 4. CSAPR NO_X Annual Program Monitoring Methodology, 2021

Notes:

• This figure displays CSAPR units which reported NO_x emissions in 2021, with a breakdown by NO_x monitoring methodology and primary fuel type group (coal, gas, oil, and other). The total number of CSAPR units that reported NO_x emissions in 2021 was 2,125. Among those, 1,417 units monitored NO_x using CEMS, and 351 are coal-fired units.

• Percent totals may not add up to 100 percent due to rounding.

• "Other fuel units" include units that combusted primarily wood, waste, or other non-fossil fuel (which also boost mercury and HCl removal by ACI and DSI).

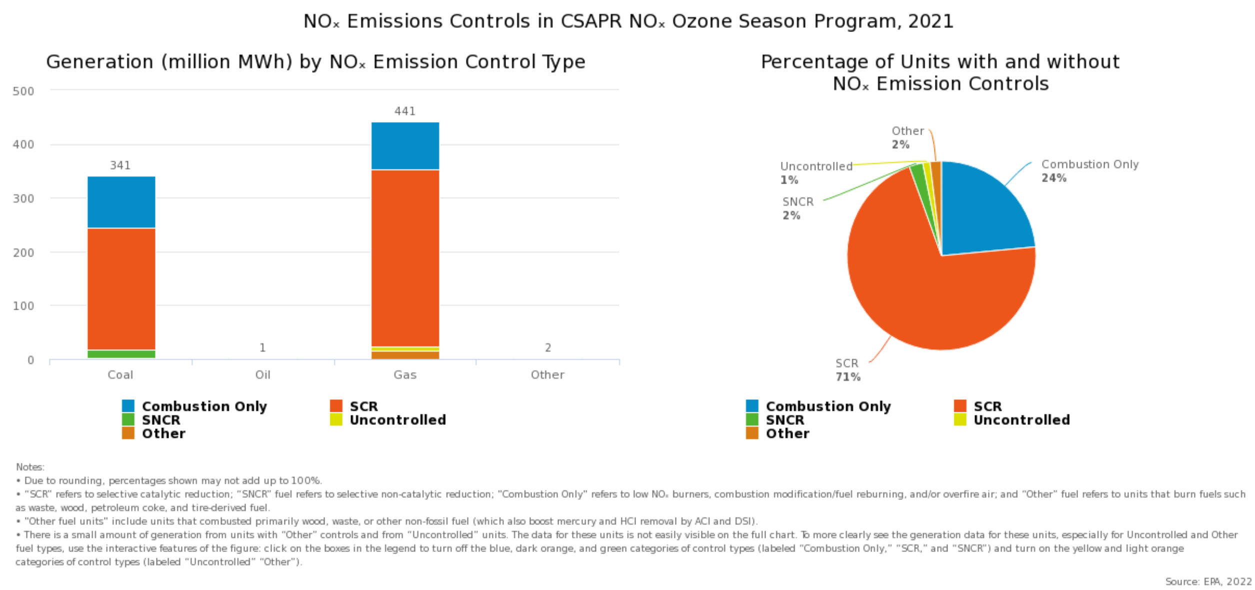

Figure 5. NO_X Emissions Controls in the CSAPR NO_X Ozone Season Program, 2021

Notes:
• Due to rounding, percentages shown may not add up to 100%.
• “SCR” refers to selective catalytic reduction; “SNCR” fuel refers to selective non-catalytic reduction; "Combustion Only" refers to low NO_x burners, combustion modification/fuel reburning, and/or overfire air; and “Other” fuel refers to units that burn fuels such as waste, wood, petroleum coke, and tire-derived fuel.
• "Other fuel units" include units that combusted primarily wood, waste, or other non-fossil fuel (which also boost mercury and HCl removal by ACI and DSI).
• There is a small amount of generation from units with “Other” controls and from “Uncontrolled” units. The data for these units is not easily visible on the full chart. To more clearly see the generation data for these units, especially for Uncontrolled and Other fuel types, use the interactive features of the figure: click on the boxes in the legend to turn off the blue, dark orange, and green categories of control types (labeled “Combustion Only,” “SCR,” and “SNCR”) and turn on the yellow and light orange categories of control types (labeled “Uncontrolled” “Other”).

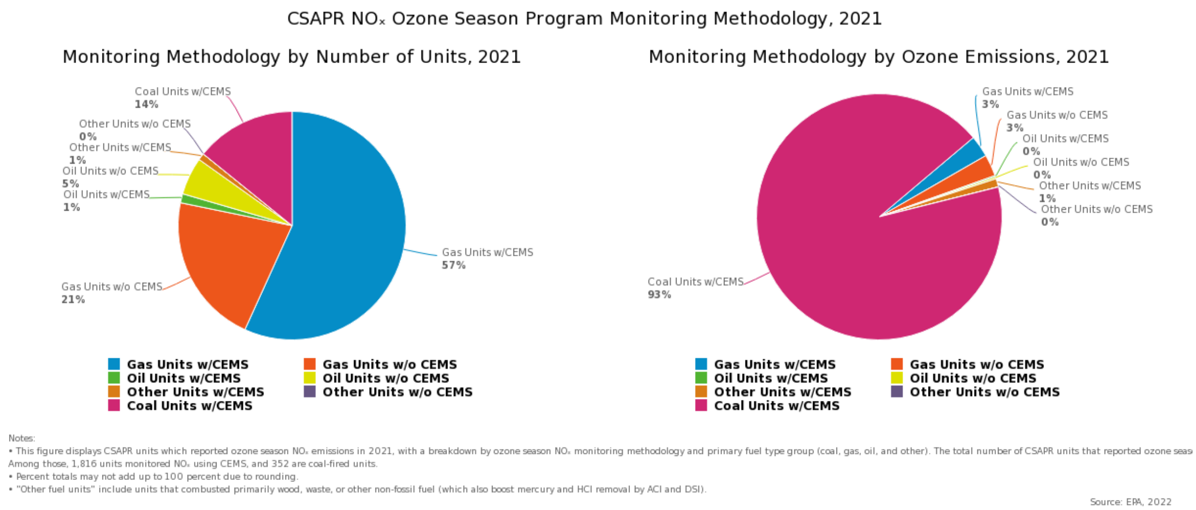

Figure 6. CSAPR NO_X Ozone Season Program Monitoring Methodology, 2021

Notes:

- This figure displays CSAPR units which reported ozone season NO_x emissions in 2021, with a breakdown by ozone season NO_x monitoring methodology and primary fuel type group (coal, gas, oil, and other). The total number of CSAPR units that reported ozone season NO_x emissions in 2021 was 2,499. Among those, 1,816 units monitored NO_x using CEMS, and 352 are coal-fired units.
- Percent totals may not add up to 100 percent due to rounding.
- "Other fuel units" include units that combusted primarily wood, waste, or other non-fossil fuel (which also boost mercury and HCl removal by ACI and DSI).

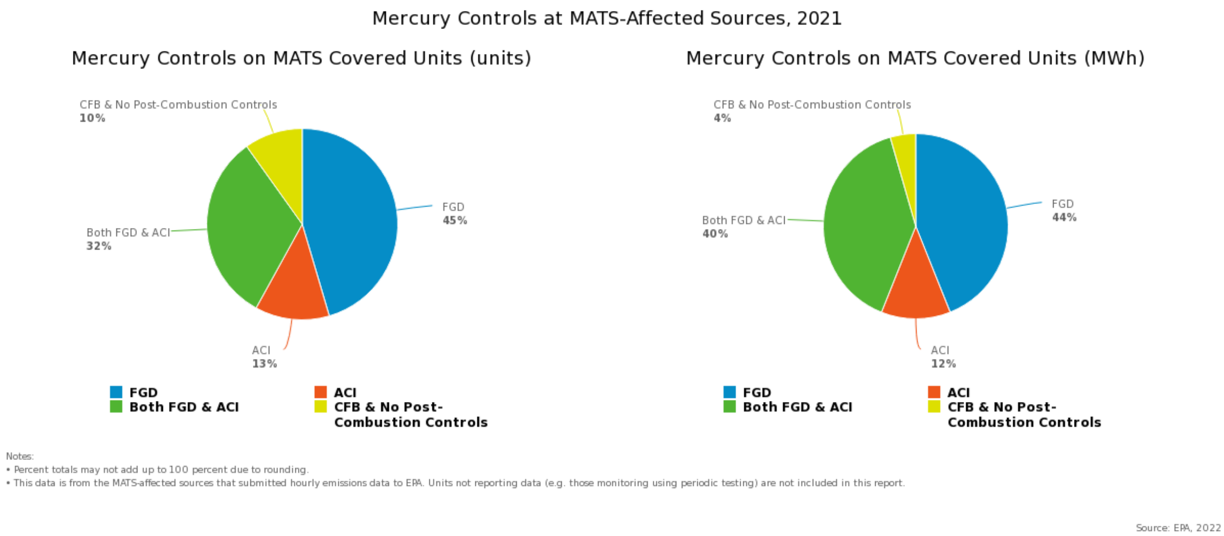

Figure 7. Mercury Controls at MATS-Affected Sources, 2021

Notes:

• Percent totals may not add up to 100 percent due to rounding.

• This data is from the MATS-affected sources that submitted hourly emissions data to EPA. Units not reporting data (e.g., those monitoring using periodic testing) are not included in this report.

Mercury Compliance and Monitoring Methods used by Units Reporting Hourly Data under MATS, 2021

Reporting Hourly Data		Compliance Method (# of Units)		Monitoring Method		
Number of reporting units	Number of reporting facilities	Electrical Output	Heat Input	Sorbent Trap	CEMS	CEMS and Sorbent Trap
405	186	115	290	177	187	41

Notes:
• This data is from the MATS-affected sources that submitted hourly emissions data to EPA and does not show complete data from all the MATS-affected sources because many sources received compliance extensions or chose to demonstrate compliance through methods other than continuously monitored emissions.

Source: EPA, 2022
Last updated: 05/2022

Figure 8. Mercury Compliance and Monitoring Methods used by Units Reporting Hourly Data under MATS, 2021

Notes:

• This data is from the MATS-affected sources that submitted hourly emissions data to EPA and does not show complete data from all the MATS-affected sources because many sources received compliance extensions or chose to demonstrate compliance through methods other than continuously monitored emissions.

Chapter 5: Program Compliance

Compliance for the Acid Rain Program (ARP) and each of the Cross-State Air Pollution Rule (CSAPR)[1] trading programs is assessed on an annual basis. Each regulated facility must hold an amount of allowances equal to or greater than its emissions for the relevant compliance period. Historically, these programs have had exceptionally high rates of compliance. This performance continued in 2021 as 100% of the facilities in each of these programs held sufficient allowances to cover their emission obligations.

The information below details how the ARP and CSAPR allowances were used for compliance under the emissions trading programs in 2021. In contrast to the ARP and CSAPR,[1] the Mercury and Air Toxics Standards (MATS) rule is issued under section 112 of the Clean Air Act and is not an emissions trading program.

Highlights

ARP SO_2 Program

- All ARP SO_2 facilities were in compliance in 2021, holding sufficient allowances to cover their SO_2 emissions.
- ARP sources reported total SO_2 emissions of 935,750 tons in 2021.
- EPA deducted 935,703 allowances for compliance with the ARP. After reconciliation, over 71 million ARP SO_2 allowances remain unused and were banked.

CSAPR SO_2 Group 1 Program

- All CSAPR SO_2 Group 1 facilities were in compliance in 2021, holding sufficient allowances to cover their SO_2 emissions.
- CSAPR SO_2 Group 1 sources reported total SO_2 emissions of 518,858 tons in 2021.
- EPA deducted 518,867 allowances for the CSAPR SO_2 Group 1 compliance. After reconciliation, about 6.6 million CSAPR SO_2 Group 1 allowances remain unused and were banked.

CSAPR SO_2 Group 2 Program

- All CSAPR SO_2 Group 2 facilities were in compliance in 2021, holding sufficient allowances to cover their SO_2 emissions.
- CSAPR SO_2 Group 2 sources reported total SO_2 emissions of 73,572 tons in 2021.
- EPA deducted 73,565 allowances for the CSAPR SO_2 Group 2 compliance. After reconciliation, about 3.4 million CSAPR SO_2 Group 2 allowances remain unused and were banked.

CSAPR NO_X Annual Program

- All CSAPR NO_X Annual Program facilities were in compliance in 2021, holding sufficient allowances to cover their NO_X emissions.

[1] CSAPR refers to the CSAPR, the CSAPR Update, and the Revised CSAPR Update programs.

- CSAPR annual NO_X sources reported total NO_X emissions of 440,051 tons in 2021.
- EPA deducted 440,184 allowances for the CSAPR NO_X Annual Program compliance. After reconciliation, about 3.4 million CSAPR NO_X Annual Program allowances remain unused and were banked.

CSAPR NO_X Ozone Season Group 1 Program

- All CSAPR NO_X Ozone Season Group 1 facilities were in compliance in 2021, holding sufficient allowances to cover their NO_X emissions.
- CSAPR NO_X Ozone Season Group 1 sources reported total ozone season NO_X emissions of 6,150 tons in 2021.
- EPA deducted 6,154 allowances for the CSAPR NO_X Ozone Season Group 1 compliance. After reconciliation, over 105,000 CSAPR NO_X Ozone Season Group 1 allowances remain unused and were banked.

CSAPR NO_X Ozone Season Group 2 Program

- All CSAPR NO_X Ozone Season Group 2 facilities were in compliance in 2021, holding sufficient allowances to cover their NO_X emissions.
- CSAPR NO_X Ozone Season Group 2 sources reported total ozone season NO_X emissions of 121,838 tons in 2021.
- EPA deducted 121,877 allowances for the CSAPR NO_X Ozone Season Group 2 compliance. After reconciliation, over 157,000 CSAPR NO_X Ozone Season Group 2 allowances remain unused and were banked.
- Based on preliminary calculations, in 2021, Missouri units covered by the CSAPR Ozone Season NO_X Group 2 Program reported emissions exceeding the state's assurance level, triggering the assurance provisions. Emissions in Missouri exceeded the state's assurance level by 1,289 tons, resulting in the surrender of 2,578 additional allowances.[2]

CSAPR NO_X Ozone Season Group 3 Program

- All CSAPR NO_X Ozone Season Group 3 facilities were in compliance for 2021, holding sufficient allowances to cover NO_X emissions.
- CSAPR NO_X Ozone Season Group 3 sources reported total ozone season NO_X emissions of 114,293 tons in 2021.
- EPA deducted over 114,337 allowances for the CSAPR NO_X Ozone Season Group 3 compliance. After reconciliation, about 30,000 CSAPR NO_X Ozone Season Group 3 allowances remain unused and were banked.

Background Information

The year 2021 was the seventh year of compliance for the CSAPR SO_2 (Group 1 and Group 2), NO_X Annual and NO_X Ozone Season Group 1 programs, while it was the fifth year of compliance for the

[2] See 87 Fed. Reg. 42459.

CSAPR NO_X Ozone Season Group 2 program and the first year of compliance for the CSAPR NO_X Ozone Season Group 3 program. Each program has its own distinct set of allowances, which cannot be used for compliance with the other programs (e.g., CSAPR SO_2 Group 1 allowances cannot be used to comply with the CSAPR SO_2 Group 2 Program). Each CSAPR trading program contains "assurance provisions" to guarantee that each covered state achieves the required emissions reductions. If a state's covered units exceed the state's assurance level under the specific trading program, then the state must surrender two allowances for each ton of emissions exceeding the assurance level.

The compliance summary emissions number cited in "Highlights" may differ slightly from the sums of emissions used for reconciliation purposes shown in the "Allowance Reconciliation Summary" figures because of variation in rounding conventions and compliance issues at certain units. Therefore, the allowance totals deducted for actual emissions in those figures differ slightly from the number of emissions shown elsewhere in this report.

More Information

- Allowance Markets https://www.epa.gov/airmarkets/allowance-markets
- Air Markets Business Center https://www.epa.gov/airmarkets/business-center
- Clean Air Markets Program Data (CAMPD) https://campd.epa.gov
- Emissions Trading https://www.epa.gov/emissions-trading-resources

Figures

ARP SO_2 Program Allowance Reconciliation Summary, 2021

Total Allowances Held (1995-2021 Vintage)	**72,424,252**	Held by Affected Facility Accounts	**42,606,024**
		Held by Other Accounts (General and Non-Affected Facility Accounts)	**29,818,228**
Allowances Deducted for ARP Compliance*	935,703		
Penalty Allowance Deduction	0		
Banked Allowances	**71,488,549**	Held by Affected Facility Accounts	**41,670,321**
		Held by Other Accounts (General and Non-Affected Facility Accounts)	**29,818,228**

* Includes allowances deducted from opt-in for reduced utilization.

Acid Rain Program Compliance Results

Reported Emissions (tons)	935,750
Rounding and compliance issues (tons)	-47
Emissions not covered by allowances (tons)	0
Total allowances deducted for emissions	935,703

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2022

Figure 1. ARP SO_2 Program Allowance Reconciliation Summary, 2021

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

CSAPR SO_2 Group 1 Program Allowance Reconciliation Summary, 2021

Total Allowances Held (2015-2021 Vintage)	**7,168,328**	Held by Affected Facility Accounts	**5,491,118**
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	**1,677,210**
Allowances Deducted for CSAPR SO_2 Group 1 Program	518,867		
Penalty Allowance Deduction	0		
Banked Allowances	**6,649,461**	Held by Affected Facility Accounts	**4,972,251**
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	**1,677,210**
CSAPR SO_2 Group 1 Program Compliance Results			
Reported Emissions (tons)	518,858		
Rounding and compliance issues (tons)	9		
Emissions not covered by allowances (tons)	0		
Total allowances deducted for emissions	518,867		

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2022

Figure 2. CSAPR SO_2 Group 1 Program Allowance Reconciliation Summary, 2021

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

CSAPR SO_2 Group 2 Program Allowance Reconciliation Summary, 2021

Total Allowances Held (2015-2021 Vintage)	**3,536,164**	Held by Affected Facility Accounts	**2,770,959**
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	**765,205**
Allowances Deducted for CSAPR SO_2 Group 2 Program	73,565		
Penalty Allowance Deduction	0		
Banked Allowances	**3,462,599**	Held by Affected Facility Accounts	**2,697,394**
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	**765,205**
CSAPR SO_2 Group 2 Program Compliance Results			
Reported Emissions (tons)	73,572		
Rounding and compliance issues (tons)	-7		
Emissions not covered by allowances (tons)	0		
Total allowances deducted for emissions	73,565		

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2022

Figure 3. CSAPR NO_X Annual Program Allowance Reconciliation Summary, 2021

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

CSAPR NO_x Annual Program Allowance Reconciliation Summary, 2021

Total Allowances Held (2015-2021 Vintage)	3,889,515	Held by Affected Facility Accounts	3,058,849
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	830,666
Allowances Deducted for CSAPR NO_x Annual Program	440,184		
Penalty Allowance Deduction	0		
Banked Allowances	3,449,331	Held by Affected Facility Accounts	2,618,665
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	830,666

CSAPR NO_x Annual Program Compliance Results	
Reported Emissions (tons)	440,051
Rounding and compliance issues (tons)	133
Emissions not covered by allowances (tons)	0
Total allowances deducted for emissions	440,184

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2022

Figure 4. CSAPR NO_X Annual Program Allowance Reconciliation Summary, 2021

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

CSAPR NO_x Ozone Season Group 1 Program Allowance Reconciliation Summary, 2021

Total Allowances Held (2015-2021 Vintage)	**112,024**	Held by Affected Facility Accounts	**49,727**
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	**62,297**
Allowances Deducted for CSAPR NO_x Ozone Season Group 1 Program	6,154		
Penalty Allowance Deduction	0		
Banked Allowances	**105,870**	Held by Affected Facility Accounts	**43,573**
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	**62,297**
CSAPR NO_x Ozone Season Group 1 Program Compliance Results			
Reported Emissions (tons)	6,150		
Rounding and compliance issues (tons)	4		
Emissions not covered by allowances (tons)	0		
Total allowances deducted for emissions	6,154		

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2022

Figure 5. CSAPR NO_X Ozone Season Program Group 1 Allowance Reconciliation Summary, 2021

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

CSAPR NO_x Ozone Season Group 2 Program Allowance Reconciliation Summary, 2021

Total Allowances Held (2017-2021 Vintage)	**279,237**	Held by Affected Facility Accounts	**217,834**
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	**61,403**
Allowances Deducted for CSAPR NO_x Ozone Season Group 2 Program	121,877		
Penalty Allowance Deduction	0		
Banked Allowances	**157,360**	Held by Affected Facility Accounts	**95,957**
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	**61,403**

CSAPR NO_x Ozone Season Group 2 Program Compliance Results

Reported Emissions (tons)	121,838
Rounding and compliance issues (tons)	39
Emissions not covered by allowances (tons)	0
Total allowances deducted for emissions	121,877

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2022

Figure 6. CSAPR NO_X Ozone Season Program Group 2 Allowance Reconciliation Summary, 2021

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

CSAPR NO_x Ozone Season Group 3 Program Allowance Reconciliation Summary, 2021

Total Allowances Held (2021 Vintage)	**143,837**	Held by Affected Facility Accounts	**140,108**
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	**3,729**
Allowances Deducted for CSAPR NO_x Ozone Season Group 3 Program	114,337		
Penalty Allowance Deduction	0		
Banked Allowances	**29,500**	Held by Affected Facility Accounts	**25,771**
		Held by Other Accounts (General, State Holding, and Non-Affected Facility Accounts)	**3,729**

CSAPR NO_x Ozone Season Group 3 Program Compliance Results	
Reported Emissions (tons)	114,293
Rounding and compliance issues (tons)	44
Emissions not covered by allowances (tons)	0
Total allowances deducted for emissions	114,337

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2022

Figure 7. CSAPR NO_X Ozone Season Program Group 3 Allowance Reconciliation Summary, 2021

Notes:
• Compliance emissions data may vary from other report sections as a result of variation in rounding conventions or allowance compliance issues at certain units.
• Reconciliation and compliance data are current as of May 2022 and subsequent allowance deduction adjustments and penalties are not reflected.

Chapter 6: Market Activity

Emissions trading programs allow participants to independently determine their best compliance strategy. Participants that reduce their emissions below the number of allowances they hold may trade allowances, sell them, or bank them for use in future years. While the Acid Rain Program (ARP) and the Cross-State Air Pollution Rule (CSAPR)[1] are emissions trading programs, Mercury and Air Toxics Standard (MATS) is not a market-based program; therefore, this section does not discuss MATS.

Highlights

Transaction Types and Volumes

- In 2021, more than 550,000 allowances were traded across all six of the CSAPR trading programs.
- Thirty-six percent of the transactions within the CSAPR programs were between distinct organizations.
- In 2021, over 3 million ARP allowances were traded.
- Twenty-six percent of the transactions within the ARP were between distinct organizations.

2021 Allowance Prices[2]

- The ARP SO_2 allowance prices averaged less than $1 per ton in 2021.
- The CSAPR SO_2 Group 1 allowance prices started and ended 2021 at $1.56 per ton.
- The CSAPR SO_2 Group 2 allowance prices started and ended 2021 at $2.31 per ton.
- The CSAPR NO_X annual program allowances started 2021 at $2.00 per ton and ended 2021 at $2.50 per ton.
- The CSAPR NO_X ozone season Group 1 program allowances started 2021 at $2.00 per ton and ended 2021 at $2.50 per ton.
- The CSAPR NO_X ozone season Group 2 program allowances started 2021 at $200 per ton and ended 2021 at $166 per ton.[3]

[1] CSAPR refers to the CSAPR, the CSAPR Update, and the Revised CSAPR Update programs.

[2] Allowance prices as reported by S&P Global Market Intelligence, 2022.

[3] The CSAPR NO_X Ozone Season Group 2 program was established by the CSAPR Update in October 2016. The program originally covered 22 states, and currently covers 10 states, including Alabama, Arkansas, Iowa, Kansas, Mississippi, Missouri, Oklahoma, Tennessee, Texas, and Wisconsin.

- The CSAPR NO_X ozone season Group 3 program allowances started in March 2021 at $3,000 per ton and ended 2021 at $3,175 per ton.[1]

Background Information

Transaction Types

Allowance transfers are the movement of allowances between allowance holding accounts. There are generally two types of transfers, those initiated by the EPA and private transactions. EPA transfers to accounts include the initial allocation of allowances by states or EPA, as well as transfers into accounts related to set-asides. Private transactions include all transfers initiated by authorized account representatives for any compliance or general account purposes. The market activity analysis is based on private transactions.

To better understand the trends in market performance and transfer history, EPA classifies private transfers of allowance transactions into two categories:

- Transfers between separate and unrelated parties (distinct organizations), which may include companies with contractual relationships (such as power purchase agreements) but excludes parent-subsidiary types of relationships.
- Transfers within a company or between related entities (e.g., holding company transfers between a facility compliance account and any account held by a company with an ownership interest in the facility).

While all transactions are important to proper market operation, EPA follows trends in transactions between distinct economic entities with particular interest. These transactions represent an actual exchange of assets between unaffiliated participants, which reflect companies making the most of the cost-minimizing flexibility of emission trading programs. Companies accomplish this by finding the cheapest emission reductions not only among their own generating assets, but across the entire marketplace of power generators.

Allowance Markets

The 2021 emissions were below emission budgets for the ARP and for all six CSAPR programs. As a result, the allowance prices for most of the CSAPR programs were well below the marginal cost for reductions projected at the time of the final rule, and are subject, in part, to downward pressure from the available banks of allowances.

[1] The CSAPR NO_X Ozone Season Group 3 program was established under the Revised CSAPR Update in April 2021 and covers 12 states, including Illinois, Indiana, Kentucky, Louisiana, Maryland, Michigan, New Jersey, New York, Ohio, Pennsylvania, Virginia, and West Virginia.

More Information

- Allowance Markets https://www.epa.gov/airmarkets/allowance-markets
- Air Markets Business Center https://www.epa.gov/airmarkets/business-center
- Clean Air Markets Program Data (CAMPD) https://campd.epa.gov
- Emissions Trading https://www.epa.gov/emissions-trading-resources

Figures

2021 Allowance Transfers under CSAPR and ARP

	Transactions Conducted	Allowances Transferred	Share of Program's Allowances Transferred	
			Related (%)	Distinct (%)
ARP SO_2	517	3,113,196	40%	60%
CSAPR SO_2 Group 1	169	201,086	68%	32%
CSAPR SO_2 Group 2	45	84,085	90%	10%
CSAPR NO_x Annual	341	96,831	78%	22%
CSAPR NO_x Ozone Season Group 1	28	4,248	99%	1%
CSAPR NO_x Ozone Season Group 2	914	165,068	57%	43%
CSAPR NO_x Ozone Season Group 3	109	9,923	49%	51%

Notes:
• The breakout between distinct and related organizations is not an exact value as relationships are often difficult to categorize in a simple bifurcated manner. EPA's analysis is conservative and the "Distinct Organizations" percentage is likely higher.
• Percentages may not add up to 100% due to rounding.

Source: EPA, 2022
Last updated: 05/2022

Figure 1. 2021 Allowance Transfers under CSAPR and ARP

Notes:
• The breakout between distinct and related organizations is not an exact value as relationships are often difficult to categorize in a simple bifurcated manner. EPA's analysis is conservative and the "Distinct Organizations" percentage is likely higher.
• Percentages may not add up to 100% due to rounding.

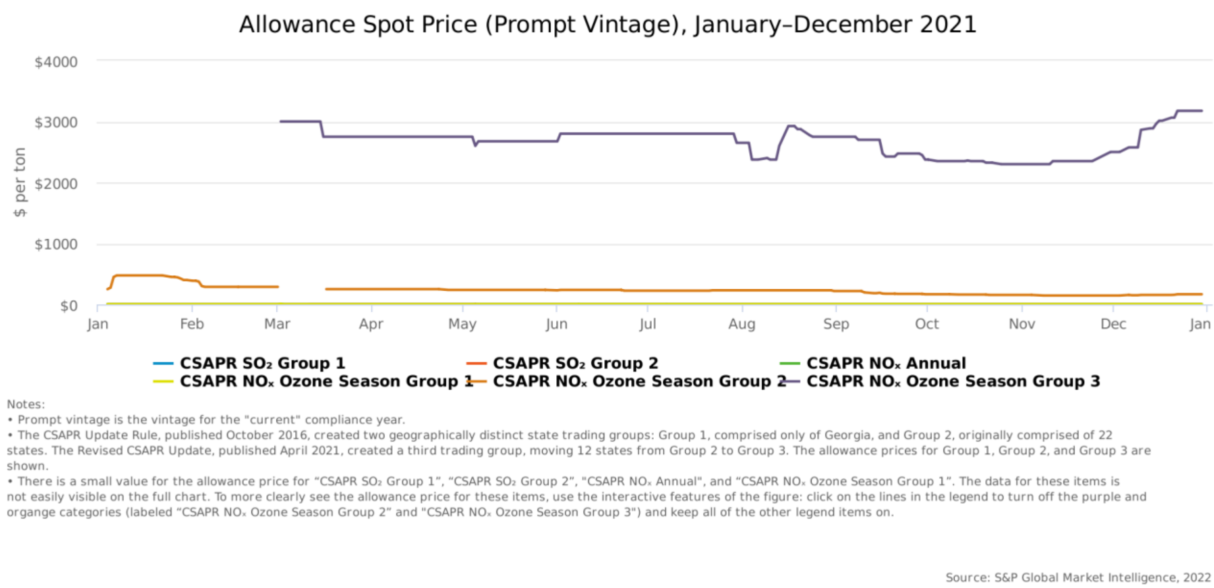

Figure 2. Allowance Spot Price (Prompt Vintage), January–December 2021

Notes:

• Prompt vintage is the vintage for the "current" compliance year.

• The CSAPR Update Rule, published October 2016, created two geographically distinct state trading groups: Group 1, comprised only of Georgia, and Group 2, originally comprised of 22 states. The Revised CSAPR Update, published April 2021, created a third trading group, moving 12 states from Group 2 to Group 3. The allowance prices for Group 1, Group 2, and Group 3 are shown.

• There is a small value for the allowance price for “CSAPR SO_2 Group 1”, “CSAPR SO_2 Group 2”, “CSAPR NO_x Annual”, and “CSAPR NO_x Ozone Season Group 1”. The data for these items is not easily visible on the full chart. To more clearly see the allowance price for these items, use the interactive features of the figure: click on the lines in the legend to turn off the purple and orange categories (labeled “CSAPR NO_x Ozone Season Group 2” and “CSAPR NO_x Ozone Season Group 3”) and keep all of the other legend items on.

Chapter 7: Air Quality

The Acid Rain Program (ARP), NO_X Budget Trading Program (NBP), Clean Air Interstate Rule (CAIR), Cross-State Air Pollution Rule (CSAPR), and CSAPR Update were designed to reduce sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emissions from power plants. These pollutants contribute to the formation of ground-level ozone and particulate matter, which cause a range of serious health effects and degrade visibility in many American cities and scenic areas, including National Parks. The dramatic emission reductions achieved under these programs have improved air quality and delivered significant human health and ecological benefits across the United States.

To evaluate the impact of emission reductions on air quality, scientists and policymakers use data collected from long-term national air quality monitoring networks. These networks provide information on a variety of indicators useful for tracking and understanding temporal trends in regional air quality.

Sulfur Dioxide and Nitrogen Oxides Trends

Highlights

National SO_2 Air Quality

- Based on EPA's air trends data, the national average of SO_2 annual mean ambient concentrations decreased from 12.0 parts per billion (ppb) to 0.7 ppb (94 percent) between 1980 and 2021.
- Since the first year of the ARP, three years have seen reductions of greater than 20 percent: 1994–1995 (22 percent); 2008–2009 (21 percent); and 2014–2015 (23 percent).

Regional Changes in Air Quality

- Regional average ambient SO_2 concentrations declined in the eastern U.S. by 95 percent from the 1989–1991 observation period to the 2019–2021 observation period.
- Average ambient particulate sulfate concentrations have decreased by 49 to 84 percent in observed regions from 1989–1991 to 2019-2021.
- Average annual ambient total nitrate concentrations declined 59 percent from 1989–1991 to 2019–2021 in the eastern U.S., with the most significant decreases occurring after 2002, coinciding with the implementation of the NO_X Budget Trading Program, followed by CAIR, CSAPR, and CSAPR Update.

Background Information

Sulfur Dioxide

Sulfur oxides are a group of highly reactive gases that can travel long distances in the upper atmosphere and predominantly exist as sulfur dioxide (SO_2). The primary source of SO_2 emissions is fossil fuel combustion at power plants. Smaller sources of SO_2 emissions include industrial processes, such as extracting metal from ore, as well as the burning of high sulfur-containing fuels by locomotives, large ships, and non-road equipment. SO_2 emissions contribute to the formation of fine particle pollution ($PM_{2.5}$) and are linked with adverse effects on the respiratory system.[1] In addition, particulate sulfate degrades visibility and, because sulfur compounds are typically acidic, can harm ecosystems when deposited.

Nitrogen Oxides

Nitrogen oxides are a group of highly reactive gases including nitric oxide (NO) and nitrogen dioxide (NO_2). In addition to contributing to the formation of ground-level ozone and $PM_{2.5}$, NO_X emissions are linked with adverse effects on the respiratory system.[2, 3] NO_X also reacts in the atmosphere to form nitric acid (HNO_3) and particulate ammonium nitrate (NH_4NO_3). HNO_3 and nitrate (NO_3), reported as total nitrate, can also lead to adverse health effects and, when deposited, cause damage to sensitive ecosystems.

Although the ARP and CSAPR programs have significantly reduced NO_X emissions (primarily from power plants) and improved air quality, emissions from other sources (such as motor vehicles and agriculture) contribute to total nitrate concentrations in many areas. Ambient nitrate levels can also be affected by emissions transported via air currents over wide regions.

More Information

- Clean Air Status and Trends Network (CASTNET) https://www.epa.gov/castnet
- Air Quality System (AQS) https://www.epa.gov/aqs
- National Ambient Air Quality Standards (NAAQS) https://www.epa.gov/criteria-air-pollutants
- Sulfur Dioxide (SO_2) Pollution https://www.epa.gov/so2-pollution
- Nitrogen Oxides (NO_X) Pollution https://www.epa.gov/no2-pollution
- EPA's Power Sector Programs https://www.epa.gov/power-sector/power-sector-programs
- EPA's 2021 National Air Quality Trends Report https://www.epa.gov/air-trends

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Figures

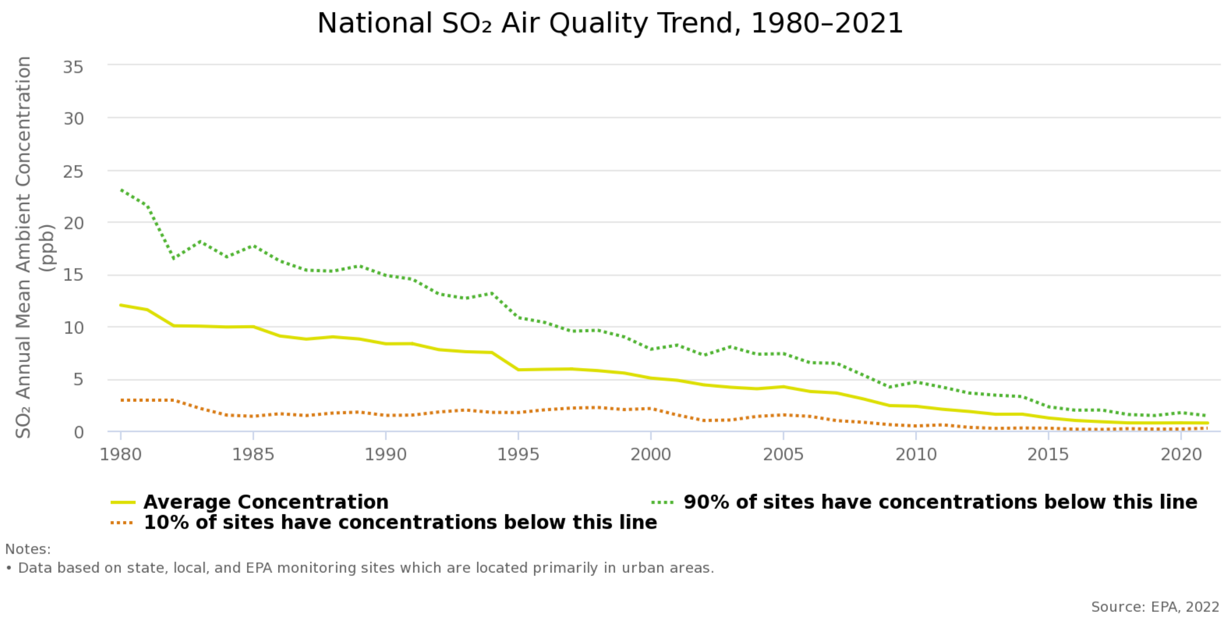

Figure 1. National SO_2 Air Quality Trend, 1980–2021

Notes:

Data based on state, local, and EPA monitoring sites which are located primarily in urban areas.

Regional Changes in Air Quality

Measurement	Region	Annual Average, 2000–2002	Annual Average, 2019–2021	Percent Change	Number of Sites
Ambient Particulate Sulfate Concentration (µg/m³)	Mid-Atlantic	4.8	1	**-79**	13
	Midwest	4.3	1.1	**-74**	16
	North Central	1.3	0.6	-54	2
	Northeast	2.6	0.6	**-77**	6
	Pacific	0.8	0.5	**-37**	5
	Rocky Mountain	0.7	0.4	**-45**	10
	South Central	2.9	1.2	-59	2
	Southeast	4.2	1	**-76**	12
Ambient Sulfur Dioxide Concentration (µg/m³)	Mid-Atlantic	8	1	**-88**	13
	Midwest	6.8	0.6	**-91**	16
	North Central	1	0.4	-60	2
	Northeast	3.4	0.3	**-91**	6
	Pacific	0.4	0.2	**-35**	5
	Rocky Mountain	0.5	0.2	**-60**	10
	South Central	1.1	0.4	-64	2
	Southeast	3.4	0.3	**-91**	12
Ambient Total Nitrate Concentration (µg/m³)	Mid-Atlantic	3	1.2	**-60**	13
	Midwest	4.1	1.8	**-56**	16
	North Central	1.2	0.8	-33	2
	Northeast	1.9	0.8	**-58**	6
	Pacific	1.8	0.9	-50	5
	Rocky Mountain	0.8	0.5	**-38**	10
	South Central	1.5	0.9	-40	2
	Southeast	2.3	0.9	**-61**	12

Notes:

- Averages are the arithmetic mean of all sites in a region that were present and met the completeness criteria in both averaging periods. Thus, average concentrations for 2000 to 2002 may differ from past reports.
- Data are from CASTNET monitoring sites which are typically located away from stationary emissions sources. Percent change is calculated from the base period of 2000–2002 to coincide with the deposition changes in Chapter 8.
- Bolded numbers indicate a statistically significant percent change. Statistical significance was determined at the 95 percent confidence level ($p < 0.05$) using a Student's t-test. Because changes that are not statistically significant may be unduly influenced by measurements having large variability or insufficient data completeness, regional results must include at least five sites to evaluate statistical significance.

Source: EPA, 2022

Figure 2. Regional Changes in Air Quality

Notes:

Averages are the arithmetic mean of all sites in a region that were present and met the completeness criteria in both averaging periods. Thus, average concentrations for 2000 to 2002 may differ from past reports.

Data are from CASTNET monitoring sites which are typically located away from stationary emissions sources. Percent change is calculated from the base period of 2000–2002 to coincide with the deposition changes in Chapter 9.

Bolded numbers indicate a statistically significant percent change. Statistical significance was determined at the 95 percent confidence level ($p < 0.05$) using a Student's t-test. Because changes that are not statistically significant may be unduly influenced by measurements having large variability or insufficient data completeness, regional results must include at least five sites to evaluate statistical significance.

Ozone

Highlights

Ozone Season Changes in 1-Hour Ozone

- There was an overall regional reduction in ozone levels between 2000–2002 and 2019–2021, with a 25 percent reduction in the highest (99th percentile) ozone concentrations in CSAPR and CSAPR Update states.
- Results demonstrate how NO_X emission reduction policies have benefitted 1-hour ozone concentrations in the eastern U.S. – historically, the region that the ozone policies were designed to target.

Annual Trends in Rural 8-Hour Ozone

- From 2019 to 2021, rural ozone concentrations averaged 61 ppb in CSAPR states, a decrease of 28 ppb (31 percent) from the 1990 to 2002 average period.
- The Autoregressive Integrated Moving Average (ARIMA) model shows how the reductions in rural ozone concentrations correlate with the implementation of the NBP in 2003 and the CAIR NO_X Ozone Season program in 2009. There was a 10 ppb reduction in O_3 from 2002 to 2004 and a 6 ppb reduction in O_3 from 2007 to 2009.
- Eight of the nine lowest observed annual ozone concentrations were between 2013 and 2021. Ozone season NO_X emissions fell steadily under CAIR and continued to drop after implementation of CSAPR in 2015 and CSAPR Update in 2017. In addition, implementation of the mercury and air toxics standards (MATS), which began in 2015, achieves co-benefit reductions of NO_X emissions.

Ozone Season Changes in 8-Hour Ozone Concentrations

- The average reduction in seasonal mean ozone concentrations in the CSAPR Update region from 2000–2002 to 2019–2021 was about 10 ppb (19 percent), while the average reduction in the 98th percentile concentrations was about 23 ppb (26 percent) before adjusting for weather-related effects.
- The average reduction in the meteorologically-adjusted seasonal mean ozone concentrations in the CSAPR Update region from 2000–2002 to 2019–2021 was about 11 ppb (21 percent), while the average reduction in the 98th percentile concentrations was about 21 ppb (24 percent) after adjusting for weather-related effects.[3]

Changes in Ozone Nonattainment Areas

- Ninety-two of the 113 areas originally designated as nonattainment for the 1997 8-hour ozone National Ambient Air Quality Standard (NAAQS) (0.08 ppm) are in the eastern U.S. and are home to about 131 million people.[1] These nonattainment areas were designated in 2004 using air quality data from 2001 to 2003.[2]

    - Based on data from 2019 to 2021, 89 of the eastern ozone nonattainment areas now show concentrations below the level of the 1997 standard, while the remaining three areas had incomplete data.
- Twenty-two of the 46 areas originally designated as nonattainment for the 2008 8-hour ozone NAAQS (0.075 ppm) are in the eastern U.S. and are home to about 80 million people.[1] These nonattainment areas were designated in 2012 using air quality data from 2008 to 2010 or 2009 to 2011.[2]
    - Based on data from 2019 to 2021, 86 percent (19 areas) of the eastern ozone nonattainment areas now show concentrations below the level of the 2008 standard, while the remaining three areas have shown progress toward meeting the standard. It is reasonable to conclude that ozone season NO_X emission reductions from the NBP, CAIR, CSAPR, and CSAPR Update have significantly contributed to these improvements in ozone air quality.
- Twenty-two of the 52 areas originally designated as nonattainment for the 2015 8-hour ozone NAAQS (0.070 ppm) are in the eastern U.S. and are home to about 85 million people.[1] These nonattainment areas were designated in 2018 using air quality data from 2014 to 2016 or 2015 to 2017.[2]
    - Based on data from 2019 to 2021, nine of the 22 eastern ozone nonattainment areas now show concentrations below the level of the 2015 standard, and an additional 10 areas have made progress toward meeting the standard.

Background Information

Ozone pollution – also known as smog – forms when NO_X and volatile organic compounds (VOCs) react in the presence of sunlight. Major anthropogenic sources of NO_X and VOC emissions include electric power plants, motor vehicles, solvents, and industrial facilities. Meteorology plays a significant role in ozone formation and hot, sunny days are most favorable for ozone production. For ozone, EPA and states typically regulate NO_X emissions during the summer when sunlight intensity and temperatures are highest.

Ozone Standards

In 1979, EPA established NAAQS for 1-hour ozone at 0.12 parts per million (ppm), or 124 parts per billion (ppb). In 1997, a more stringent 8-hour ozone standard of 0.08 ppm (84 ppb) was finalized, revising the 1979 standard. CSAPR was designed to help downwind states in the eastern U.S. achieve the 1997 ozone NAAQS. Based on extensive scientific evidence about ozone's effects on public health and welfare, EPA strengthened the 8-hour ozone standard to 0.075 ppm (75 ppb) in 2008. Finalized in 2016, the CSAPR Update was designed to help downwind states meet and maintain the 2008 ozone NAAQS. EPA further strengthened the 8-hour NAAQS for ground-level ozone to 0.070 ppm (70 ppb) in 2015. EPA revoked the 1-hour ozone standard in 2005 and more recently revoked the 1997 8-hour ozone standard in 2015.

Regional Trends in Ozone

EPA investigated trends in daily maximum 8-hour ozone concentrations measured at rural Clean Air Status and Trends Network (CASTNET) monitoring sites within the states requiring ozone season reductions under CSAPR and CSAPR Update, as well as in adjacent states. Rural ozone measurements are useful in assessing the impacts on air quality resulting from regional NO_X emission reductions because they are typically less affected by local sources of NO_X emissions (e.g., industrial and mobile) than urban measurements. Reductions in rural ozone concentrations are largely attributed to reductions in regional NO_X emissions and transported ozone.

The Autoregressive Integrated Moving Average (ARIMA) model is an advanced statistical analysis tool used to visualize the trend in regional ozone concentrations following implementation of various programs geared toward reducing ozone season NO_X emissions. To show the shift in the highest daily ozone levels, EPA modeled the average of the 99th percentile of the daily maximum 8-hour ozone concentrations measured at CASTNET sites (as described above).

Meteorologically–Adjusted Daily Maximum 8-Hour Ozone Concentrations

Variations in weather conditions play an important role in determining ozone concentrations. Ozone is more readily formed on warm, sunny days when the air is stagnant. Conversely, ozone production is more limited when it is cloudy, cool, rainy, or windy. EPA uses statistical models to adjust for the variability in seasonal ozone concentrations due to weather to provide a more accurate assessment of the underlying trend in ozone caused by emissions.

Meteorologically–adjusted ozone trends provide additional insight on the influence of CSAPR NO_X Ozone Season program and CSAPR Update emission reductions on regional air quality. EPA retrieved daily maximum 8-hour ozone concentration data from the Air Quality System (AQS) and daily meteorology data from the National Weather Service for 386 ozone monitoring sites located in the CSAPR Update region. EPA uses these data in statistical models to account for the influence of weather on seasonal average and 98th percentile ozone concentrations at each monitoring site.[3]

Changes in Ozone Nonattainment Areas

The majority of ozone season NO_X emission reductions in the power sector after 2003 are attributable to the NBP, CAIR, CSAPR, and CSAPR Update. As power sector emissions are an important component of the NO_X emission inventory, it is reasonable to conclude that the reduction in ozone season NO_X emissions from these programs have significantly contributed to improvements in ozone concentrations and attainment of the 1997 ozone health-based air quality standard.

Emission reductions under these power sector programs have helped many areas in the eastern U.S. reach attainment for the 2008 ozone NAAQS. However, several areas continue to be out of attainment with the 2008 ozone NAAQS, and additional ozone season NO_X emission reductions are needed to attain that standard as well as the strengthened ozone standard that was finalized in 2015.

In order to help downwind states and communities meet and maintain the 2008 ozone standard, EPA finalized the CSAPR Update in September 2016 to address the transport of ozone pollution that crosses state lines in the eastern U.S. Implementation began in May 2017 to further reduce ozone season NO_X emissions from power plants in 22 states in the eastern U.S. Starting June 2021, further emission reductions were required under the Revised CSAPR Update at power plants in 12 of the 21 CSAPR Update states.

More Information

- Clean Air Status and Trends Network (CASTNET) https://www.epa.gov/castnet
- Air Quality System (AQS) https://www.epa.gov/aqs
- National Ambient Air Quality Standards (NAAQS) https://www.epa.gov/criteria-air-pollutants
- Ozone Pollution https://www.epa.gov/ozone-pollution
- Nitrogen Oxides (NO_X) Pollution https://www.epa.gov/no2-pollution
- Nonattainment Areas https://www.epa.gov/green-book
- EPA's Power Sector Programs https://www.epa.gov/power-sector/power-sector-programs
- EPA's 2021 National Air Quality Trends Report https://www.epa.gov/air-trends

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3. Wells, B. et al. (2021). Improved Estimation of Trends in U.S. Ozone Concentrations Adjusted for Interannual Variability in Meteorological Conditions. *Atmospheric Environment*, 248 (2021): 118234.

Figures

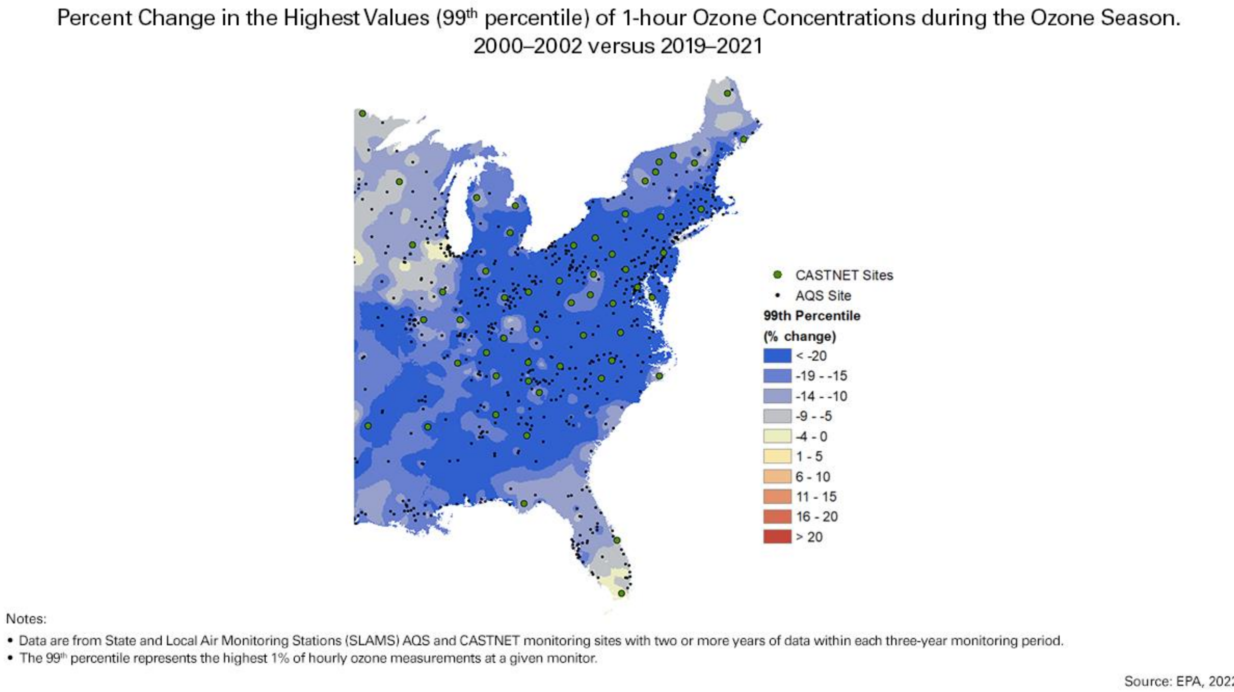


Figure 1. Percent Change in the Highest Values (99th percentile) of 1-hour Ozone Concentrations during the Ozone Season, 2000–2002 versus 2019–2021

Notes:

Data are from State and Local Air Monitoring Stations (SLAMS) AQS and CASTNET monitoring sites with two or more years of data within each three-year monitoring period.

The 99th percentile represents the highest 1% of hourly ozone measurements at a given monitor.

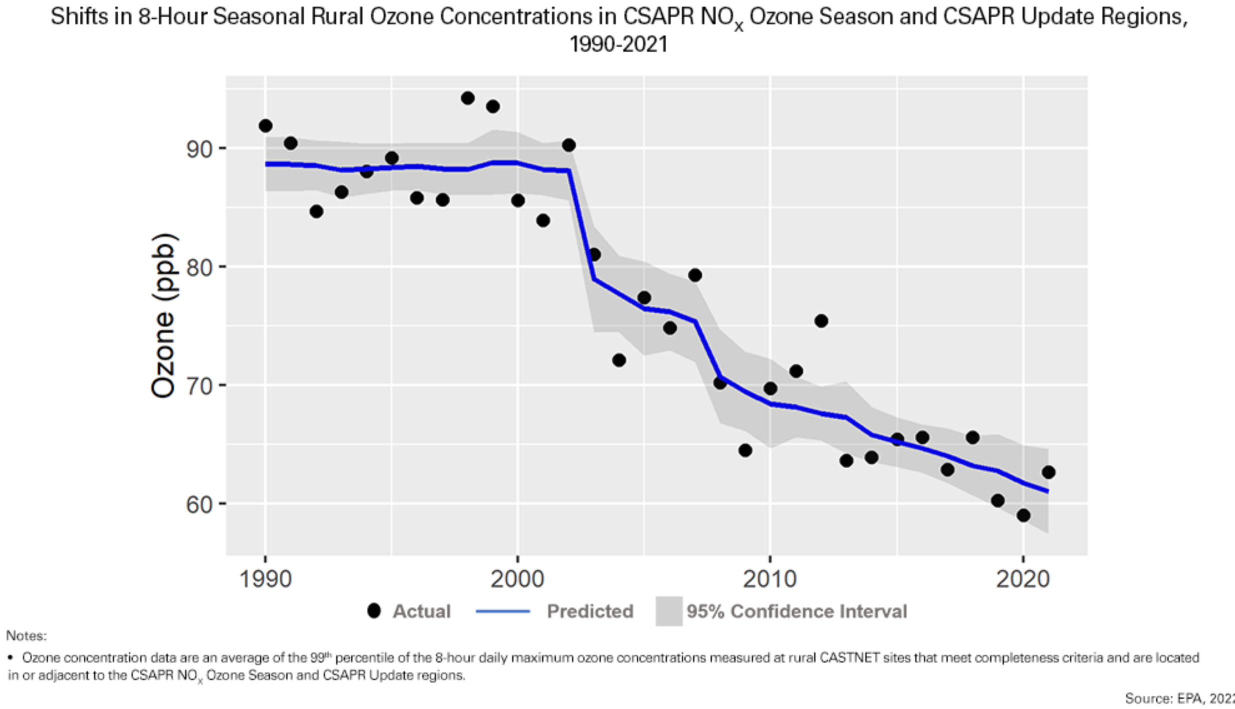


Figure 2. Shifts in 8-Hour Seasonal Rural Ozone Concentrations in CSAPR NO_X Ozone Season and CSAPR Update Regions, 1990–2021

Notes:

Ozone concentration data are an average of the 99th percentile of the 8-hour daily maximum ozone concentrations measured at rural CASTNET sites that meet completeness criteria and are located in or adjacent to the CSAPR NO_x ozone season program region.

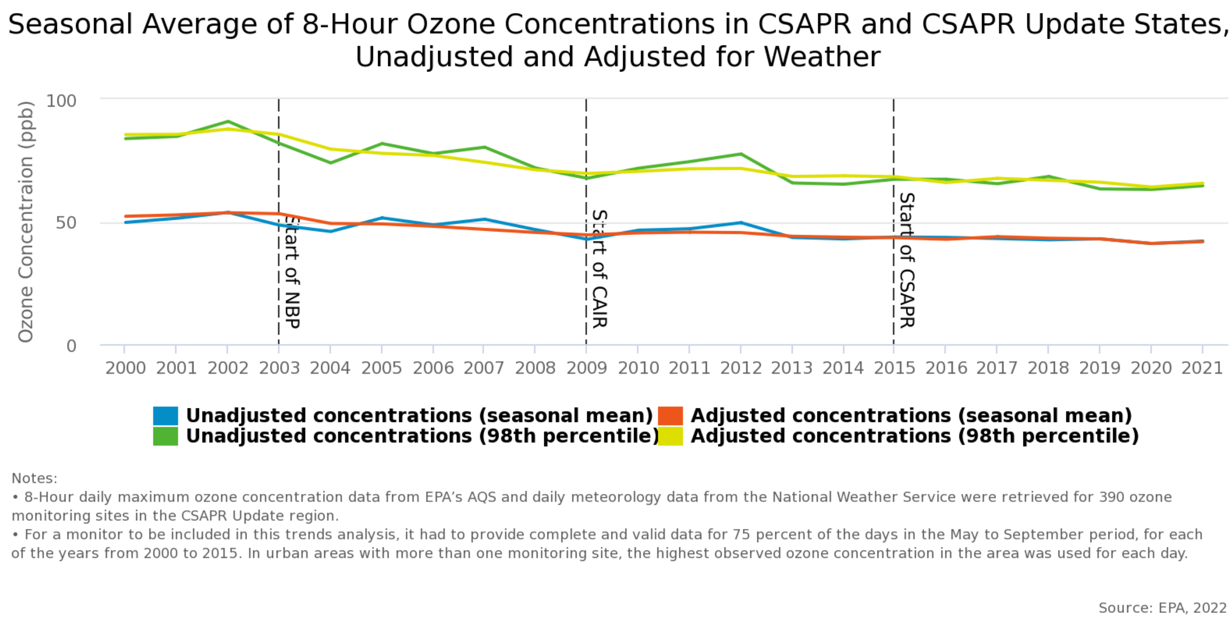


Figure 3. Seasonal Average of 8-Hour Ozone Concentrations in CSAPR and CSAPR Update States, Unadjusted and Adjusted for Weather

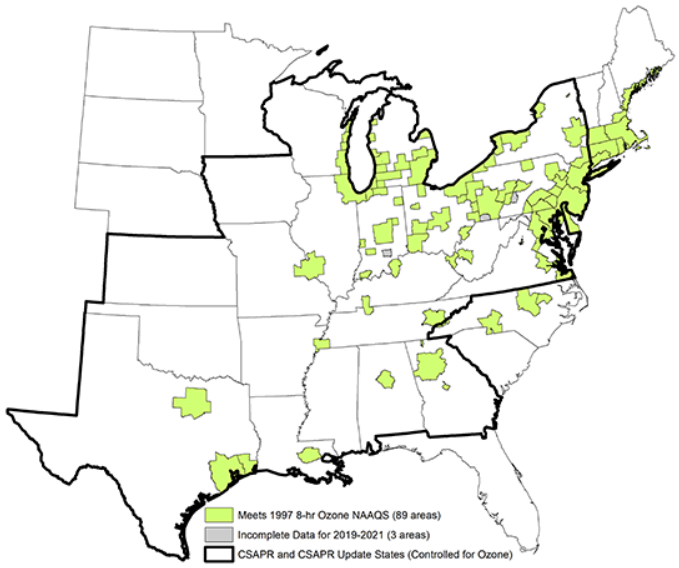
Notes:

8-Hour daily maximum ozone concentration data from EPA's AQS and daily meteorology data from the National Weather Service were retrieved for 78 urban areas and 37 rural CASTNET monitoring sites located in the CSAPR NO_X ozone season program region.

For a monitor to be included in this trends analysis, it had to provide complete and valid data for 75 percent of the days in the May to September period, for each of the years from 2000 to 2020. In urban areas with more than one monitoring site, the highest observed ozone concentration in the area was used for each day.

Seasonal mean ozone values indicate the average ozone concentrations across the U.S. The 98th percentile ozone values show the highest ozone concentrations across the U.S. NO_X reductions are generally effective in reducing these peak ozone levels in all regions of the U.S.

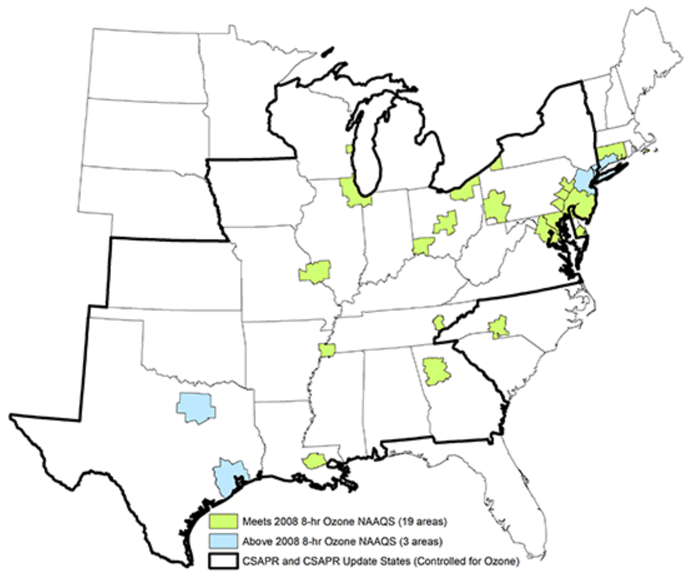
Changes in 1997 Ozone NAAQS Nonattainment Areas in CSAPR Region, 2001–2003 (Original Designations) versus 2019–2021



Source: EPA, 2022

Figure 4. Changes in 1997 Ozone NAAQS Nonattainment Areas in CSAPR Region, 2001–2003 (Original Designations) versus 2019–2021

Changes in 2008 Ozone NAAQS Nonattainment Areas, 2008–2010 (Original Designations) versus 2018–2021



Source: EPA, 2022

Figure 5. Changes in 2008 Ozone NAAQS Nonattainment Areas, 2008–2010 (Original Designations) versus 2019

Particulate Matter

Highlights

Particulate Matter Seasonal Trends

- The Air Quality System (AQS) includes average $PM_{2.5}$ concentration data for 127 sites located in the CSAPR SO_2 and annual NO_X program region. Trend lines in $PM_{2.5}$ concentrations show decreasing trends in both the warm months (April to September) and cool months (October to March) unadjusted for the influence of weather.
- The seasonal average $PM_{2.5}$ concentrations have decreased by about 39 and 46 percent in the warm and cool season months, respectively, between 2000 and 2021.

Changes in $PM_{2.5}$ Nonattainment

- Thirty six of the 39 designated nonattainment areas for the 1997 annual average $PM_{2.5}$ NAAQS are in the eastern U.S. and are home to about 79 million people.[1,2] The nonattainment areas were designated in January 2005 using 2001 to 2003 data.
- Based on data gathered from 2019 to 2021, 35 of these eastern areas originally designated nonattainment have concentrations below the level of the 1997 $PM_{2.5}$ standard (15.0 $\mu g/m^3$), indicating improvements in $PM_{2.5}$ air quality. One area has incomplete data.
- Given that power sector emissions are an important component of the SO_2 and annual NO_X emission inventory and that the majority of power sector SO_2 and annual NO_X emission reductions occurring after 2003 are attributable in part to the ARP, NBP, CAIR, and CSAPR, it is reasonable to conclude that these emission reduction programs have significantly contributed to these improvements in $PM_{2.5}$ air quality.

Background Information

Particulate matter—also known as soot, particle pollution, or PM—is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of several components, including acid-forming nitrate and sulfate compounds, organic compounds, metals, and soil or dust particles. Fine particles (defined as particulate matter with aerodynamic diameter < 2.5 µm, and abbreviated as $PM_{2.5}$) can be directly emitted or can form when gases emitted from power plants, industrial sources, automobiles, and other sources react in the air.

Particle pollution—especially fine particles—contains microscopic solids or liquid droplets so small that they can get deep into the lungs and cause serious health problems. Numerous scientific studies have linked particle pollution exposure to a variety of problems, including the following: premature death; increased respiratory symptoms such as irritation of the airways, coughing, or difficulty breathing; decreased lung function; aggravated asthma; development of chronic bronchitis; irregular heartbeat; and nonfatal heart attacks.[3,4,5]

PM Standards

The CAA requires EPA to set NAAQS for particle pollution. In 1997, EPA set the first standards for fine particles at 65 micrograms per cubic meter ($\mu g/m^3$) measured as the three-year average of the 98th percentile for 24-hour exposure, and at 15.0 $\mu g/m^3$ for annual exposure measured as the three-year annual mean. EPA revised the air quality standards for particle pollution in 2006, tightening the 24-hour fine particle standard to 35 $\mu g/m^3$ and retaining the annual fine particle standard at 15.0 $\mu g/m^3$. In December 2012, EPA strengthened the annual fine particle standard to 12.0 $\mu g/m^3$.

CSAPR was promulgated to help downwind states in the eastern U.S. achieve the 1997 annual average $PM_{2.5}$ NAAQS and the 2006 24-hour $PM_{2.5}$ NAAQS; therefore, analyses in this report focus on those standards.

Changes in $PM_{2.5}$ Nonattainment Areas

In the eastern U.S., recent data indicate that no areas are violating the 1997, 2006, or 2012 $PM_{2.5}$ NAAQS. The majority of SO_2 and annual NO_X emission reductions in the power sector that occurred after 2003 are attributable to the ARP, NBP, CAIR, and CSAPR. As power sector emissions are an important component of the SO_2 and annual NO_X emission inventory, it is reasonable to conclude that these emission reduction programs have significantly contributed to these improvements in $PM_{2.5}$ air quality.

More Information

- Air Quality System (AQS) https://www.epa.gov/aqs
- National Ambient Air Quality Standards https://www.epa.gov/criteria-air-pollutants
- Particulate Matter (PM) Pollution https://www.epa.gov/pm-pollution
- Sulfur Dioxide (SO_2) Pollution https://www.epa.gov/so2-pollution
- Nitrogen Oxides (NO_X) Pollution https://www.epa.gov/no2-pollution
- Nonattainment Areas https://www.epa.gov/green-book
- EPA's Power Sector Programs https://www.epa.gov/power-sector/power-sector-programs
- EPA's 2021 National Air Quality Trends Report https://www.epa.gov/air-trends

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Figures

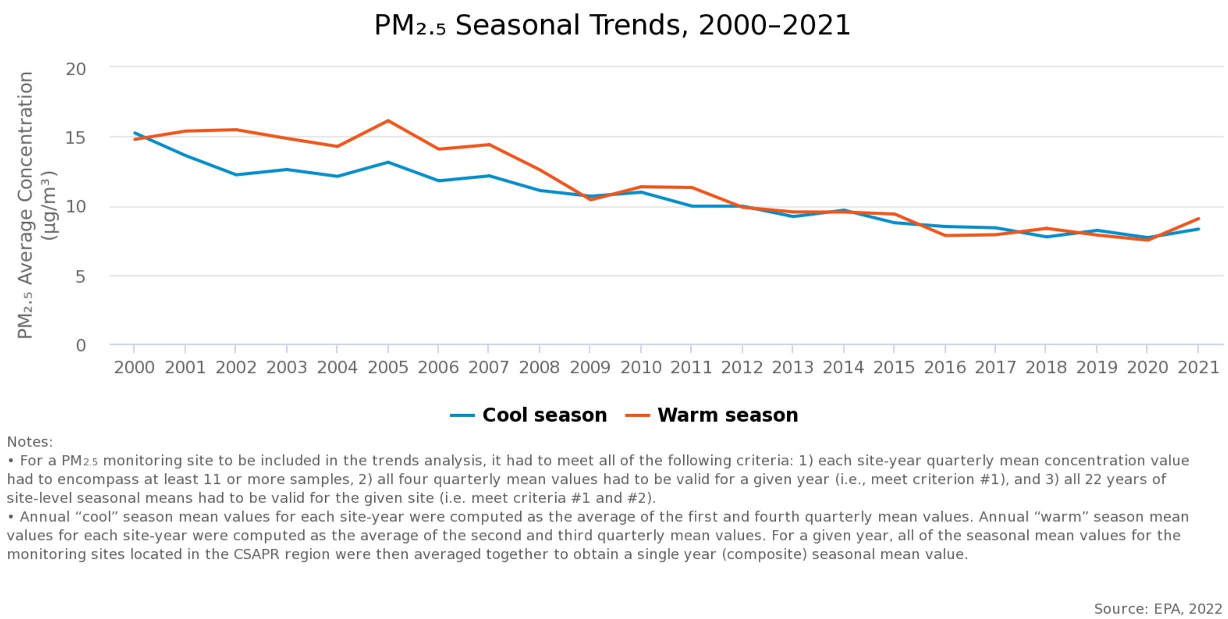


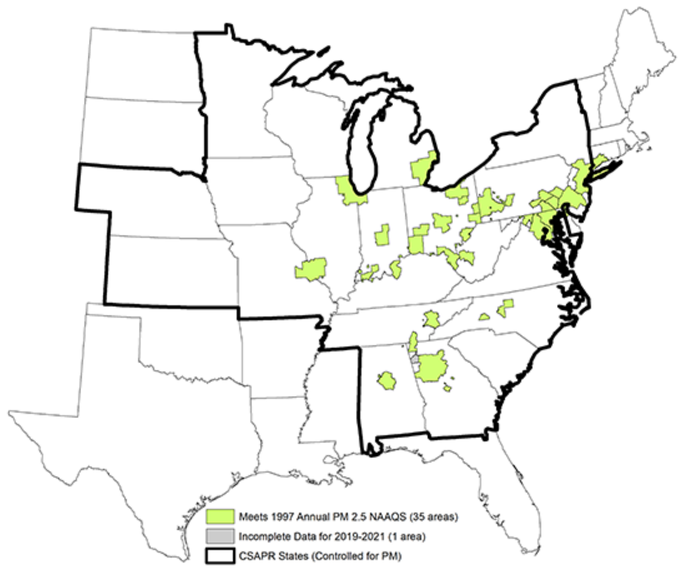
Figure 1. $PM_{2.5}$ Seasonal Trends, 2000–2021

Notes:

For a $PM_{2.5}$ monitoring site to be included in the trends analysis, it had to meet all of the following criteria: 1) each site-year quarterly mean concentration value had to encompass at least 11 or more samples, 2) all four quarterly mean values had to be valid for a given year (i.e., meet criterion #1), and 3) all 22 years of site-level seasonal means had to be valid for the given site (i.e. meet criteria #1 and #2).

Annual "cool" season mean values for each site-year were computed as the average of the first and fourth quarterly mean values. Annual "warm" season mean values for each site-year were computed as the average of the second and third quarterly mean values. For a given year, all of the seasonal mean values for the monitoring sites located in the CSAPR region were then averaged together to obtain a single year (composite) seasonal mean value.

Changes in 1997 Annual $PM_{2.5}$ NAAQS Nonattainment Areas in CSAPR States, 2001–2003 (Original Designations) versus 2019–2021



Source: EPA, 2022

Figure 2. Changes in the 1997 Annual $PM_{2.5}$ NAAQS Nonattainment Areas in CSAPR States, 2001–2003 (Original Designations) versus 2019–2021

Chapter 8: Affected Communities

Regulatory programs implemented under the Clean Air Act to reduce emissions in the power sector have delivered substantial air quality improvements since the first nationwide program was implemented decades ago.[1] However, fossil fuel-fired power plants continue to be a leading source of ozone- and particulate-forming pollution, impacting our communities, lands, and waterways.

Environmental hazards can be inequitably distributed in the United States, with people of color and low-income populations consistently bearing a disproportionate burden of environmental pollution in some areas.[2] Further, climate change impacts human health through increasing concentrations of ambient air pollutants, including ground-level ozone.[3] In this chapter of the Progress Report, we examine the results of the EPA's power sector programs through an environmental justice lens to better understand the impacts of those programs on changes in emissions at plants located near disadvantaged communities.

We draw on detailed air emissions data that EPA collects from power plants across the country to provide three types of analyses.[4] First, we estimate the U.S. population living within three miles of a fossil-fired power plant and characterize the demographics in those areas.[5] Second, we compare 2021 emissions from plants located near areas of potential environmental justice (EJ) concern to emissions from all other plants. Lastly, we present emission trends associated with these plants from 2014, prior to implementation of the Cross-State Air Pollution Rule (CSAPR), through 2021. These analyses rely on approaches established by EPA's environmental justice screening and mapping tools, including EJScreen, which provides a nationally consistent approach for combining environmental and demographic indicators to highlight places that may have higher environmental burdens and vulnerable populations.

This chapter focuses on the people who live within three miles of the power plants regulated under EPA's Acid Rain Program (ARP) and three CSAPR programs.[6] At this time, it does not consider other pollution sources which may contribute to a disproportionate environmental burden for some people, nor does it consider the people who live more than three miles from each plant and who may be affected by air pollution from these facilities.

Highlights

People Living Near Power Plants

Proximity analysis is a frequently used approach to examine impacts on people who reside in areas that may be affected by a pollution source. In 2021, over 1,200 fossil fuel-fired power plants were covered under the ARP and CSAPR programs. Of the 329.3 million people in the contiguous U.S. (excluding Alaska, Hawaii, Puerto Rico and other U.S. territories), 10 percent live within three miles of one or more of these power plants.[7] Most of that population (greater than 8 percent) live near a plant fueled by natural gas. Less than 2 percent live near other types of fossil fuel-fired facilities, such as coal-fired or oil-fired power plants, which are typically higher-emitting (see Figure 1).

The federal government has long recognized the heightened vulnerability of people of color and low-income[8] individuals to environmental pollutants. EPA compared the percentages of people of color and low-income populations living within three miles of these power plants to the national average and found that there is a greater percentage of people of color and low-income individuals living near power plants than in the rest of the country on average. According to 2020 census data, on average, the U.S. population is comprised of 40 percent people of color and 30 percent low-income individuals. In contrast, the population living near fossil fuel-fired power plants is comprised of 53 percent people of color and 34 percent low-income individuals. For higher-emitting coal plants, the average population of people of color and low-income is slightly higher than the national average percentages. Figure 2 summarizes the percentages and national percentiles[9] for people of color and low-income populations.

The rest of this chapter takes a closer look at the emissions associated with plants that are located near areas of potential EJ concern. In the following analyses, those plants include any that are located within three miles of at least one census block group[10] where the population is characterized by either a relatively high[11] people of color or low-income population, based on data available in EPA's EJScreen. As shown in Figure 1, 886 power plants (72 percent) were located near areas of potential EJ concern in 2021.[12]

Emissions Affecting People Living Near Power Plants

This section focuses on 2021 sulfur dioxide (SO_2) and nitrogen oxide (NO_X) emissions from plants located near areas of potential EJ concern. Sulfur dioxide is a highly reactive gas that is generated primarily from coal-fired power plants. In addition to contributing to the formation of acid rain and fine particle pollution, SO_2 emissions are linked to many adverse human health effects. Nitrogen oxide emissions contribute to the formation of ground-level ozone and fine particle pollution, which cause a variety of adverse health effects, including decreased lung function, aggravated asthma, and premature death.

The majority of the 2021 electricity generation from all ARP and CSAPR power plants comes from plants located near areas of potential EJ concern (63 percent). A measure of power plant output, like electricity generation (i.e., the amount of electricity produced), may often be more informative than comparing the number of plants and can give a sense of scale to comparisons between different groups of plants or when comparing changes across time periods. This group of plants is also responsible for a larger share of emissions near areas of potential EJ concern: 53 percent of SO_2 emissions and 54 percent of annual and ozone season (May 1-September 30) NO_X emissions (see Figure 3).

Emissions Trends: 2014–2021

EPA analyzed emission trends between 2014 and 2021 for the ARP and CSAPR power plants. During this time, the percent reduction in total net SO_2 and NO_x emissions was greater at the group of plants located near areas of potential EJ concern than for all other plants. On average, SO_2 emission reductions decreased by 67 percent at the plants located near areas of potential EJ concern, compared to a 55 percent reduction from all other plants. Annual NO_x and ozone season NO_x emissions decreased by 46 percent and 41 percent, respectively, from plants near areas of potential EJ concern. This is slightly greater than the percent reduction in those pollutants at all other plants, where annual NO_x emissions decreased by 43 percent and seasonal NO_x emissions decreased by 36 percent (see Figure 4).

Conclusion

This chapter of the Progress Report combines publicly available emissions data with information in EJScreen and contributes to our understanding of the relationship between the power sector and nearby areas of potential EJ concern. The intent of this report is to focus on emissions at the fossil-fired power plants in the contiguous U.S. which are covered by EPA's regulatory programs developed to reduce acid rain and cross-state transport of particulate matter and ozone and relate those emissions to nearby areas. It does not yet consider the aggregate of all pollutants affecting these areas. Additionally, unlike EPA's regulatory analyses, this chapter does not consider the ability of emissions to travel more than three miles and combine with other pollutants. These considerations are important to evaluating the full impact of the fossil-fuel fired power plants in the U.S.

The chapter provides a first step toward that evaluation and consists of three analyses:

First, EPA looked within three miles of each power plant regulated under EPA's ARP and CSAPR programs and found that 10 percent of people in the contiguous U.S. live within three miles of a power plant. These are mostly gas-fired power plants, with less than 2 percent of the population living near coal- or oil-fired plants. Compared to the national average, the population living near power plants is characterized by a higher percentage people of color and low-income population.

Next, looking carefully at each census block group within a three-mile radius, EPA found that most of these power plants are located nearby at least one area of potential EJ concern.[13] These plants were responsible for 53 percent of SO_2 emissions and 54 percent of both annual and ozone season NO_X emissions in 2021.

Finally, the third analysis found that aggregate emission trends between 2014 and 2021 show a greater percent reduction in pollutants from plants located near areas of potential EJ concern, compared to all other ARP and CSAPR plants. Specifically, SO_2 emissions decreased by 67 percent at the plants located near areas of potential EJ concern, compared to a 55 percent reduction from all other plants. Annual NO_x and ozone season NO_X emissions decreased by 46 percent and 41 percent, respectively, from plants near areas of potential EJ concern. At all other plants annual NO_X emissions decreased by 43 percent and ozone season NO_X emissions decreased by 36 percent.

While EPA's programs have been effective in achieving overall emissions reductions, there is clearly more to do, both to address the adverse health outcomes and environmental harms associated with power plant emissions and, importantly, to advance the fair distribution of air quality and human health benefits from EPA's emission reduction programs. We are dedicated to continuous progress toward these goals. EPA will continue to assess the results of existing and future power plant emissions reduction programs through a demographic lens. Future analyses will build upon the findings presented in this chapter.

EPA invites your feedback. We would like to make this work accessible and useful to as many people as possible and welcome your ideas about how to do so. The data informing these analyses can be found here. We also encourage you to explore our tools, such as Power Plants and Neighboring Communities, and access the wealth of additional public data, interactive maps, graphs, and other resources available through our website.

Background Information

EPA conducted three analyses:

1. **People living near power plants -** EPA mapped the power plants in the contiguous U.S., estimated the U.S. population living within three miles of a power plant, and identified areas of potential EJ concern using two demographic indicators: people of color and low-income. EPA defined an area as being of potential EJ concern if, on average, either or both indicators showed a population greater than or equal to the 80th percentile on a national basis.
2. **Emissions affecting people living near power plants -** Drawing on detailed 2021 air emissions data collected from power plants across the country, EPA compared emissions from plants located near areas of potential EJ concern to emissions from all other plants.
3. **Emissions trends: 2014-2021** - Looking at the time period from 2014, prior to implementation of CSAPR, through 2021, EPA compared emission trends from power plants located near areas of potential EJ concern to emissions trends from all other plants.

More Information

- Environmental Justice Screening and Mapping Tool (EJ Screen) https://www.epa.gov/ejscreen
- Power Plants and Neighboring Communities https://www.epa.gov/power-sector/power-plants-and-neighboring-communities

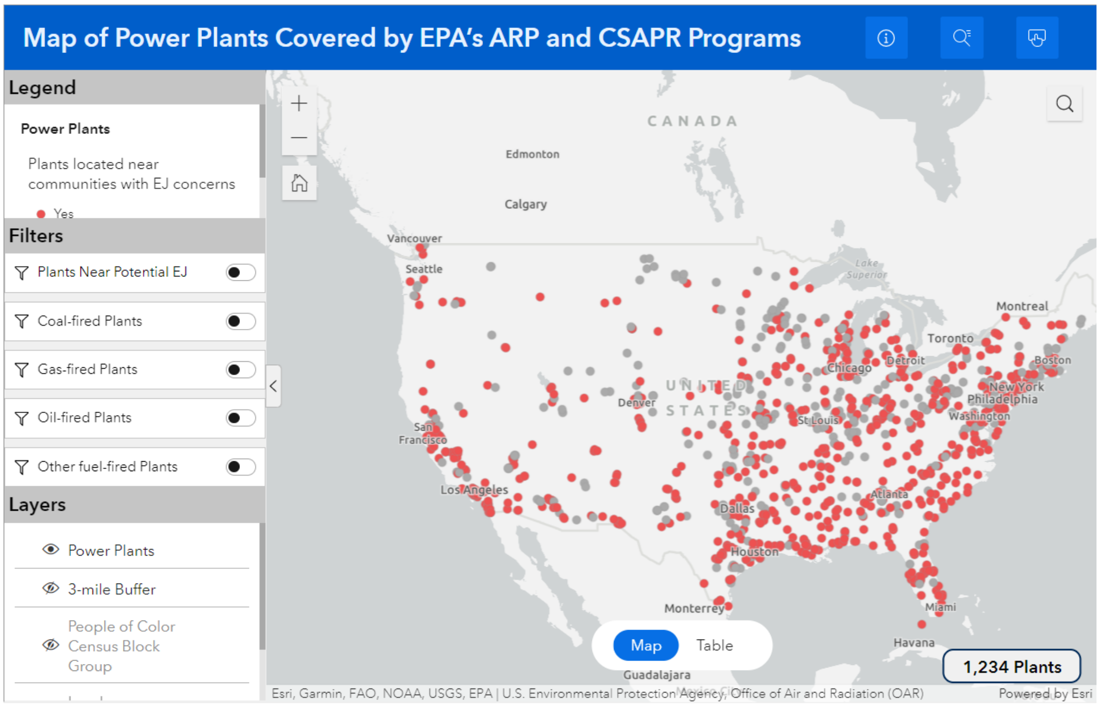
- Power Sector Emissions, Operations, and Environmental Data https://epa.gov/power-sector/data-tools

References

1. For more information about reductions in emissions and improved air quality, see the emissions reductions chapter of the Progress Report.
2. See, for example, Cole, L. W., & Foster, S. R. (2001). *From the ground up: Environmental racism and the rise of the environmental justice movement* (Vol. 34). NYU Press; Jbaily, A., Zhou, X., Liu, J., Lee, T. H., Kamareddine, L., Verguet, S., & Dominici, F. (2022). Air pollution exposure disparities across U.S. population and income groups. Nature, *601*(7892), 228-233; and Liu, J., Clark, L. P., Bechle, M. J., Hajat, A., Kim, S. Y., Robinson, A. L., ... & Marshall, J. D. (2021). *Disparities in air pollution exposure in the United States by race/ethnicity and income, 1990–2010*. *Environmental Health Perspectives*, *129*(12), 127005.
3. Nolte, C.G., Dolwick, P.D., Fann, N., Horowitz, L.W., Naik, V., Pinder, R.W., Spero, T.L., Winner, D.A., Ziska, L.H. (2018a). Air Quality. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, U.S. Global Change Research Program, Washington, DC.
4. The most recent annual emissions data are from 2021.
5. U.S. Census. (2020).
6. These are power plants that combust fossil fuels to generate electricity and emit air pollution. CSAPR refers to the Cross-State Air Pollution Rule (CSAPR), the CSAPR Update, and the Revised CSAPR Update programs.
7. It is important to note that the impacts of power plant emissions are not limited to a three-mile radius. Because pollution can travel over long distances from a power plant, the impacts of both potential increases and decreases in power plant emissions can be felt many miles away, meaning that the air quality in a community can be due to far-distant sources as well as those sited within a community. Still, being aware of the characteristics of communities closest to power plants is a starting point in understanding the potential sources of pollution that may impact a community and how changes in a power plant’s air emissions may affect the air quality experienced by some of those already vulnerable to environmental burdens.
8. EJScreen defines people of color as the percent of individuals in a block group who list their racial status as a race other than white alone and/or list their ethnicity as Hispanic or Latino (all people other than non-Hispanic white-alone individuals). The word "alone" in this case indicates that the person is of a single race, not multiracial. EJScreen defines low-income as the percent of a block group’s population in households where the household income is less than or equal to twice the federal "poverty level."
9. Percentiles are a way to see how areas of interest compare to everywhere else in the United States. The national percentile indicates what percent of the U.S. population has an equal or lower value, e.g., a lower percent of people of color or low-income population.
10. Census block groups are statistical divisions of census tracts and are generally defined as containing between 600 and 3,000 people.

11. In this report, we define "relatively high" to include percentile values greater than or equal to the 80th percentile on a national basis. This threshold is applied here as a starting point for the purpose of identifying geographic areas that may warrant further consideration, analysis, or outreach. The application of this threshold in this report is not intended to determine the existence or absence of EJ concerns or designate an area as an "EJ community." Rather, the intent of this report is to provide screening level analysis.
12. In this example, for an area to be in the 80th percentile nationwide means that the percent people of color and/or low-income within that block group is higher than 80 percent of all block groups across the country. In other words, the percent people of color and/or low income in the area is significantly higher than average.
13. Again, in this report, an "area of potential EJ concern" is defined as a census block group where the population is characterized by either a relatively high people of color or low-income population. It does not take the number of people living within the block group into account.

Figures



[Click here to view the map fullscreen.]

Source: EPA, 2023

Figure 1. Map of Power Plants Covered by EPA's ARP and CSAPR Programs

Notes:

Click the image above to open the interactive version of the figure.

Comparative Percentages of People of Color and Low-Income Populations Within Three Miles of a Power Plant, 2021

	National Percentage	All Plants	Coal	Gas	Oil	Other Fuel
People of Color	40%	53% (68th)	31% (51st)	54% (69th)	46% (64th)	49% (66th)
Low Income	30%	34% (60th)	33% (59th)	34% (60th)	35% (61st)	45% (74th)

Notes:
Percentiles are shown in parentessis.
Percentiles are a way to see how areas of interest compare to everywhere else in the United States. The national percentile indicates what percent of the U.S. population has an equal or lower value, e.g., a lower percent of people of color or low-income population.

Source: EPA, 2023

Figure 2. Comparative Percentages of People of Color and Low-Income Populations Within Three Miles of a Power Plant

Notes:

Percentiles are shown in parenthesis.

Percentiles are a way to see how areas of interest compare to everywhere else in the U.S. The national percentile indicates what percent of the U.S. population has an equal or lower value, e.g., a lower percent of people of color or low-income population.

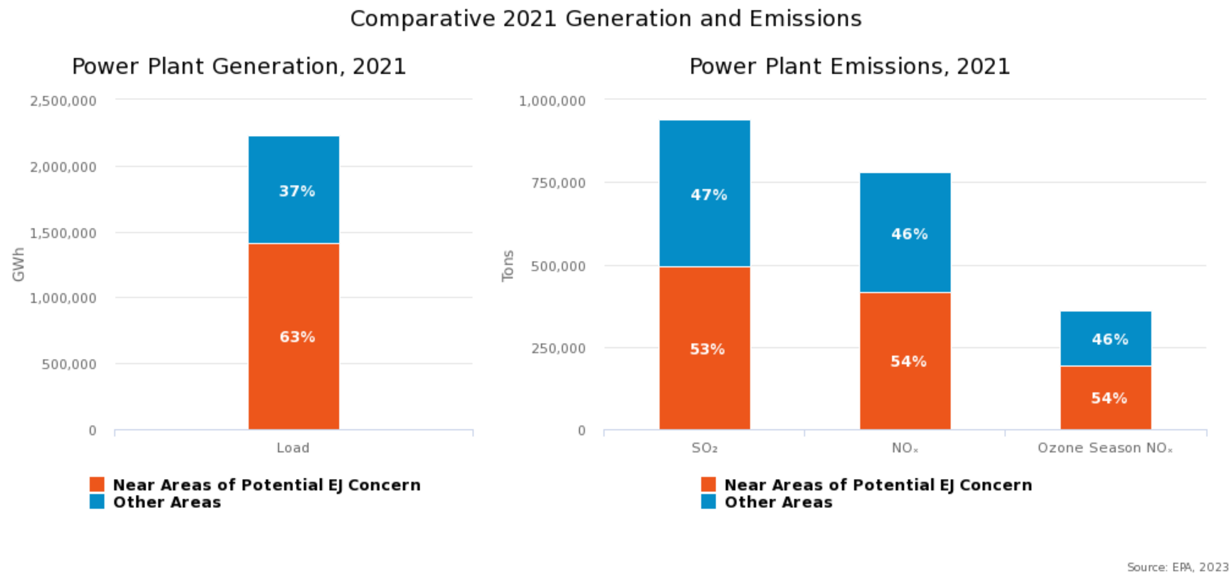


Figure 3. Comparative 2021 Generation and Emissions

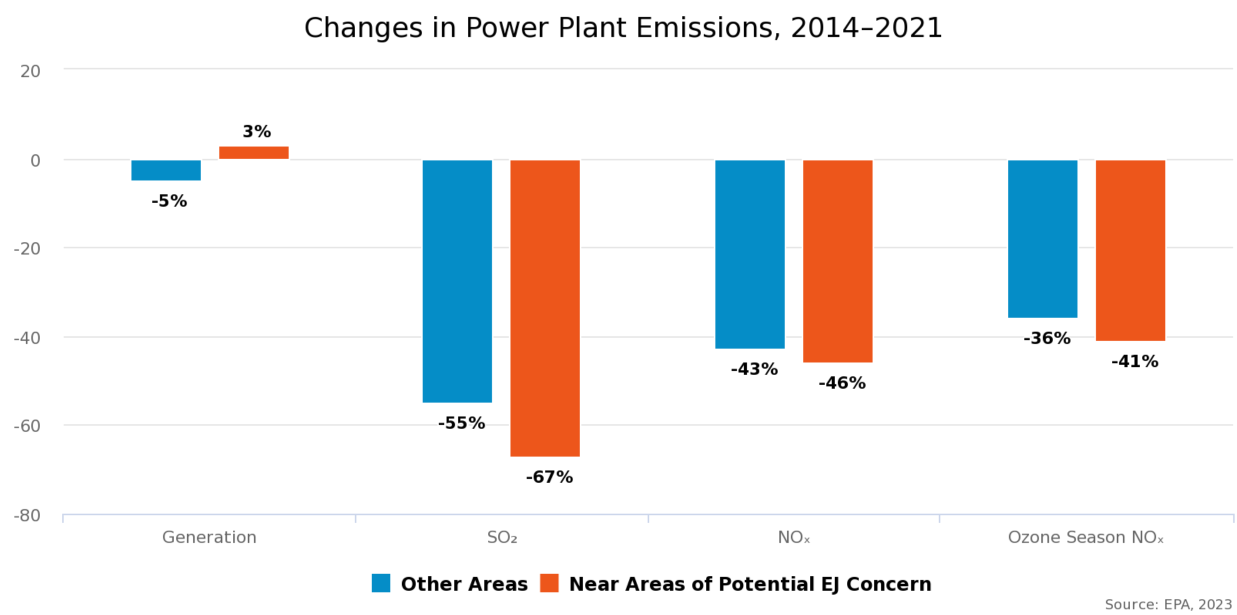


Figure 4. Changes in Power Plant Emissions, 2014–2021

Chapter 9: Acid Deposition

Acid deposition, commonly known as "acid rain," is a broad term referring to the mixture of wet and dry deposition from the atmosphere containing higher than normal amounts of sulfur and nitrogen-containing acidic pollutants. The precursors of acid deposition are primarily the result of emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) from fossil fuel combustion; however, natural sources, such as volcanoes and decaying vegetation, also contribute a small amount.

Highlights

Wet Sulfate Deposition

- All areas of the eastern United States have shown significant improvement, with an overall 71 percent reduction in wet sulfate deposition from 2000–2002 to 2019–2021.
- Between 2000–2002 and 2019–2021, the Northeast and Mid-Atlantic experienced a 77 percent reduction in wet sulfate deposition.
- SO_2 emissions reductions and the consequent decrease in the formation of sulfates that are transported long distances have resulted in reduced sulfate deposition in the Northeast. The sulfate reductions documented in the region, particularly across New England and portions of New York, were also affected by lowered SO_2 emissions in eastern Canada.[1]

Wet Inorganic Nitrogen Deposition

- Wet deposition of inorganic nitrogen decreased an average of 25 percent in the Mid-Atlantic and 32 percent in the Northeast but increased in the Mountain and Central regions from 2000–2002 to 2019–2021. Increases in wet deposition of inorganic nitrogen in the Rocky Mountain and Central regions are attributed to 36 and 34 percent increases in wet deposition of reduced nitrogen (NH_4^+), respectively, between 2000 and 2021.
- Reductions in nitrogen deposition recorded since the early 1990s have been less pronounced than those for sulfur. Emissions from other source categories (e.g., mobile sources, agriculture, biomass burning, and manufacturing) contribute to air concentrations and deposition of nitrogen.

Regional Trends in Total Deposition

- The reduction in total sulfur deposition (wet plus dry) in the eastern U.S. has been of similar magnitude to that of wet deposition with an overall average reduction of 82 percent from 2000–2002 to 2019–2021.
- Decreases in oxidized nitrogen (NO_X) have generally been greater than that of reduced nitrogen (NH_X) deposition. Total oxidized nitrogen deposition decreased 59 percent in the east. In contrast, total deposition of reduced nitrogen increased by an average of 46 percent in the east from 2000–2002 to 2019–2021.

Background Information

Acid Deposition

As SO_2 and NO_X gases react in the atmosphere with water, oxygen, and other pollutants, they form acidic compounds that are deposited to the earth's surface in the form of wet and dry deposition.

Long-term monitoring network data show significant improvements in the primary indicators of acid deposition. For example, wet sulfate deposition (sulfate that falls to the earth through rain, snow, and other forms of precipitation) has decreased in much of the eastern U.S. due to SO_2 emission reductions achieved through implementation of the Acid Rain Program (ARP), the Clean Air Interstate Rule (CAIR) and the Cross-State Air Pollution Rule (CSAPR). Some of the most dramatic reductions have occurred in the mid-Appalachian region, including Maryland, New York, West Virginia, Virginia, and most of Pennsylvania. Along with wet sulfate deposition, precipitation acidity, expressed as hydrogen ion (H^+ or pH) concentration, has also decreased by similar percentages.

Reductions in nitrogen deposition compared to the early 1990s have been less pronounced than those for sulfur. As noted earlier, emissions from source categories other than ARP and CSAPR regulated sources contribute to changes in air concentrations and deposition of oxidized, reduced, and organic forms of nitrogen.

Monitoring Networks

The Clean Air Status and Trends Network (CASTNET) provides long-term monitoring of regional air quality to determine trends in atmospheric concentrations and deposition of nitrogen, sulfur, and ozone in order to evaluate the effectiveness of national and regional air pollution control programs. In 2021, CASTNET operated 100 regional sites throughout the contiguous U.S., Alaska, and Canada. Sites are located in areas where urban influences are minimal.

The National Atmospheric Deposition Program/National Trends Network (NADP/NTN) is a nationwide, long-term network tracking the chemistry of precipitation. The NADP/NTN provides concentration and wet deposition data on hydrogen ion (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations. The NADP/NTN has grown to more than 250 sites spanning the U.S., Canada, Puerto Rico, and the Virgin Islands.

Together, these complementary networks provide long-term data needed to estimate spatial patterns and temporal trends in total deposition.[2] Maps and regional trends provided in this chapter were produced using the measurement-model fusion method developed by NADP's Total Deposition Science Committee. Briefly, CASTNET and NADP/NTN data are combined with modeled deposition results from EPA's Community Multiscale Air Quality Model (CMAQ) to produce gridded estimates of total deposition. The deposition values provided in this report have been updated using CMAQv5.3.2, incorporating the state of the science input data for emissions, meteorology, and air quality over the timeseries (2002-2019).[3] Improvements to the model have resulted in significant changes to the modeled deposition (e.g., reduced dry nitrogen deposition, non-measured oxidized nitrogen deposition).

More Information

- Acid Rain https://www.epa.gov/acidrain
- Clean Air Status and Trends Network (CASTNET) https://epa.gov/castnet
- EPA's Air QUAlity TimE Series (EQUATES) for the Community Multi-Scale Air Quality Modeling System (CMAQ) https://www.epa.gov/cmaq/equates
- National Atmospheric Deposition Program (NADP) https://nadp.slh.wisc.edu/

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2. Schwede, DB and Lear, GG. (2014). A novel hybrid approach for estimating total deposition in the United States. Atmosphere Environment 92: 207-220.
3. Appel, K.W., Bash, J.O., Fahey, K.M., Foley, K.M., Gilliam, R.C., Hogrefe, C., Hutzell, W.T., Kang, D., Mathur, R., Murphy, B.N., Napelenok, S.L., Nolte, C.G., Pleim, J.E., Pouliot, G.A., Pye, H.O.T., Ran, L., Roselle, S.J., Sarwar, G., Schwede, D.B., Sidi, F.I., Spero, T.L., and Wong, D.C. The Community Multiscale Air Quality (CMAQ) model versions 5.3 and 5.3.1: system updates and evaluation, Geosci. Model Dev., 14, 2867-2897, https://doi.org/10.5194/gmd-14-2867-2021, 2021.

Figures

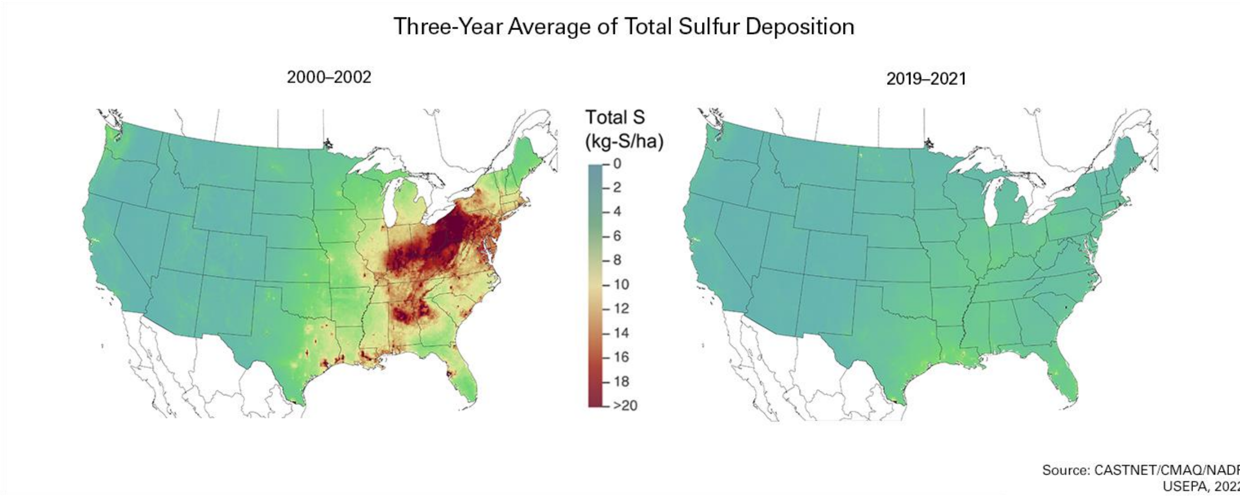

Figure 1. Three-Year Average of Total Sulfur Deposition

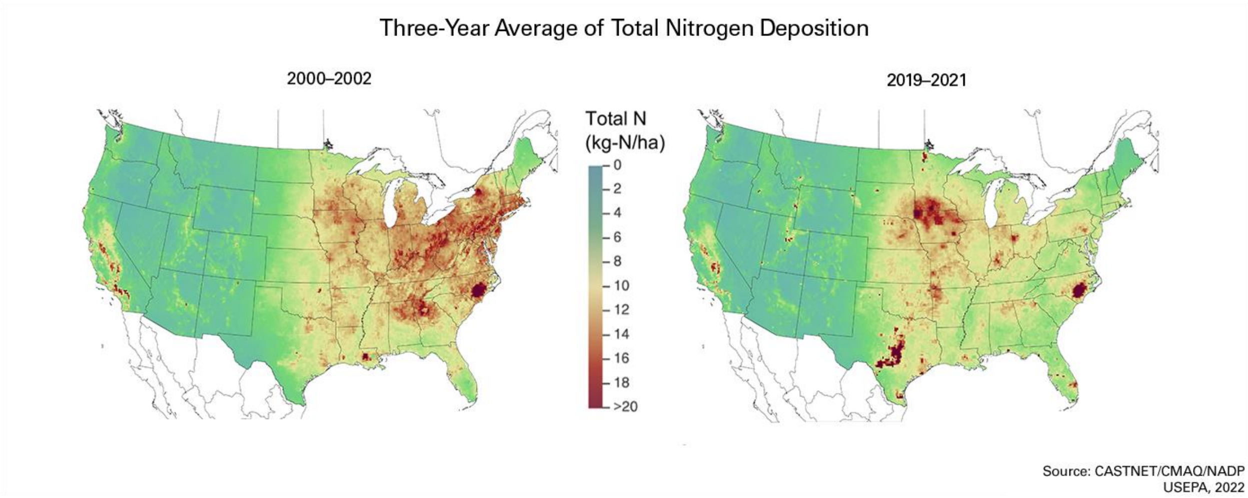

Figure 2. Three-Year Average of Total Nitrogen Deposition

Regional Trends in Deposition – Nitrogen

Measurement	Region	Annual Average, 2000–2002	Annual Average, 2019–2021	Percent Change
Dry Nitrogen Deposition (kg-N/ha)	Mid-Atlantic	8.4	4.8	-43
	Midwest	6.3	4.6	-27
	North Central	4.1	4.7	14
	Northeast	5.5	2.9	-47
	Pacific	2.7	2.2	-18
	Rocky Mountain	1.5	1.6	5
	South Central	4.3	5.3	22
	Southeast	6.8	4.9	-29
Wet Nitrogen Deposition (kg-N/ha)	Mid-Atlantic	5.0	3.7	-25
	Midwest	5.9	5.2	-12
	North Central	4.4	4.8	8
	Northeast	4.9	3.3	-32
	Pacific	1.1	0.9	-17
	Rocky Mountain	1.5	1.5	1
	South Central	3.5	3.8	8
	Southeast	4.0	3.6	-11
Total Deposition of Nitrogen (kg-N/ha)	Mid-Atlantic	13.4	8.5	-36
	Midwest	12.2	9.8	-20
	North Central	8.5	9.5	11
	Northeast	10.4	6.2	-40
	Pacific	3.8	3.1	-18
	Rocky Mountain	3.0	3.1	3
	South Central	7.8	9.0	16
	Southeast	10.8	8.4	-22
Total Deposition of Oxidized Nitrogen (kg-N/ha)	Mid-Atlantic	10.3	4.0	-62
	Midwest	8.0	3.6	-54
	North Central	4.1	2.6	-37
	Northeast	7.7	2.9	-62
	Pacific	2.4	1.4	-42
	Rocky Mountain	1.9	1.3	-35
	South Central	5.0	3.1	-39
	Southeast	7.7	3.4	-56
Total Deposition of Reduced Nitrogen (kg-N/ha)	Mid-Atlantic	3.0	4.6	51
	Midwest	4.3	6.2	45
	North Central	4.4	6.9	56
	Northeast	2.7	3.3	22
	Pacific	1.4	1.7	22
	Rocky Mountain	1.1	1.8	72
	South Central	2.8	6.0	111
	Southeast	3.1	5.0	63

Regional Trends in Deposition – Sulfur

Measurement	Region	Annual Average, 2000–2002	Annual Average, 2019–2021	Percent Change
Dry Sulfur Deposition (kg-S/ha)	Mid-Atlantic	10	0.7	-93
	Midwest	5.9	0.6	-90
	North Central	1.3	0.4	-70
	Northeast	3.7	0.4	-90
	Pacific	0.4	0.3	-30
	Rocky Mountain	0.3	0.2	-42
	South Central	2.2	0.7	-67
	Southeast	5.5	0.7	-87
Wet Sulfur Deposition (kg-S/ha)	Mid-Atlantic	6.1	1.4	-77
	Midwest	5.3	1.6	-69
	North Central	2.2	1.2	-48
	Northeast	5.0	1.1	-77
	Pacific	0.5	0.3	-46
	Rocky Mountain	0.7	0.4	47
	South Central	3.2	2.1	-36
	Southeast	4.8	2.0	-59
Total Deposition of Sulfur (kg-S/ha)	Mid-Atlantic	15.9	2.1	-87
	Midwest	11.2	2.2	-80
	North Central	3.5	1.5	56
	Northeast	8.7	1.5	-83
	Pacific	1.0	0.6	-38
	Rocky Mountain	1.0	0.6	-46
	South Central	5.4	2.8	-49
	Southeast	10.3	2.6	-74

Notes:
• Averages are the arithmetic mean of all spatial grids in a region for each time period.

Source: EPA, 2023

Figure 3. Regional Trends in Deposition

Notes:

Averages are the arithmetic mean of all spatial grids in a region for each time period.

Chapter 10: Ecosystem Response

Acidic deposition resulting from sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emissions may negatively affect the biological health of lakes, streams, forests, grasslands, and other ecosystems in the United States. Trends in measured chemical indicators allow scientists to determine whether water bodies are improving and heading towards recovery or if they are still acidifying. Assessment tools, such as critical loads analysis, provide a quantitative estimate of whether decreases in acidic deposition levels of sulfur and nitrogen resulting from SO_2 and NO_X emission reductions are sufficient to protect aquatic resources.

Ground-level ozone is an air pollutant that can impact ecological systems like forests, altering a plant's health and leading to changes in individual tree growth (e.g., biomass loss) and to the biological community. Analyzing the biomass loss of certain trees before and after implementation of NO_X emission reduction programs provides information about the effect of reduced NO_X emissions and ozone concentrations on forested areas.

Ecosystem Health

Highlights

Regional Trends in Water Quality

- Between 1990 and 2021, improved lake and stream health was demonstrated by significant decreasing trends in sulfate concentrations in water at all long-term monitoring (LTM) program lake and stream monitoring sites in New England, the Adirondacks, and the Catskill mountains.
- On the other hand, between 1990 and 2021, streams in the central Appalachian region have experienced mixed results due in part to their soils and geology. Only 64 percent of monitored streams show lower sulfate concentrations (and statistically significant trends), while 4 percent show increased sulfate concentrations.
- Nitrate concentrations and trends are highly variable and many sites do not show consistent improving trends between 1990 and 2021, despite reductions in NO_X emissions and inorganic nitrogen deposition.
- In 2021, levels of acid neutralizing capacity (ANC), a key indicator of aquatic ecosystem recovery from acidification, have increased significantly from 1990 in lake and stream sites in the Adirondack Mountains, New England, and the Catskill mountains. In the central Appalachian region, sites with increasing ANC remain low at 14 percent.

Ozone Impacts on Forests

- Between 2000–2002 and 2019–2021, the area in the eastern U.S. with combined biomass loss > 2 percent, 5 percent, and 10 percent for the forest decreased from 35 percent to 4.5 percent, 8.7 percent to 0.5 percent, and 1.7 percent to 0.1 percent, respectively, for seven tree species combined – black cherry, yellow poplar, sugar maple, eastern white pine, Virginia pine, red maple, and quaking aspen. This is an improvement of over 90 percent.

- For black cherry and yellow poplar individually (the tree species most sensitive to ground-level ozone), the total land area in the eastern U.S. with significant biomass loss decreased from 17.0 percent to 4 percent for black cherry, and from 5.6 percent to 0 percent for yellow poplar between 2000–2002 and 2019–2021.
- For the period 2019–2021, total land area in the eastern U.S. with significant biomass loss for the remaining five species combined (red maple, sugar maple, quaking aspen, Virginia pine, and eastern white pine) is now zero. This is in contrast to 6.9 percent for the period of 2000–2002.
- While this change in biomass loss cannot be exclusively attributed to the implementation of the NBP, CAIR, CSAPR, CSAPR Update, and Revised CSAPR Update, it is likely that NO_X ozone season emission reductions achieved under these programs, and the corresponding decreases in ozone concentration, contributed to this environmental improvement.

Background Information

Acidified Surface Water Trends

Acidified precipitation can impact lakes and streams by mobilizing toxic forms of aluminum from soils, (particularly in clay rich soils) and/or by lowering the pH of the water, harming fish and other aquatic wildlife. In a healthy well-buffered lake or stream, decreased acid deposition would be reflected by decreasing trends in surface water acidity. Four chemical indicators of aquatic ecosystem response to emission changes are presented here: trends in sulfate and nitrate anions, acid neutralizing capacity (ANC), and sum of base cations. Improvement in surface water status is generally indicated by decreasing concentration of sulfate and nitrate anions and increasing base cations and ANC. The following is a description of each indicator:

- **Sulfate** is the primary anion in most acid-sensitive waters and has the potential to acidify surface waters (lower the pH) and leach base cations and toxic forms of aluminum from soils, leaving soils depleted of their ability to neutralize acidic inputs.
- **Nitrate** has the potential to acidify surface waters. However, nitrogen is an important nutrient for plant and algae growth, and most of the nitrogen inputs from deposition are quickly taken up by plants and algae, leaving less in surface waters.
- **ANC** is a key indicator of ecosystem recovery and is a measure of overall buffering capacity of surface waters against acidification; it indicates the ability to neutralize strong acids that enter aquatic systems from deposition and other sources.
- **Base cations** neutralize both sulfate and nitrate anions, thereby preventing surface water acidification. Base cation availability is largely a function of underlying geology, soil type, and the vegetation community. Surface waters with fewer base cations are more susceptible to acidification.

In the central Appalachian region, some watersheds have soils which have also accumulated and stored sulfate over the past decades of high sulfate deposition. As a result, the substantial decrease in acidic deposition has not yet resulted in comparably lower sulfate concentrations in many of the monitored Appalachian streams. A combination of low base cation availability and stored sulfate in the soils means that stream sulfate concentrations in some areas are not changing, or may be increasing, as the stored sulfate slowly bleeds out without adequate base cation concentrations to neutralize sulfate anions.[1]

Surface Water Monitoring Networks

In collaboration with other federal and state agencies and universities, EPA administers the LTM program which provides information on the impacts of acidic deposition on otherwise pristine lakes and streams. This program is designed to track changes in surface water chemistry in the four regions sensitive to acid rain in the eastern U.S.: New England, the Adirondack Mountains, the Northern Appalachian Plateau, and the central Appalachians (the Valley, Ridge, and Blue Ridge geologic provinces).

Forest Health

Ground-level ozone is one of many air pollutants that can alter a plant's health and ability to reproduce and can make the plant more susceptible to disease, insects, fungus, harsh weather, and other environmental stressors. These impacts can lead to changes in the biological community, both in the diversity of species and in the health, vigor, and growth of individual species. As an example, many studies have shown that ground-level ozone reduces the health of commercial and ecologically important forest tree species throughout the U.S.[2, 3] By looking at the distribution and abundance of seven sensitive tree species and the level of ozone at particular locations, it is possible to estimate reduction in growth – or biomass loss – for each species. The EPA evaluated biomass loss for seven common tree species in the eastern U.S. that have a higher sensitivity to ozone (black cherry, yellow poplar, sugar maple, eastern white pine, Virginia pine, red maple, and quaking aspen) to determine whether decreasing ozone concentrations are reducing biomass loss in forest ecosystems.

More Information

- Surface water monitoring at EPA https://www.epa.gov/power-sector/monitoring-surface-water-chemistry
- Acid Rain https://www.epa.gov/acidrain/
- Ozone W126 Index https://www.epa.gov/air-quality-analysis/ozone-w126-index

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3. Ollinger, S.V., Aber, J.D., & Reich, P.B. (1997). Simulating ozone effects on forest productivity: interactions among leaf-canopy and stand-level processes. Ecological Applications 7(4), 1237–1251.

Figures

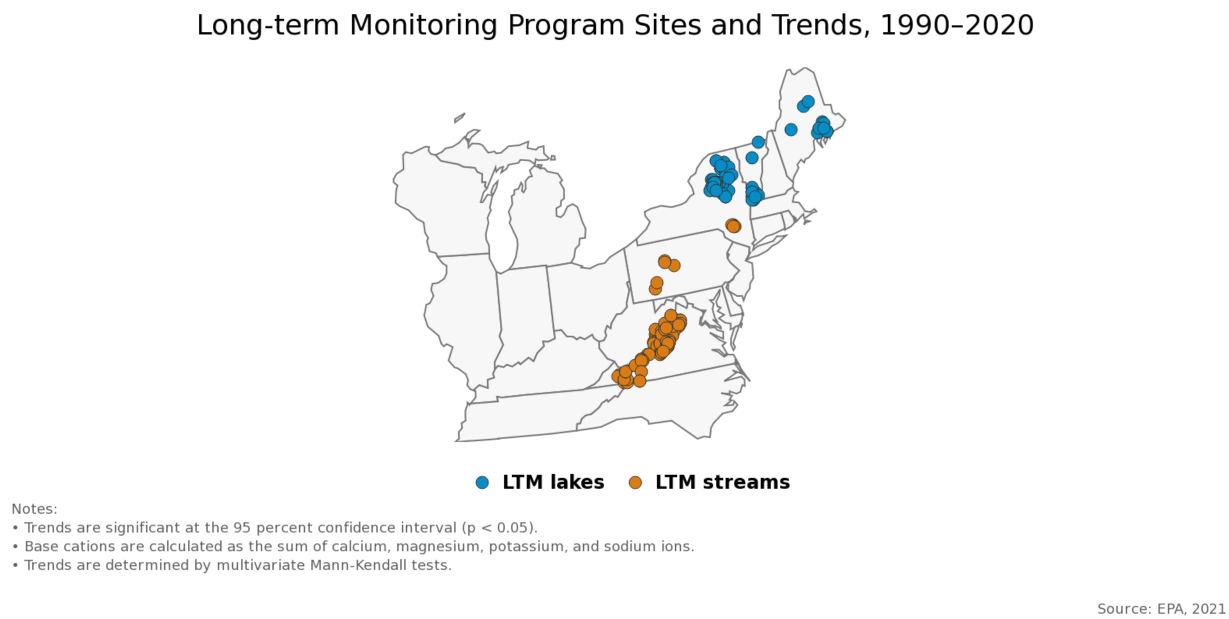

Figure 1. Long-term Monitoring Program Sites and Trends, 1990–2021

Notes:

Trends are significant at the 95 percent confidence interval ($p < 0.05$).

Base cations are calculated as the sum of calcium, magnesium, potassium, and sodium ions.

Trends are determined by multivariate Mann-Kendall tests.

Regional Trends in Sulfate, Nitrate, ANC, and Base Cations at Long-term Monitoring Sites, 1990–2021

Region	Water Bodies Covered	% of Sites with Improving Sulfate Trend	% of Sites with Improving Nitrate Trend	% of Sites with Improving ANC Trend	% of Sites with Improving Base Cations Trend
Adirondack Mountains	58 lakes in NY*	98%	86%	88%	91%
New England	26 lakes in ME and VT	100%	8%	77%	65%
Catskills/ N. Appalachian Plateau	9 streams in NY and PA**	78%	56%	67%	89%
Central Appalachians	70 streams in VA	64%	79%	14%	47%

Notes:
- Trends are determined by multivariate Mann-Kendall tests
- Trends are significant at the 95 percent confidence interval ($p < 0.05$)
- DOC is not routinely measured in Central Appalachian streams
- Sum of Base Cations calculated as (Ca+Mg+K+Na)

* Data for Adirondack lakes from 1992

** Data for PA streams in N. Appalachian Plateau is only through 2015

Source: EPA, 2023

Figure 2. Regional Trends in Sulfate, Nitrate, ANC, and Base Cations at Long-term Monitoring Sites, 1990–2021

Notes:

Trends are determined by multivariate Mann-Kendall tests

Trends are significant at the 95 percent confidence interval (p < 0.05)

DOC is not routinely measured in Central Appalachian streams

Sum of Base Cations calculated as (Ca+Mg+K+Na)

* Data for Adirondack lakes from 1992

** Data for PA streams in N. Appalachian Plateau is only through 2015

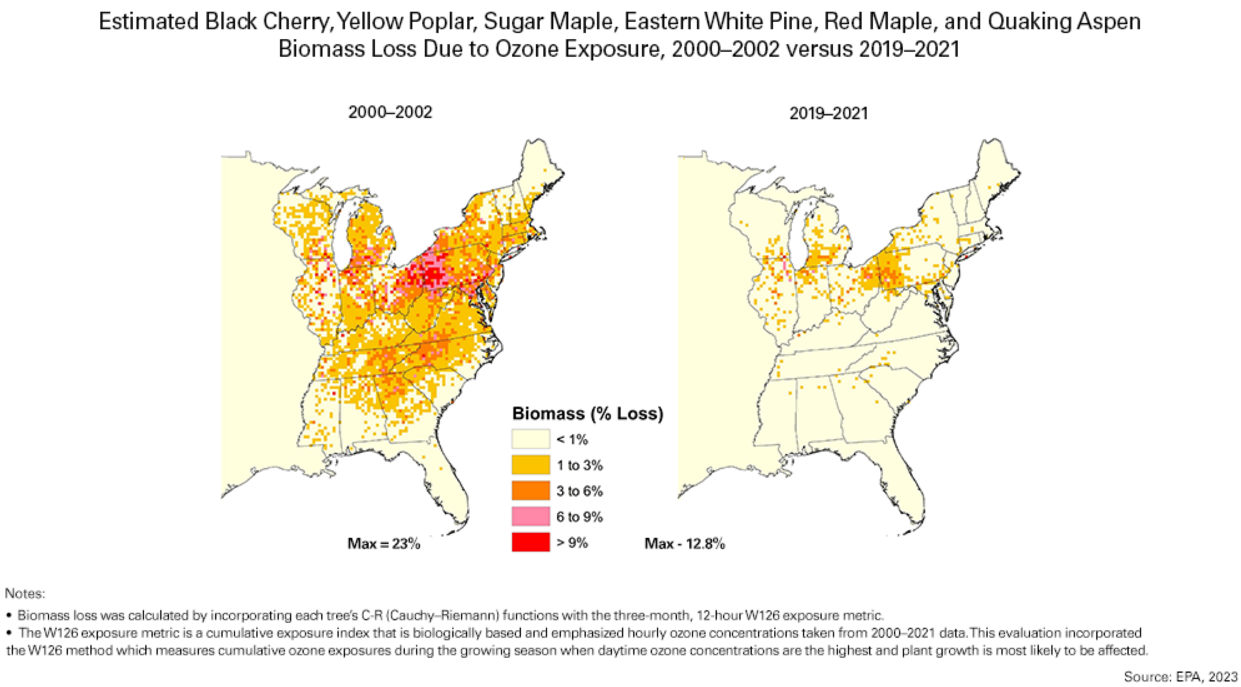

Figure 3. Estimated Black Cherry, Yellow Poplar, Sugar Maple, Eastern White Pine, Virginia Pine, Red Maple, and Quaking Aspen Biomass Loss Due to Ozone Exposure, 2000–2002 versus 2019–2021

Notes:

- Biomass loss was calculated by incorporating each tree's C-R (Cauchy–Riemann) functions with the three-month, 12-hour W126 exposure metric.
- The W126 exposure metric is a cumulative exposure index that is biologically based and emphasizes hourly ozone concentrations taken from 2000-2020 data. This evaluation incorporated the W126 method which measures cumulative ozone exposures during the growing season when daytime ozone concentrations are the highest and plant growth is most likely to be affected.

Critical Loads Analysis

Highlights

Critical Loads and Exceedances

- For the period from 2019 to 2021, 5.8 percent of the 7,869 studied lakes and streams still received levels of combined total sulfur and nitrogen deposition exceeding their calculated critical load. This is an 84 percent improvement over the period from 2000 to 2002 when 38 percent of all studied lakes and streams exceeded their calculated critical load.
- Emission reductions achieved between 2000 and 2021 have contributed and will continue to contribute to broad surface water improvements and increased aquatic ecosystem protection across the five LTM regions along the Appalachian Mountains.
- Based on this analysis, current sulfur and nitrogen deposition loadings for the period of 2019 to 2021 still exceed levels required for recovery of some lakes and streams, indicating that some additional emission reductions are necessary for some acid-sensitive aquatic ecosystems along the Appalachian Mountains to recover and be protected from acid deposition.

Background Information

A critical loads analysis is an assessment used to provide a quantitative estimate of whether acid deposition levels are negatively impacting ecosystem health. The analysis here focuses on aquatic biological resources. If acidic deposition is less than the calculated critical load, harmful ecological effects (e.g., reduced reproductive success, stunted growth, loss of biological diversity) are not expected to occur, and ecosystems damaged by past exposure are expected to eventually recover.[1]

Lake and stream waters having an ANC value greater than 50 μeq/L are classified as having a moderately healthy aquatic biological community; therefore, this ANC concentration is often used as a goal for ecological protection of surface waters affected by acidic deposition. In this analysis, the critical load represents the amount of combined sulfur and nitrogen that could be deposited annually to a lake or stream and its watershed and still support a moderately healthy aquatic ecosystem (i.e., having an ANC greater than 50 μeq/L). Surface water samples from 7,869 lakes and streams along acid-sensitive regions of the Appalachian Mountains and some adjoining northern coastal plain regions were collected through a number of water quality monitoring programs. Critical load exceedances were calculated using the Steady-State Water Chemistry model.[2,3]

More Information

- Surface water monitoring at EPA https://www.epa.gov/power-sector/monitoring-surface-water-chemistry
- National Acid Precipitation Assessment Program (NAPAP) Report to Congress https://ny.water.usgs.gov/projects/NAPAP/

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3. Nilsson, J. & Grennfelt, P. (Eds) (1988). Critical loads for sulphur and nitrogen. UNECE/Nordic Council workshop report, Skokloster, Sweden. Nordic Council of Ministers: Copenhagen.

Figures

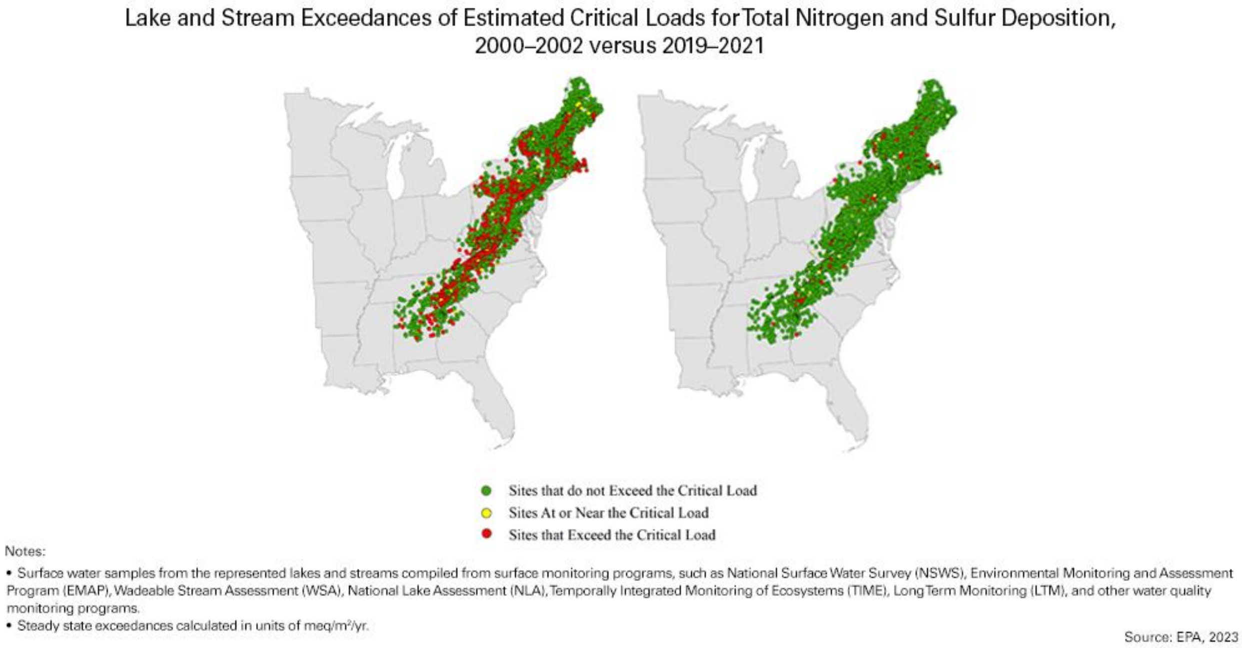

Figure 1. Lake and Stream Exceedances of Estimated Critical Loads for Total Nitrogen and Sulfur Deposition, 2000–2002 versus 2019–2021

Notes:

Surface water samples from the represented lakes and streams complied from surface monitoring programs, such as National Surface Water Survey (NSWS), Environmental Monitoring and Assessment Program (EMAP), Wadeable Stream Assessment (WSA), National Lake Assessment (NLA), Temporally Integrated Monitoring of Ecosystems (TIME), Long Term Monitoring (LTM), and other water quality monitoring programs.

Steady state exceedances calculated in units of $meq/m^2/yr$.

Critical Load Exceedances by Region, 2000–2002 versus 2019–2021

Region	Number of Water Bodies Modeled	Water Bodies in Exceedance of Critical Load				Percent Reduction
		2000–2002		2019–2021		
		Number of Sites	Percent of Sites	Number of Sites	Percent of Sites	
New England (CT, MA, ME, NH, RI, VT)	2,309	548	24%	101	4%	82%
Adirondack (NY)	1,581	688	44%	151	10%	78%
Northern Mid-Atlantic (NY, NJ, PA)	1,200	351	29%	32	3%	91%
Southern Mid-Atlantic (KY, MD, VA, WV)	1,840	1000	54%	94	5%	91%
Southern Appalachian Mountains (AL, GA, SC, TN)	939	364	39%	80	9%	78%
Total Units	**7,869**	**2,951**	**38%**	**458**	**5.8%**	**84%**

Notes:
• Surface water samples from the represented lakes and streams complied from surface monitoring programs, such as National Surface Water Survey (NSWS), Environmental Monitoring and Assessment Program (EMAP), Wadeable Stream Assessment (WSA), National Lake Assessment (NLA), Temporally Integrated Monitoring of Ecosystems (TIME), Long Term Monitoring (LTM), and other water quality monitoring programs.
• Steady state exceedances calculated in units of meq/m^2/year.

Source: EPA, 2023

Figure 2. Critical Load Exceedances by Region, 2000–2002 versus 2019–2021

Notes:

Surface water samples from the represented lakes and streams complied from surface monitoring programs, such as National Surface Water Survey (NSWS), Environmental Monitoring and Assessment Program (EMAP), Wadeable Stream Assessment (WSA), National Lake Assessment (NLA), Temporally Integrated Monitoring of Ecosystems (TIME), Long Term Monitoring (LTM), and other water quality monitoring programs.

Steady state exceedances calculated in units of meq/m^2/yr.