POWER SECTOR PROGRAMS
PROGRESS REPORT

2017

- Program Basics
- Emission Controls & Monitoring
- Air Quality
- Affected Units
- Program Compliance
- Acid Deposition
- Emission Reductions
- Market Activity
- Ecosystem Response

Executive Summary

Under the Clean Air Act, EPA implements several regulations that affect power plants, including the Acid Rain Program (ARP), the Cross-State Air Pollution Rule (CSAPR) and 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 third year of CSAPR implementation, the twenty-second year of ARP, and the first year of MATS implementation in which the majority of sources were required to report emissions for the full year. This report summarizes annual progress through 2017, highlighting data that EPA systematically collects on emissions for all three programs, on compliance, and environmental effects for ARP and CSAPR. Transparency and data availability are a hallmark of these programs, and a cornerstone of their success.

Sulfur dioxide, nitrogen oxides, and hazardous air pollutants, including mercury, are fossil fuel combustion byproducts that impact public health and the environment. SO_2 and NO_X, and their sulfate and nitrate byproducts, are transported and deposited as acid rain at levels 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 Acid Rain Program, CSAPR, 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 demonstrated reductions achieved by the power sector emission control programs described in this report, SO_2, NO_X, and hazardous air pollutant emissions have declined steadily in recent years due to a variety of power industry trends that are expected to continue.

2017 ARP, CSAPR and MATS at a Glance

- **Annual SO_2 emissions:**
  CSAPR - 0.8 million tons (91 percent below 2005)
  ARP - 1.3 million tons (92 percent below 1990)
- **Annual NO_X emissions**:
  CSAPR - 0.6 million tons (73 percent below 2005)
  ARP - 1.0 million tons (84 percent below 1990)
- **CSAPR ozone season NO_X emissions:** 300,000 tons (53 percent below 2005)
- **Compliance:** 100 percent compliance for power plants in the market-based ARP and CSAPR allowance-trading programs.
- **Emissions reported under MATS:**
  Mercury - 4 tons (86 percent below 2010)
  Acid gases - 4,831 tons (96 percent below 2010)
  Non-mercury metals - 221 tons (81 percent below 2010)

- **Ambient particulate sulfate concentrations:** The eastern United States has shown substantial improvement, decreasing 33 to 71 percent between 2000–2002 and 2015–2017.
- **Ozone NAAQS attainment:** Based on 2015–2017 data, all 92 areas in the East originally designated as nonattainment for the 1997 ozone NAAQS are now meeting the standard.
- **$PM_{2.5}$ NAAQS attainment:** Based on 2015–2017 data, 36 of the 39 areas in the East originally designated as nonattainment for the 1997 $PM_{2.5}$ NAAQS are now meeting the standard (one area has incomplete data).
- **Wet sulfate deposition:** All areas of the eastern United States have shown significant improvement with an overall 64 percent reduction in wet sulfate deposition from 2000–2002 to 2015–2017.
- **Levels of acid neutralizing capacity (ANC):** This indicator of 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), and the CSAPR Update are implemented through cap and trade programs designed to reduce emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) from covered power plants. Established under Title IV of the 1990 Clean Air Act Amendments, the Acid Rain Program was a landmark nationwide cap and trade program, with a goal of reducing the emissions that cause acid rain. The undisputed success of the program in achieving significant emission reductions in a cost-effective manner led to the application of the market-based cap and trade 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 can make it difficult for downwind states to meet health-based air quality standards for regional pollutants, particularly $PM_{2.5}$ and ozone. EPA first employed trading to address regional criteria 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, 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 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 seasonal NO_X emissions, to facilitate attainment of the fine particle and ozone NAAQS. Most recently, implementation of CSAPR Update began in 2017. CSAPR Update further reduces seasonal NO_X emissions to help states attain and maintain a newer ozone National Ambient Air Quality Standards (NAAQS).

The Mercury and Air Toxics Standards (MATS) set limits on emissions of hazardous air pollutants from covered 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, 2017 is the first full year for which the vast majority of sources covered by MATS have reported emissions data to the EPA.

Highlights

Acid Rain Program (ARP): 1995 - present

- ARP began in 1995 and covers fossil fuel-fired power plants across the contiguous United States. 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.
- The ARP's market-based SO_2 cap and trade program sets an annual cap on the total amount of SO_2 that may be emitted by covered electricity generating units (EGUs) 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 ARP are achieved through a rate-based approach that applies to a subset of coal-fired EGUs.

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

- CSAPR addresses regional interstate transport of fine particle and ozone pollution for the 1997 ozone and $PM_{2.5}$ NAAQS and the 2006 $PM_{2.5}$ NAAQS. In 2015, CSAPR required a total of 28 eastern states to reduce SO_2 emissions, annual NO_X emissions and/or ozone season NO_X emissions. Specifically, 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.
- CSAPR includes four separate cap and trade programs to achieve these reductions: CSAPR SO_2 Group 1 and Group 2 trading programs, CSAPR NO_X Annual trading program, and CSAPR NO_X Ozone Season Group 1 trading program.

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

- 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.
- Starting in May 2017, CSAPR Update began further reducing ozone season NO_X emissions from power plants in 22 states in the eastern U.S.
- CSAPR Update achieves these reductions through the CSAPR NO_X Ozone Season Group 2 trading program. The total CSAPR Update budget equals the sum of the individual state budgets for those states included in the program. The CSAPR Update budget is set at 316,464 tons in 2017.

CSAPR and CSAPR Update Budgets

- The total CSAPR and CSAPR Update budget for each of the five trading programs equals the sum of the individual state budgets for those states affected by each program. In 2017, some original CSAPR budgets tightened, particularly in the SO_2 Group 1 program. Also, CSAPR Update replaced the original CSAPR ozone season NO_X program for most states. The total budget for each program was set at the following level in 2017:
    - 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[1]
    - NO_X Ozone Season Group 2 – 316,464 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.

[1]The CSAPR NO_X Ozone Season Group 1 program applies only to sources in Georgia.

- 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 2017 progress report only provides data from affected sources that submitted hourly emissions data in 2017. Units not reporting data (e.g. those monitoring using periodic testing) are not included in this report.

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. 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, reduced electricity demand, and policy and regulatory efforts have resulted in a notable 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.

Looking ahead, the price of natural gas is expected to remain low for the foreseeable future as improvements in drilling technologies and techniques continue to reduce the cost of extraction. In addition, the existing fleet of coal-fired EGUs is aging and there are very few new coal-fired generation projects under development. 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 2024 provide incentives for new wind capacity in the near-term. 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. All of these factors, in total, have resulted in declining power sector emissions in recent years, a trend that is expected to continue going forward.

Acid Rain Program

Title IV of the 1990 Clean Air Act Amendments established 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 allowance trading system that harnessed the economic incentives of the market to reduce pollution. This market-based cap and trade program was implemented in two phases. Phase I began in 1995 and affected the most polluting coal-burning units 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 allowance trading system. Instead, 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 can comply through the use of 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

NBP was a market-based cap and trade 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 1997 ozone NAAQS. All 21 jurisdictions (20 states plus Washington, D.C.) covered by the NO_X SIP Call opted to participate in NBP. In 2009, CAIR's NO_X ozone season program began, effectively replacing 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 cap and trade 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 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 United States to significantly improve air quality by reducing power plant emissions that cross 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 and/or 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 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 CSAPR ozone season program by issuing the CSAPR Update. This rule addresses the summertime ozone pollution in the eastern U.S. that crosses state lines and will help downwind states and communities meet and maintain the 2008 ozone NAAQS. In May 2017, CSAPR Update began further reducing ozone season NO_X emissions from power plants in 22 states in the eastern U.S.

Cross-State Air Pollution Rule Close-Out

Under the Clean Air Act's "good neighbor" provision (section 110(a)(2)(D)(i)(I)), upwind states that contribute significantly to nonattainment or interfere with maintenance of NAAQS in downwind areas must implement emission reductions through a state implementation plan (SIP) or, in the absence of an approved SIP, a federal implementation plan (FIP). When issuing the CSAPR Update in September 2016, EPA found that, while it would result in meaningful, near-term reductions in ozone pollution that crosses state lines, the CSAPR Update may not be sufficient to fully address all covered states' good neighbor obligations with respect to the 2008 ozone NAAQS. However, based on additional analysis conducted after issuance of the rule, EPA determined in December 2018 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. As a result, the covered states do not need to submit SIPs to establish additional emission reduction requirements beyond the existing CSAPR Update requirements to further reduce transported ozone under the 2008 ozone NAAQS. Likewise, EPA has no obligation to establish additional emission reduction requirements for this purpose.

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 electric utility steam generating units (EGUs) 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, allowed under the CAA, and so, were required to comply with the final rule by April 16, 2016.

More Information

- Acid Rain Program (ARP) https://www.epa.gov/airmarkets/acid-rain-program
- Interstate Air Pollution Transport https://www.epa.gov/airmarkets/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
- Cross-State Air Pollution Rule Close-Out (CSAPR Close-Out) https://www.epa.gov/airmarkets/final-csapr-close-out
- 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
- MATS https://www.epa.gov/mats

Figures

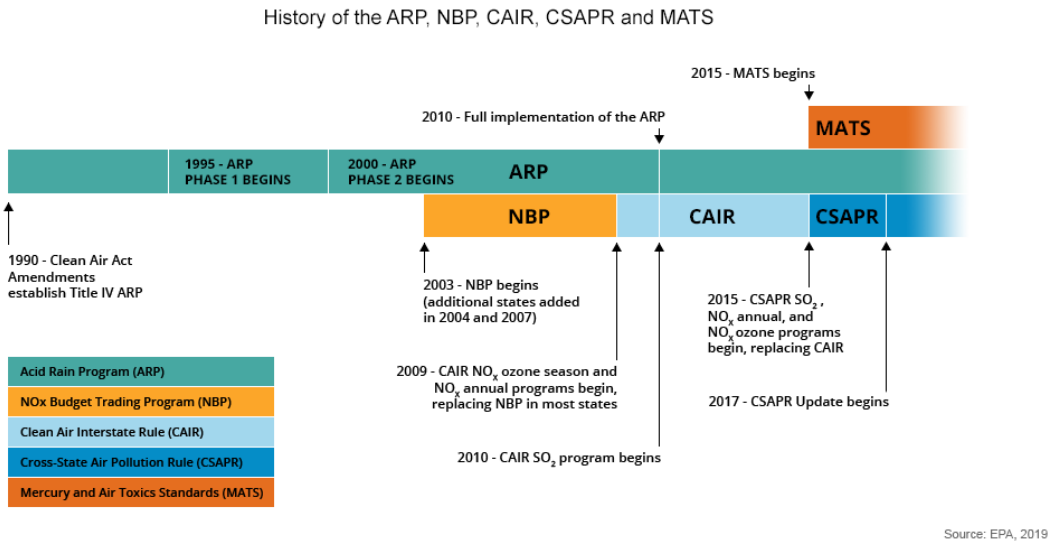

Figure 1. History of the ARP, NBP, CAIR, CSAPR and MATS

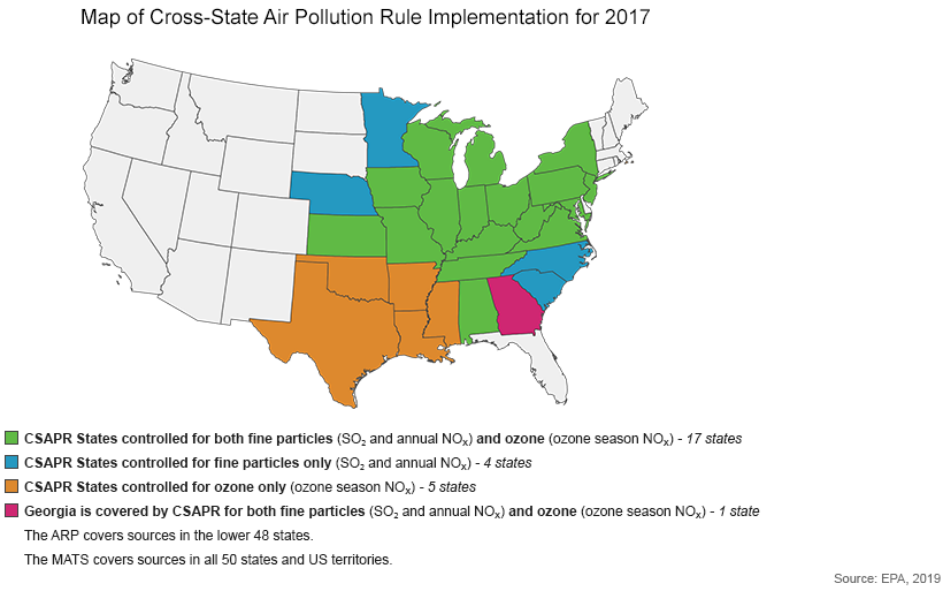

Figure 2. Map of Cross-State Air Pollution Rule Implementation for 2017

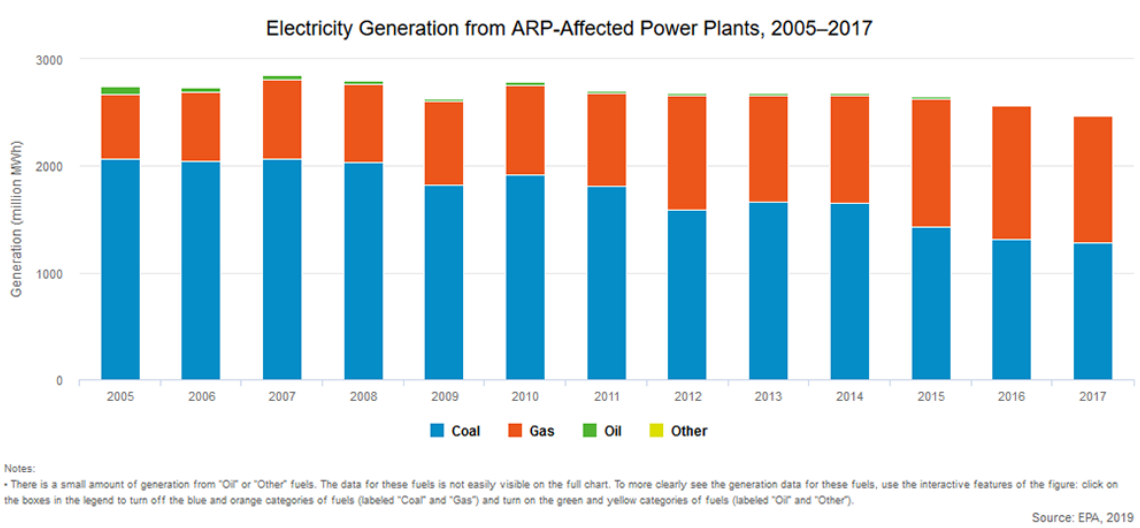

Figure 3. Electricity Generation from ARP-Affected Power Plants, 2005–2017

Chapter 2: Affected Units

The Acid Rain Program (ARP), the Cross-State Air Pollution Rule's (CSAPR) sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emission reduction programs, apply to large electricity generating units (EGUs) that burn fossil fuels to generate electricity for sale. The Mercury and Air Toxics Standards only cover large EGUs that burn coal or oil to generate electricity for sale. This is the primary reason that this report includes less units for MATS. This section covers units affected in 2017.

Highlights

Acid Rain Program (ARP)

- In 2017, ARP SO_2 requirements applied to 3,383 fossil fuel-fired combustion units at 1,195 facilities across the country; 657 units at 295 facilities were subject to the ARP NO_X program.

Cross-State Air Pollution Rule (CSAPR)

- In 2017, there were 2,287 affected EGUs at 712 facilities in the CSAPR SO_2 program. Of those, 1,805 (79 percent) were also covered by ARP.
- In 2017, there were 2,287 affected EGUs at 712 facilities in the CSAPR NO_X annual program and 2,623 affected EGUs at 837 facilities in the CSAPR NO_X ozone season program. Of those, 1,805 (79 percent) and 2,124 (81 percent), respectively, were also covered by 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 (EGUs) in all 50 states and U.S. territories. MATS is issued under section 112 of the Clean Air Act and requires units to conduct testing and submit emissions data to EPA periodically. EPA is including a summary of the mercury data submitted by affected sources in this report.
- In 2017, 530 units at 235 facilities reported hourly mercury emissions to EPA under MATS.

Background Information

In general, ARP; the CSAPR SO_2, NO_X annual, and NO_X ozone season trading programs; apply to large EGUs – 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 EGUs (i.e., utility boilers). It does not apply to turbines, combined cycle units, or to natural gas-fired utility boilers. These EGUs 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.

More Information

- Acid Rain Program (ARP) https://www.epa.gov/airmarkets/acid-rain-program
- Cross-State Air Pollution Rule (CSAPR) https://www.epa.gov/csapr

- Mercury and Air Toxics Standards (MATS) https://www.epa.gov/mats

Figures

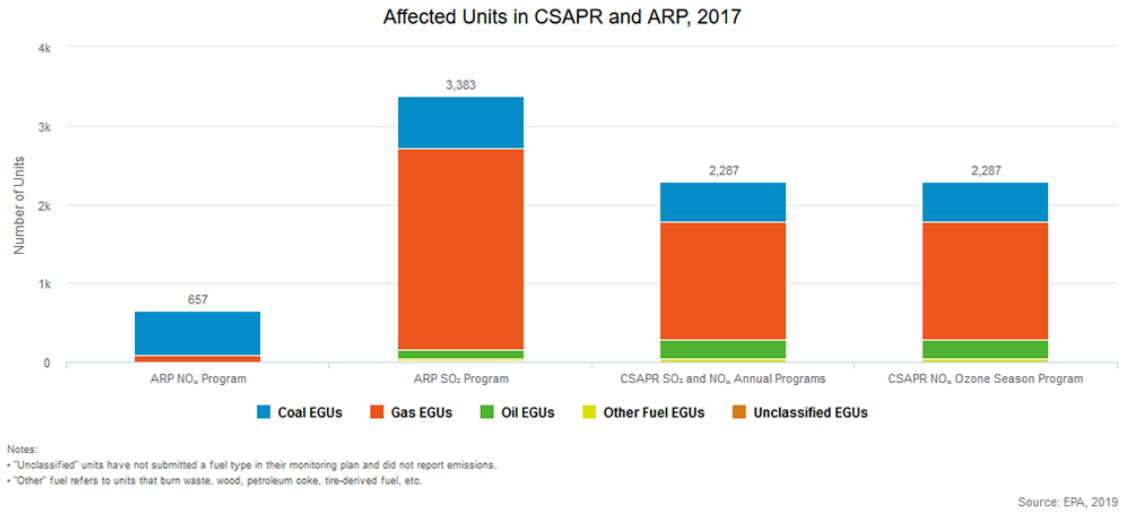

Figure 1. Affected Units in CSAPR and ARP, 2017

Affected Units in CSAPR and ARP, 2017

Fuel	ARP NO_x	ARP SO_2	CSAPR SO_2 and Annual NO_x	CSAPR Ozone Season NO_x
Coal	575	666	503	503
Gas	80	2,562	1,498	1,498
Oil	0	117	249	249
Other	2	29	37	37
Unclassified	0	9	0	0
Total Units	**657**	**3,383**	**2,287**	**2,287**

Notes:
- "Unclassified" units have not submitted a fuel type in their monitoring plan and did not report emissions.
- "Other" fuel refers to units that burn waste, wood, petroleum coke, tire-derived fuel, etc.

Source: EPA, 2019

Figure 2. Affected Units in CSAPR and ARP, 2017

Chapter 3: Emission Reductions

The Acid Rain Program (ARP) and Cross-State Air Pollution Rule (CSAPR) programs significantly reduced sulfur dioxide (SO_2), annual nitrogen oxides (NO_X), and ozone season NO_X emissions from power plants. Most of the emission reductions since 2005 occurred in response to the Clean Air Interstate Rule (CAIR), which was replaced by CSAPR in 2015. 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 (EGUs) and have been one of the reasons for reductions in those emissions since 2010. This section covers changes in emissions at units affected by CSAPR, ARP, and MATS between 2017 and previous years.

Sulfur Dioxide (SO_2)

Highlights

Overall Results

- Under the ARP, CAIR, and now CSAPR, power plants have significantly lowered SO_2 emissions 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, 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 ARP emitted 1.3 million tons of SO_2 in 2017, well below the ARP's statutory annual cap of 8.95 million tons. ARP sources reduced emissions by 14.4 million tons (92 percent) from 1990 levels and 15.9 million tons (92 percent) from 1980 levels.
- **CSAPR and ARP:** In 2017, the third year of operation of the CSAPR SO_2 program, sources in both the CSAPR SO_2 annual program and ARP together reduced SO_2 emissions by 14.4 million tons (92 percent) from 1990 levels (before implementation of ARP), 9.9 million tons (88 percent) from 2000 levels (ARP Phase II), and 8.9 million tons (87 percent) from 2005 levels (before implementation of CAIR and CSAPR). All ARP and CSAPR sources together emitted a total of 1.3 million tons of SO_2 in 2017.
- **CSAPR:** Annual SO_2 emissions from sources in the CSAPR SO_2 program alone fell from 8.1 million tons in 2005 to 0.8 million tons in 2017, a 91 percent reduction. In 2017, SO_2 emissions were about 1.2 million tons below the regional CSAPR emission budgets (0.7 million in Group 1 and 0.5 million in Group 2); the CSAPR SO_2 annual program's 2017 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 2017, annual SO_2 emissions from sources in ARP and the CSAPR SO_2 program dropped in 46 states plus Washington, D.C. by a total of 14.4 million tons. In

contrast, annual SO_2 emissions increased in two states (Idaho and Vermont) by a combined total of 7 tons from 1990 to 2017.

- **CSAPR:** All 22 states (16 states in Group 1 and 6 states in Group 2) had emissions below their CSAPR allowance budgets, collectively by about 1.2 million tons.

SO_2 Emission Rates

- The average SO_2 emission rate for units in ARP or CSAPR SO_2 program fell to 0.12 pounds per million British thermal units (lb/mmBtu). This indicates an 84 percent reduction from 2005 rates, with the majority of 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 fine particle pollution ($PM_{2.5}$), 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 ARP, and this trend continued under CAIR and CSAPR. Most of these states are located in the Ohio River Valley and are upwind of the areas 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
- Air Markets Program Data (AMPD) https://ampd.epa.gov/ampd/
- Acid Rain Program (ARP) https://www.epa.gov/airmarkets/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

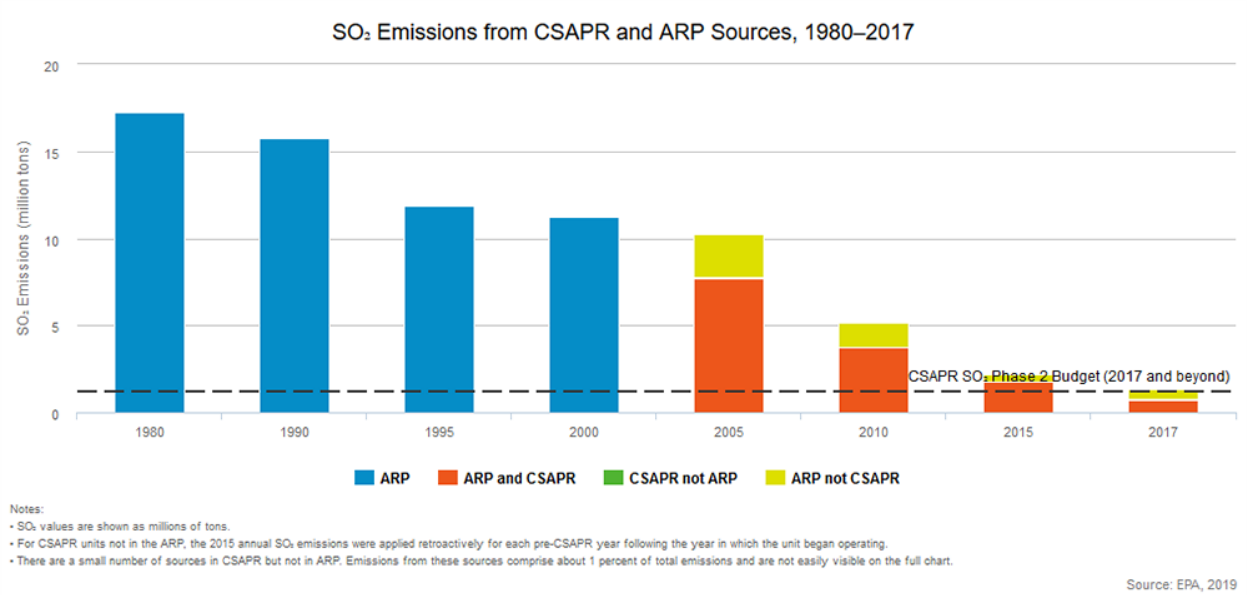

Figure 1. SO_2 Emissions from CSAPR and ARP Sources, 1980–2017

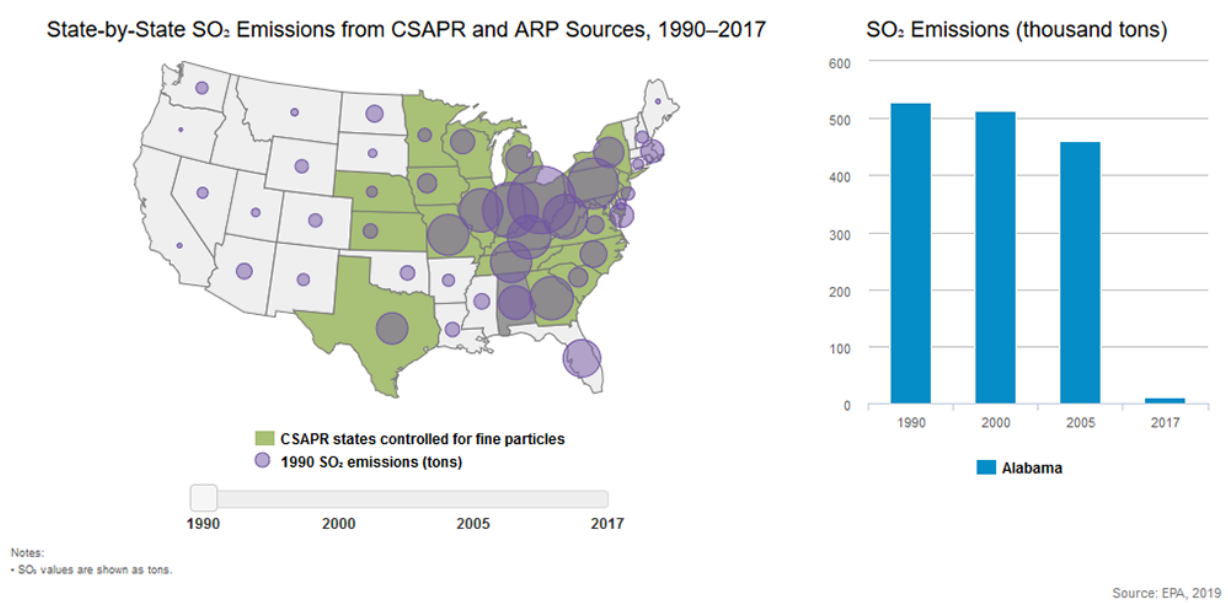

Figure 2. State-by-State SO_2 Emissions from CSAPR and ARP Sources, 1990–2017

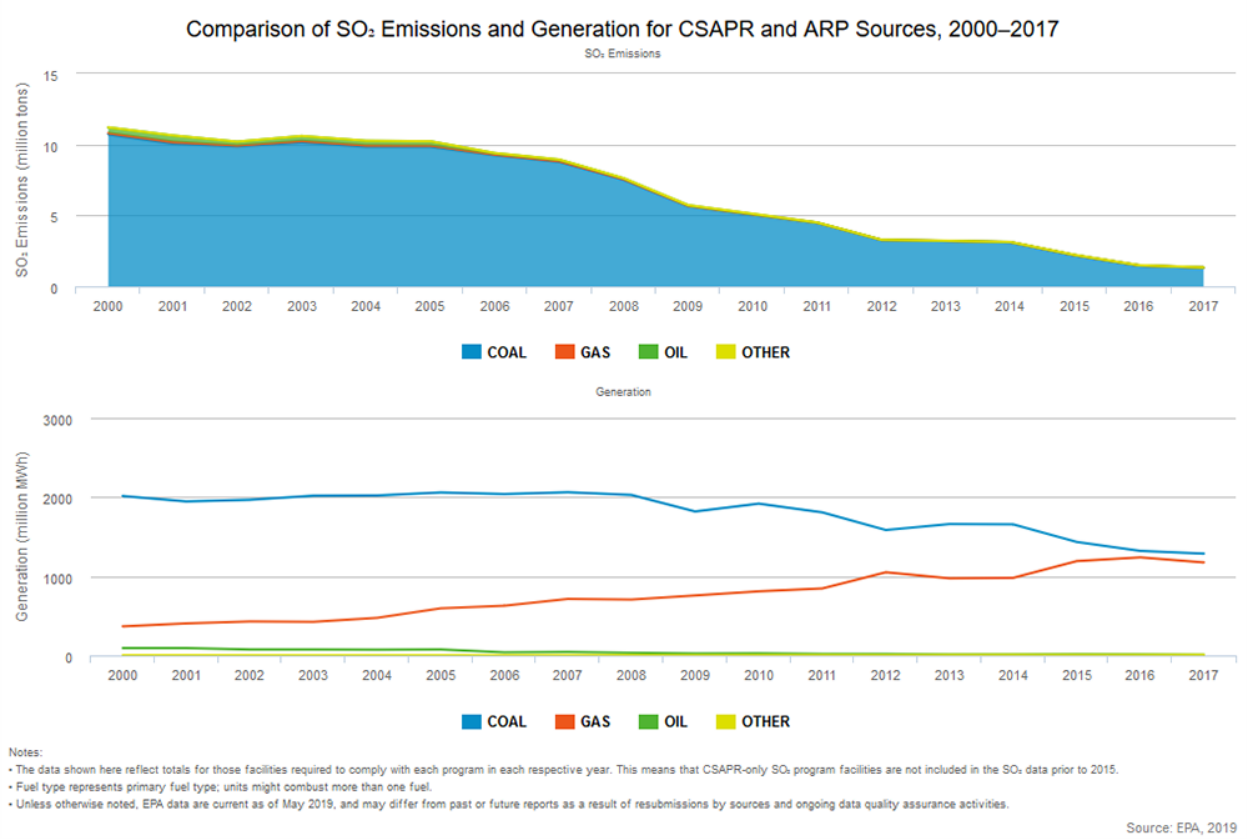

Figure 3. Comparison of SO_2 Emissions and Generation for CSAPR and ARP Sources, 2000–2017

CSAPR and ARP SO_2 Emissions Trends, 2017

	SO_2 Emissions (thousand tons)				SO_2 Rate (lb/mmBtu)			
Primary Fuel	**2000**	**2005**	**2010**	**2017**	**2000**	**2005**	**2010**	**2017**
Coal	10,708	9,835	5,051	1,316	1.04	0.95	0.53	0.14
Gas	108	91	19	8	0.06	0.03	0.01	0.03
Oil	384	292	28	2	0.73	0.70	0.19	0.11
Other	1	4	22	12	0.20	0.27	0.57	0.10
Total / Average	**11,201**	**10,222**	**5,120**	**1,338**	**0.88**	**0.75**	**0.39**	**0.09**

Notes:
- The data shown here reflect totals for those facilities required to comply with each program in each respective year. This means that CSAPR-only SO_2 program facilities 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 facility influences the annual emission rate in proportion to its heat input, and heat input is unevenly distributed across the fuel categories.
- Unless otherwise noted, EPA data are current as of May 2019, and may differ from past or future reports as a result of resubmissions by sources and ongoing data quality assurance activities.

Source: EPA, 2019

Figure 4. CSAPR and ARP SO_2 Emissions Trends, 2017

Annual Nitrogen Oxides

Highlights

Overall Results

- Annual NO_X emissions have declined dramatically under the ARP, CAIR, and CSAPR programs, with the majority of 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 2017.

Annual NO_X Emissions Trends

- **ARP:** Units in the ARP NO_X program emitted 1.0 million tons of NO_X emissions in 2017. Sources reduced emissions by 7.1 million tons from the projected level in 2000 without ARP, over three times the program's NO_X emission reduction objective.
- **CSAPR and ARP:** In 2017, the third year of operation of the CSAPR NO_X annual program, sources in both the CSAPR NO_X annual program and ARP together emitted 1.1 million tons, a reduction of 5.4 million tons (84 percent reduction) from 1990 levels, 4.1 million tons (79 percent reduction) from 2000, and 2.7 million tons (71 percent reduction) from 2005 levels.
- **CSAPR:** Emissions from CSAPR NO_X annual program sources alone were 586,000 tons in 2017. This is about 1.6 million tons (73 percent) lower than in 2005 and 480,000 tons (45 percent) below the CSAPR NO_X annual program's 2017 regional budget of 1,069,256 tons.

Annual NO_X State-by-State Emissions

- **CSAPR and ARP:** From 1990 to 2017, annual NO_X emissions in ARP and the CSAPR NO_X program dropped in 47 states plus Washington, D.C. by a total of approximately 5.4 million tons. In contrast, annual emissions increased in one state (Idaho) by 200 tons from 1990 to 2017.
- **CSAPR:** Twenty-one states had emissions below their CSAPR 2017 allowance budgets, collectively by 480,000 tons. A single state (Missouri) exceeded its 2017 budget by 950 tons.

Annual NO_X Emission Rates

- In 2017, the CSAPR and ARP average annual NO_X emission rate was 0.10 lb/mmBtu, a 64 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 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
- Air Markets Program Data (AMPD) https://ampd.epa.gov/ampd/
- Acid Rain Program (ARP) https://www.epa.gov/airmarkets/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

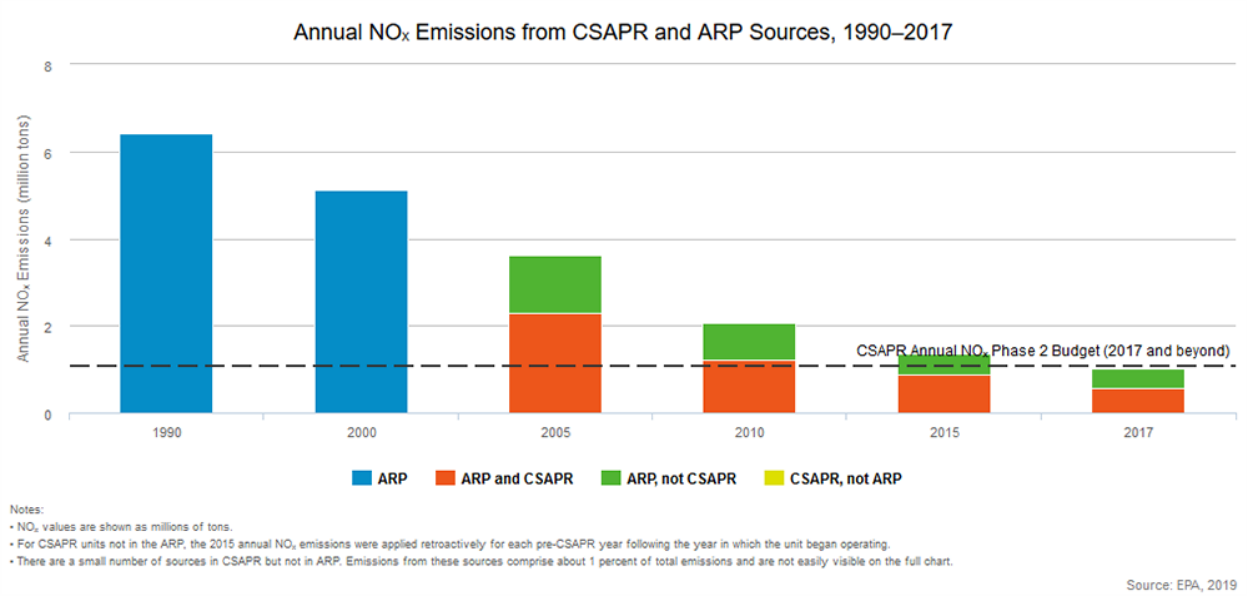

Figure 1. Annual NO_X Emissions from CSAPR and ARP Sources, 1990–2017

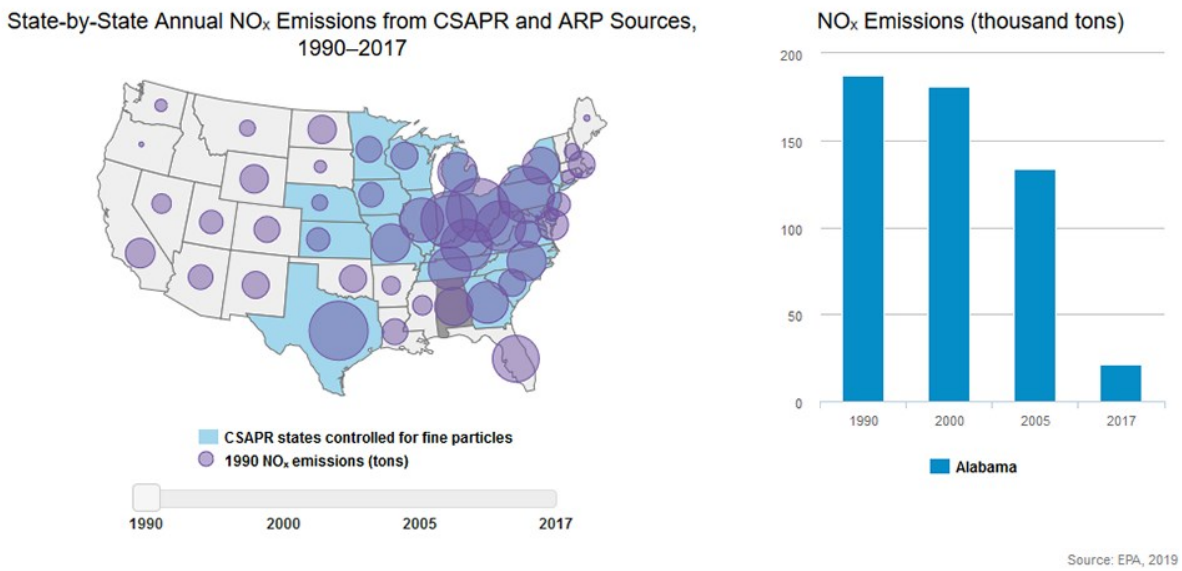

Figure 2. State-by-State Annual NO_X Emissions from CSAPR and ARP Sources, 1990-2017

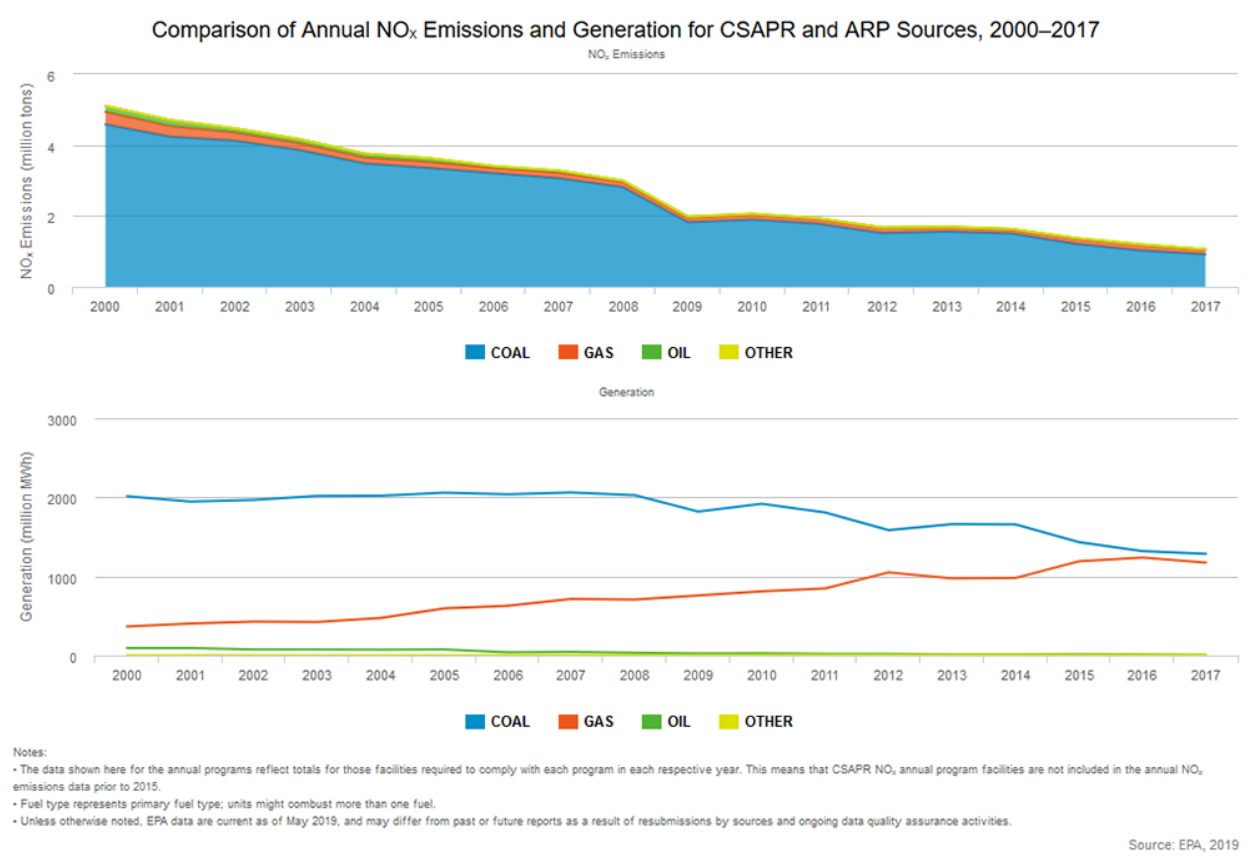

Figure 3. Comparison of Annual NO_X Emissions and Generation for CSAPR and ARP Sources, 2000–2017

CSAPR and ARP Annual NO_x Emissions Trends, 2017

	NO_x Emissions (thousand tons)				NO_x Rate (lb/mmBtu)			
Primary Fuel	**2000**	**2005**	**2010**	**2017**	**2000**	**2005**	**2010**	**2017**
Coal	4,587	3,356	1,896	918	0.44	0.32	0.20	0.14
Gas	355	167	142	131	0.18	0.06	0.04	0.03
Oil	162	104	20	4	0.31	0.25	0.13	0.11
Other	2	6	5	7	0.24	0.42	0.13	0.10
Total / Average	**5,106**	**3,633**	**2,063**	**1,060**	**0.40**	**0.27**	**0.16**	**0.09**

Notes:
- The data shown here reflect totals for those facilities required to comply with each program in each respective year. This means that CSAPR-only annual NO_x program facilities 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 facility influences the annual emission rate in proportion to its heat input, and heat input is unevenly distributed across the fuel categories.
- Unless otherwise noted, EPA data are current as of May 2019, and may differ from past or future reports as a result of resubmissions by sources and ongoing data quality assurance activities.

Source: EPA, 2019

Figure 4. CSAPR and ARP Annual NO_X Emissions Trends, 2017

Ozone Season Nitrogen Oxides

Highlights

Overall Results

- Ozone season NO_X emissions have declined dramatically under ARP, NBP, CAIR, and CSAPR programs.
- 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 program. 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 2017.

Ozone Season NO_X Emissions Trends

- Units in the CSAPR NO_X ozone season program emitted 300,000 tons in 2017
  - A reduction of 1.7 million tons (85 percent) from 1990,
  - 1.0 million tons lower (76 percent reduction) than in 2000 (before implementation of NBP),
  - 350,000 tons lower (53 percent reduction) than in 2005 (before implementation of CAIR), and
  - 87,000 tons lower (22 percent reduction) than in 2015.
- In 2017, CSAPR NO_X ozone season program emissions were 11 percent below the regional emission budget of 340,505 tons (24,041 tons for Group 1 and 316,464 tons for Group 2).

Ozone Season NO_X State-by-State Emissions

- Between 2005 and 2017, ozone season NO_X emissions from CSAPR sources fell in every state participating in the CSAPR NO_X ozone season program.
- Seventeen states had emissions below their CSAPR 2017 allowance budgets, collectively by about 43,000 tons. Six states (Arkansas, Ohio, Tennessee, Texas, West Virginia, and Wisconsin) exceeded their 2017 budgets by about 3,900 tons combined.

Ozone Season NO_X Emission Rates

- In 2017, the average NO_X ozone season emission rate fell to 0.08 lb/mmBtu for CSAPR ozone season program states and 0.09 lb/mmBtu nationally. This represents a 50 and 56 percent reduction, respectively, from 2005 emission rates, with the majority of reductions coming from coal-fired units.

- 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 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 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.

More Information

- Power Plant Emission Trends https://www.epa.gov/airmarkets/power-plant-emission-trends
- Air Markets Program Data (AMPD) https://ampd.epa.gov/ampd/
- 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

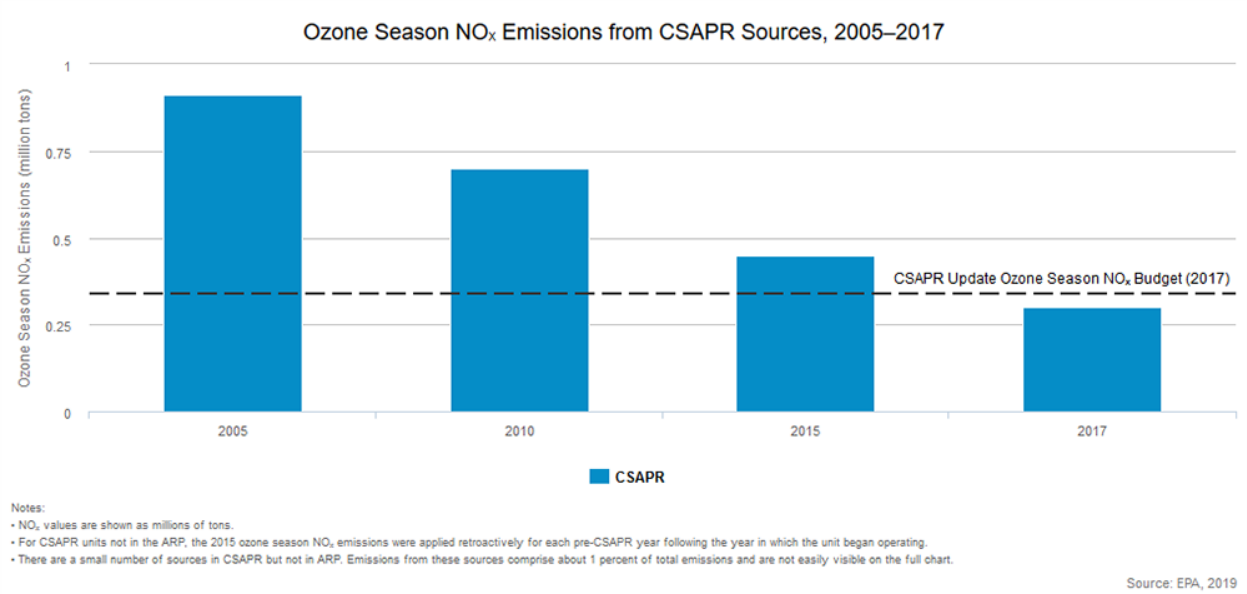

Figure 1. Ozone Season NO_X Emissions from CSAPR Sources, 2005–2017

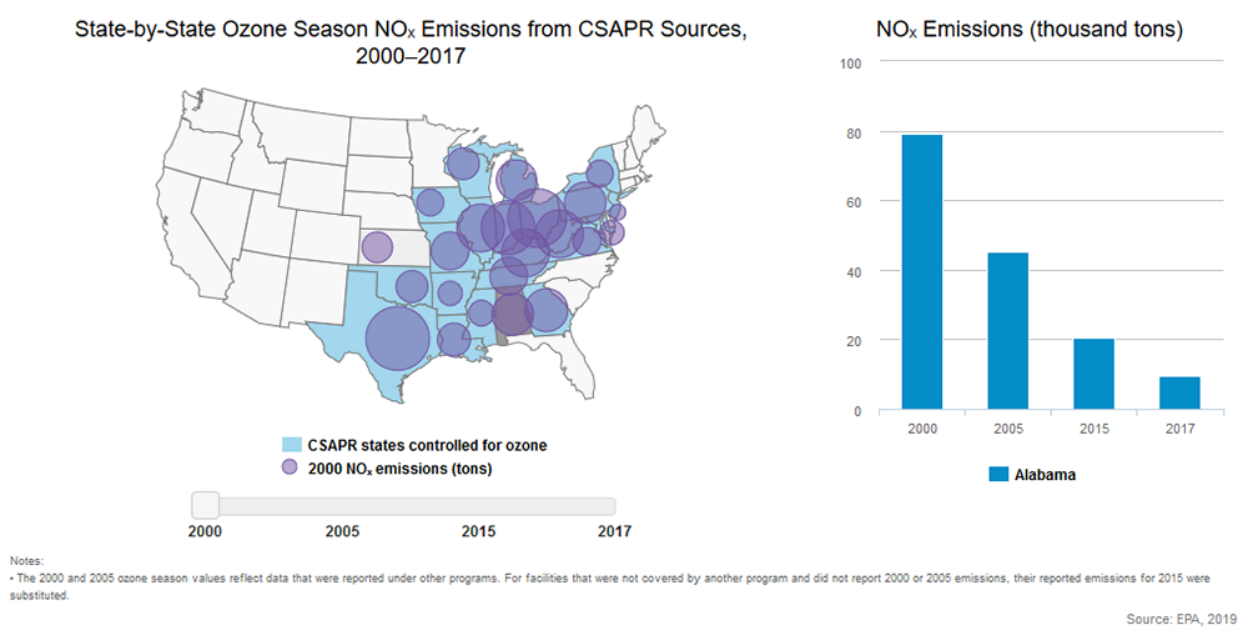

Figure 2. State-by-State Ozone Season NO_X Emissions from CSAPR Sources, 2000–2017

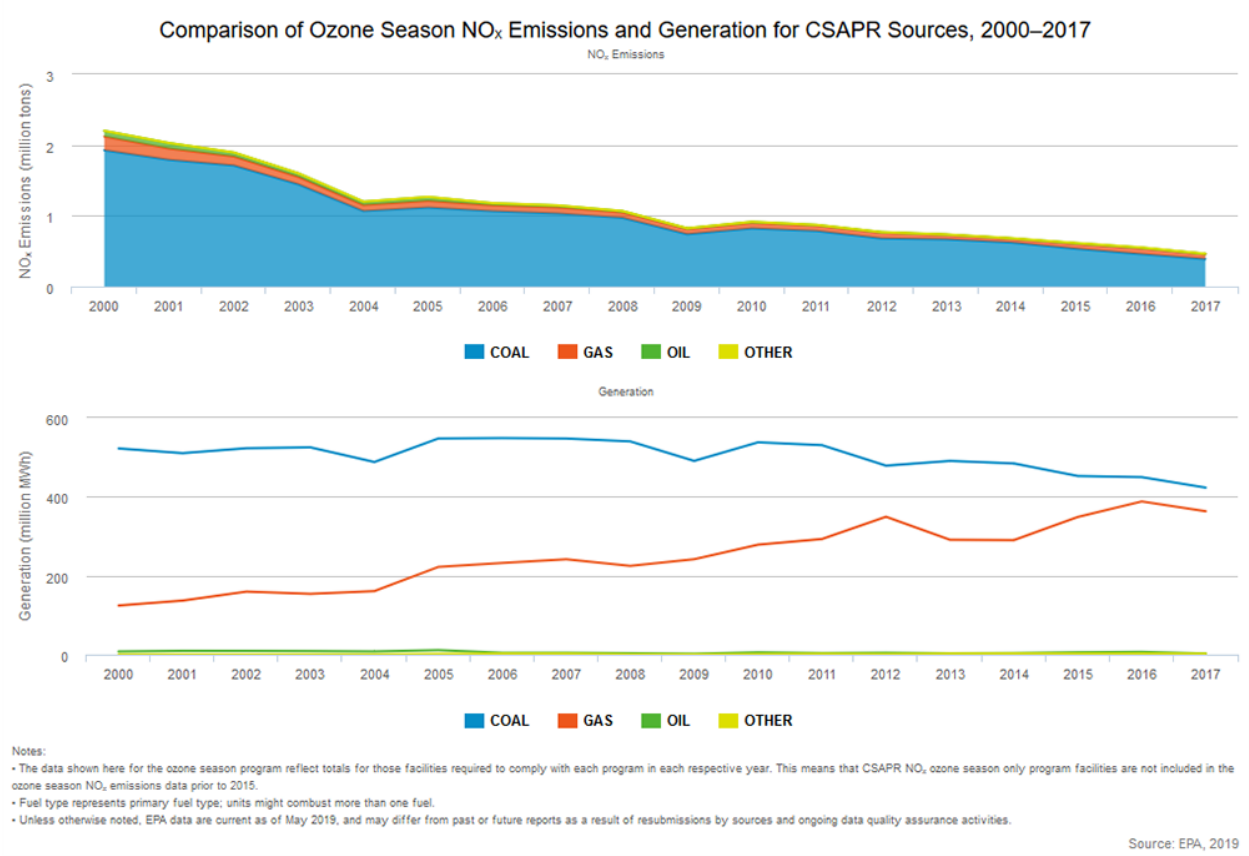

Figure 3. Comparison of Ozone Season NO_X Emissions and Generation for CSAPR Sources, 2000–2017

CSAPR Ozone Season NO_X Emissions Trends, 2017

	Ozone Emissions (thousand tons)				Ozone Rate (lb/mmBtu)			
Primary Fuel	**2000**	**2005**	**2010**	**2017**	**2000**	**2005**	**2010**	**2017**
Coal	1,926	1,117	821	389	0.43	0.25	0.19	0.13
Gas	195	95	78	69	0.19	0.06	0.04	0.03
Oil	79	53	13	2	0.31	0.25	0.13	0.10
Other	1	2	2	3	0.21	0.39	0.11	0.08
Total / Average	**2,201**	**1,267**	**915**	**463**	**0.38**	**0.20**	**0.15**	**0.09**

Notes:
- The data shown here reflect totals for those facilities required to comply with each program in each respective year. This means that CSAPR NO_x ozone season only program facilities 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 facility influences the annual emission rate in proportion to its heat input, and heat input is unevenly distributed across the fuel categories.
- Unless otherwise noted, EPA data are current as of May 2019, and may differ from past or future reports as a result of resubmissions by sources and ongoing data quality assurance activities.

Source: EPA, 2019

Figure 4. CSAPR Ozone Season NO_X Emissions Trends, 2017

Mercury and Air Toxics

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 HAP. 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 2017.

Mercury and Hazardous Air Pollutant Emission Trends

- Compared to 2010[1], units covered under MATS in 2017 emitted
  - 25 fewer tons of mercury (86% reduction),[2]
  - 120,877 fewer tons of acid gases (96% reduction),[3] and
  - 949 fewer tons of non-mercury metals (81% reduction).[4]

Reducing Mercury Emissions from Coal-Fired Power Plants Since 2010

Over the past decade, the power sector has undergone significant changes in the mix of generating sources (e.g., coal, gas, and renewables), as well as in the prevalence of pollution control technologies. These changes have led to substantial decreases in mercury emissions, from about 29 tons in 2010 to 4 tons in 2017. These drivers are explained in more detail below.

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[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.

[2] Certain units did not report from January-May 2017. Also, data do not include emissions from low emitting electric generating units (LEEs). Mercury emissions from 87 LEEs are estimated to be 326 pounds. Emissions from 24 additional LEEs are not available.

[3] Most coal- and oil- fired EGUs report emissions of SO_2 as a surrogate to demonstrate compliance with standards for the acid gas HAP. The EPA used those SO_2 emissions to estimate emission of the acid gas HAP (hydrogen chloride and hydrogen fluoride).

[4] Most coal- and oil- fired EGUs report emissions of filterable particulate matter (fPM) as a surrogate to demonstrate compliance with standards for the non-mercury metal HAP. The EPA used those fPM emissions to estimate emission of the non-mercury metal HAP (e.g., lead, arsenic, selenium, etc.).

Decreasing Coal-Fired Generation

Coal-fired EGUs are the main source of mercury emissions in the power sector, so reductions in the amount of generation from coal will have an impact on power sector mercury emissions. Reductions in coal-fired generation at the EGU-level can occur in a number of ways: decreased utilization of an existing EGU, retirement of an EGU, or conversion from coal to other fuels with lower or no mercury emissions. The following trends in coal-fired generation since 2010 have contributed to the observed reduction of mercury emissions:

- Electricity generation from all coal-fired EGUs decreased by approximately one-third between 2010 and 2017.
- In 2010, nearly 10 percent of electricity generation from coal-fired EGUs was from 259 units that have since retired.
- In addition, 74 EGUs that were coal-fired in 2010 have been converted to burn natural gas or other fuel sources (which do not emit as much mercury as coal).

Controlling Mercury Emissions at Coal-Fired EGUs

Coal-fired EGUs have also installed post-combustion pollution control technologies, like activated carbon injection (ACI) and flue-gas desulfurization (FGD), to comply with air quality regulatory programs. ACI controls are designed to specifically capture mercury, while FGD are designed to reduce sulfur dioxide (SO_2) and other acid gases, but, in certain situations, can also capture mercury effectively. These technologies can work independently or in combination with other technologies to improve mercury control. Circulating fluidized bed (CFB) boilers can also reduce emissions of SO_2 through the addition of lime or limestone during the combustion process or downstream using a dry sorbent injection system. The following trends in pollution control technology have contributed to the observed reduction of mercury emissions:

- Half of all electricity generation from coal-fired EGUs in 2010 was from units that had installed a post-combustion control device, like ACI or FGD; in 2017, that share increased to more than 90 percent.
- Generation from coal-fired EGUs that had no post-combustion pollution control technology declined 91 percent between 2010 and 2017.
- In 2010, only 4 percent of coal generation was from units that reported using ACI; in 2017, that share increased to nearly 40 percent.

Background Information

Hazardous air pollutants (HAPs) emitted by power plants include mercury, acid gases (e.g., HCl, HF), 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 cancer and immune system damage, along with neurological, reproductive, developmental, 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 1990 Clean Air Act amendments. The MATS emission standards were established using data from a 2010 information collection request (ICR) that was sent to selected coal- and oil- fired EGUs.

More Information

- Air Markets Program Data (AMPD) https://ampd.epa.gov/ampd/
- MATS https://www.epa.gov/mats
- HAPs https://www.epa.gov/haps

Figures

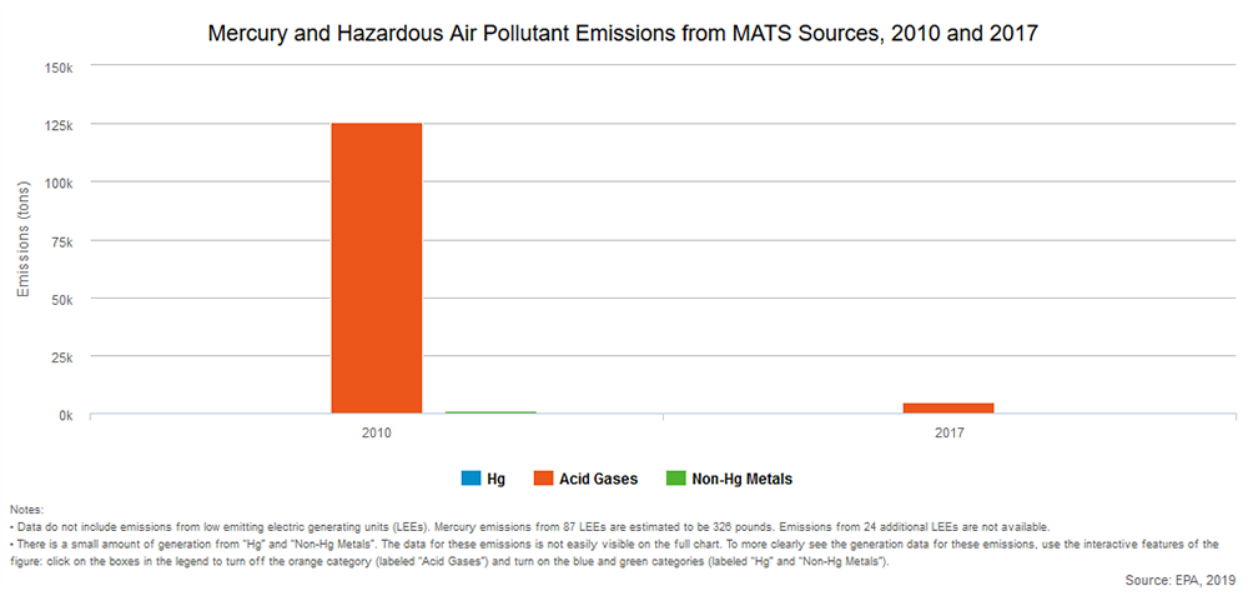
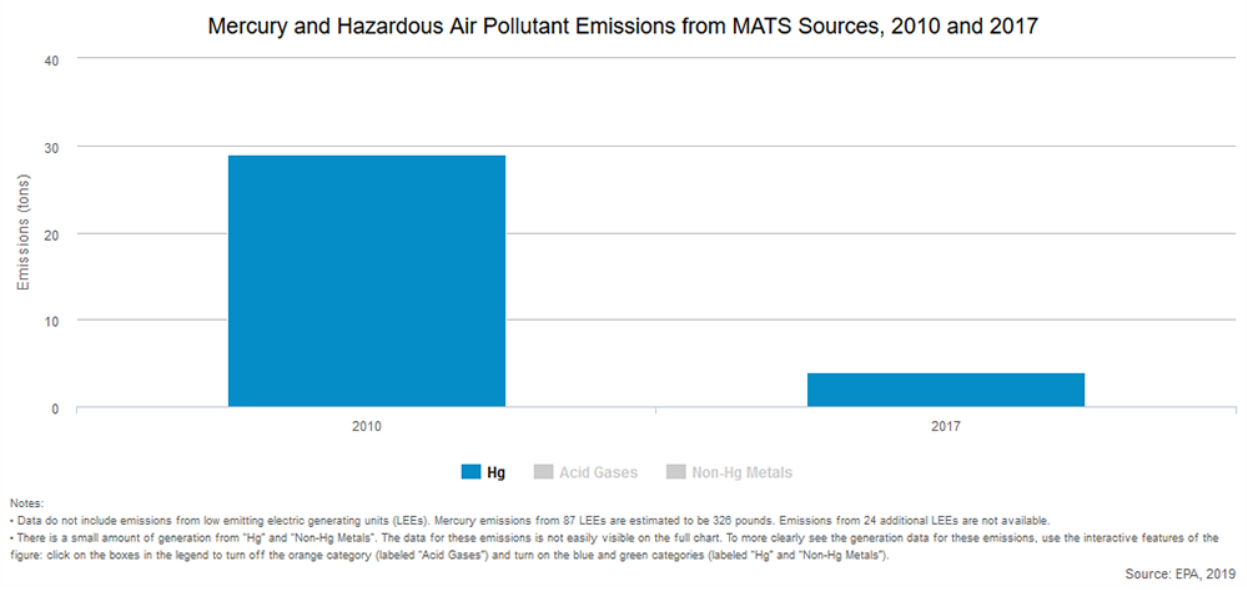


Figure 1. Mercury and Hazardous Air Pollutant Emissions from MATS Sources, 2010 and 2017



Mercury and Hazardous Air Pollutant Emission Trends, 2017

Pollutant	2010 Emissions (tons)	2017 Emissions (tons)	Reduction (%)
Hg	29	4	86%
Acid Gases	125,708	4,831	96%
Non-Hg Metals	1,170	221	81%
Organic HAP	Not Available	< 3	Not Available

Notes:
• Data do not include emissions from low emitting electric generating units (LEEs). Mercury emissions from 87 LEEs are estimated to be 326 pounds. Emissions from 24 additional LEEs are not available.
• MATS units could request up to two one-year compliance extensions under the rule. Units under this extension were not required to report emissions and comply with the standards until April of 2017.

Source: EPA, 2019

Figure 2. Mercury and Hazardous Air Pollutant Emission Trends, 2017

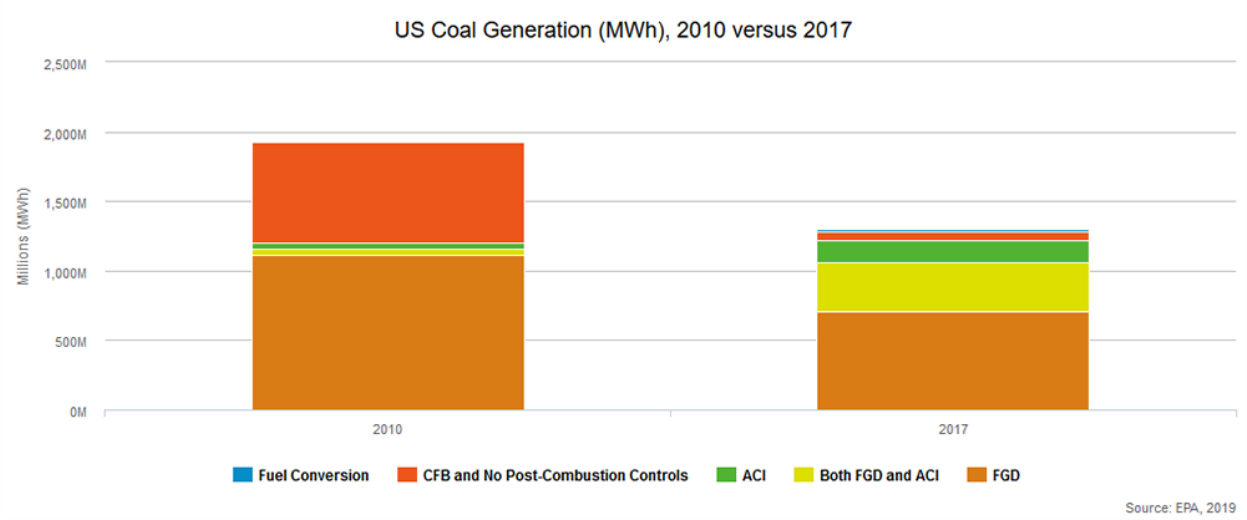


Figure 3. US Coal Generation (MWh), 2010 versus 2017

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. 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 is critical to ensure program results. 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 76 percent of coal-fired units and 83 percent of coal-fired electricity generation, measured in megawatt hours, or MWh, in 2017.
- In 2017, 30 percent of 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

- Seventy-nine percent of fossil fuel-fired generation (as measured in megawatt hours, or MWh) was produced by units with advanced pollution controls (either selective catalytic reduction [SCR] or selective non-catalytic reduction [SNCR]).
- In 2017, the 298 coal-fired units with advanced add-on controls (either SCRs or SNCRs) generated 77 percent of coal-fired electricity. At oil- and natural gas-fired units, SCR- and SNCR-controlled units produced 82 percent of generation.
- In 2017, 69 percent of CSAPR units (including 100 percent of coal-fired units) monitored NO_X emissions using CEMS. Ninety-nine percent of NO_X emissions were measured by CEMS.

CSAPR NO_X Ozone Season Program Controls and Monitoring

- Seventy-one percent of all the fossil fuel-fired generation (as measured in megawatt hours, or MWh) was produced by units with advanced pollution controls (either SCRs or SNCRs).
- In 2017, 278 units with advanced add-on controls (either SCR or SNCR) accounted for 71 percent of coal-fired generation. At oil- and natural gas-fired units, SCR- and SNCR-controlled units produced 71 percent of generation.
- In 2017, 75 percent of CSAPR units (including 100 percent of coal-fired units) monitored ozone season NO_X emissions using CEMS. Ninety-nine percent of ozone season NO_X emissions were measured by CEMS.

MATS Controls and Monitoring

- In 2017, 530 units at 235 facilities reported continuous mercury emissions data to EPA under MATS. Fifty-six percent of MATS units reporting mercury emissions and 44 percent of the

electricity generation at MATS reporting units used activated carbon injection (ACI), a mercury-specific pollution control method to reduce mercury emissions and SO_2.

- About 78 percent of units that reported continuous mercury emissions data (or 87 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 2017. These controls also reduce other pollutants, including SO_2. Some oil-fired units are able to 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 ton of emissions measured at one facility is equivalent to a ton measured at a different facility. EPA conducts comprehensive electronic and field data audits to validate the reported data. While some units with low levels of SO_2 and 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.

Under MATS measurement regulations (40 CFR part 63), affected units can continuously measure emissions using CEMS for mercury, SO_2, HCl, PM, and HF, or sorbent traps for Hg. Some qualifying units with low emissions can conduct periodic stack tests in lieu of continuous monitoring.

SO_2 Emission Controls

Sources in ARP and the CSAPR SO_2 program 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 – also known as scrubbers – 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 ARP and the CSAPR NO_X annual and ozone season programs have a variety of options by which to reduce NO_X emissions, including advanced post-combustion 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 (scrubbers), 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
- Air Markets Program Data (AMPD) https://ampd.epa.gov/ampd/
- Emissions Monitoring https://www.epa.gov/airmarkets/emissions-monitoring
- Plain English guide to 40 CRF 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

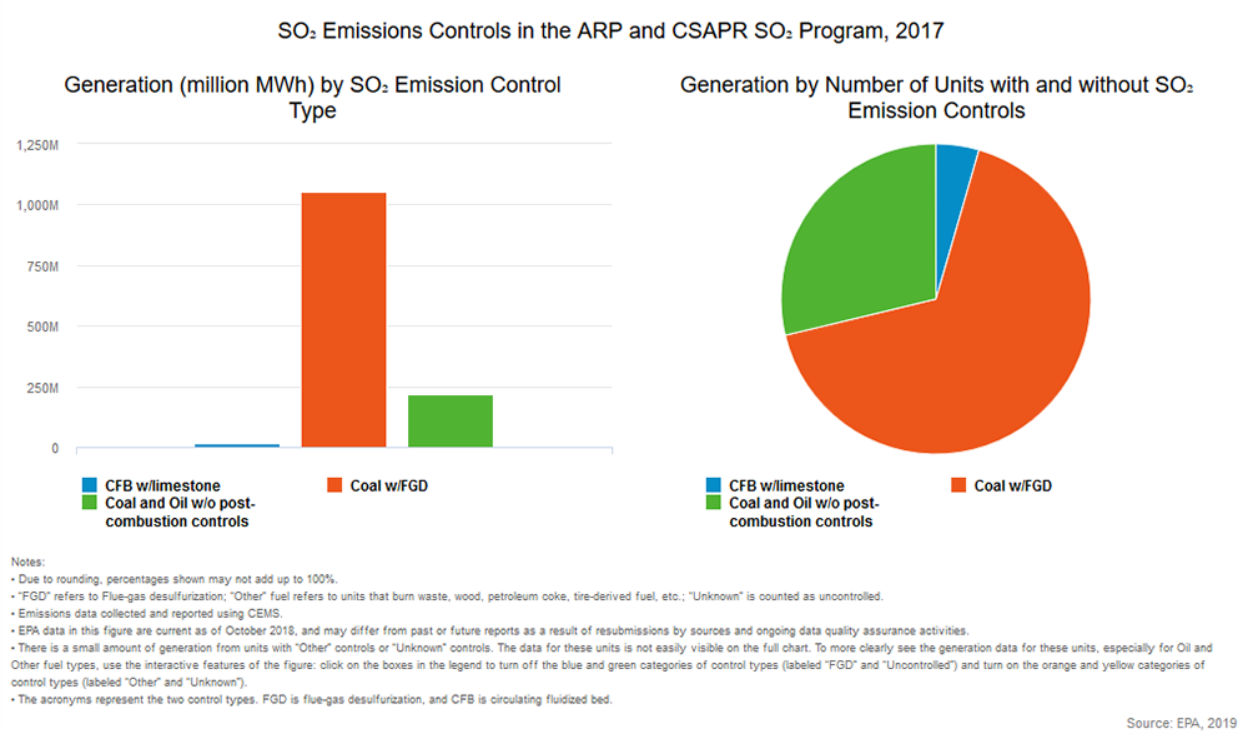


Figure 1. SO_2 Emissions Controls in the ARP and CSAPR SO_2 Program, 2017

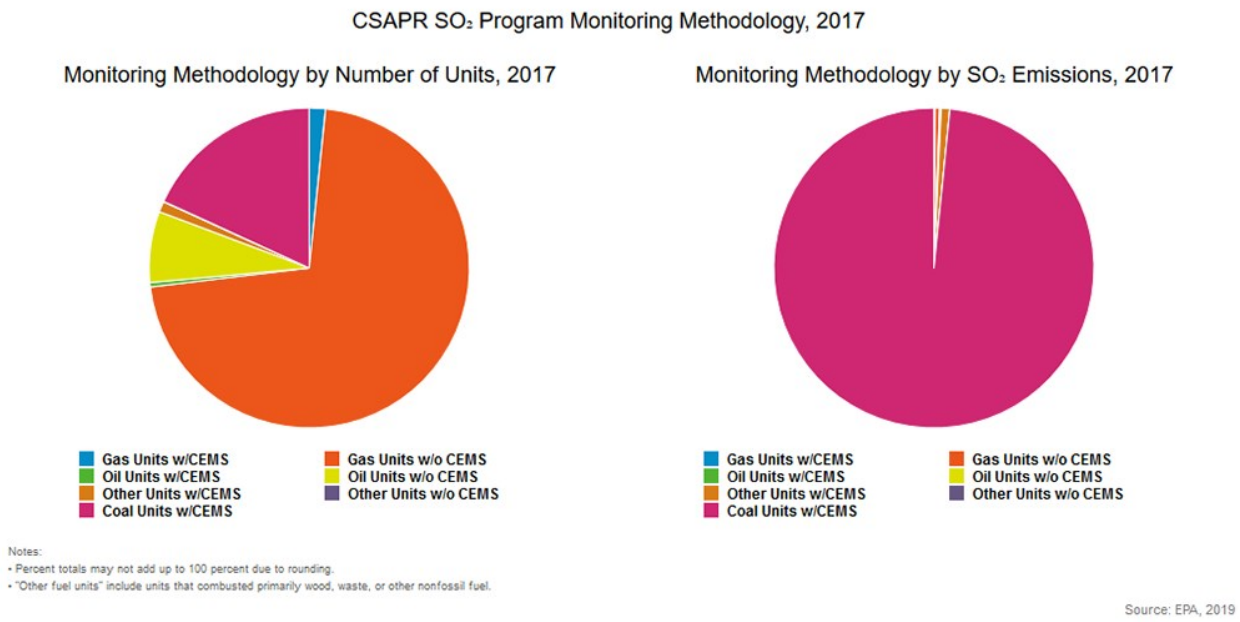


Figure 2. CSAPR SO_2 Program Monitoring Methodology, 2017

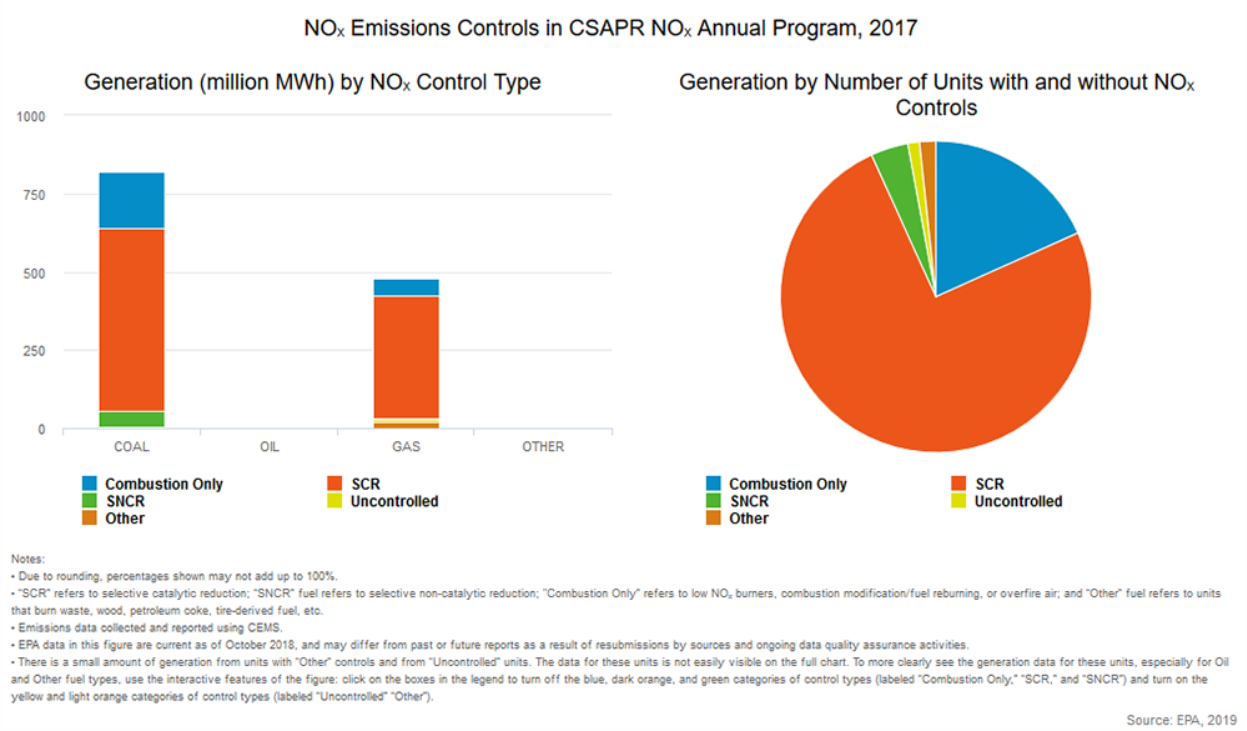


Figure 3. NO_X Emissions Controls in CSAPR NO_X Annual Program, 2017

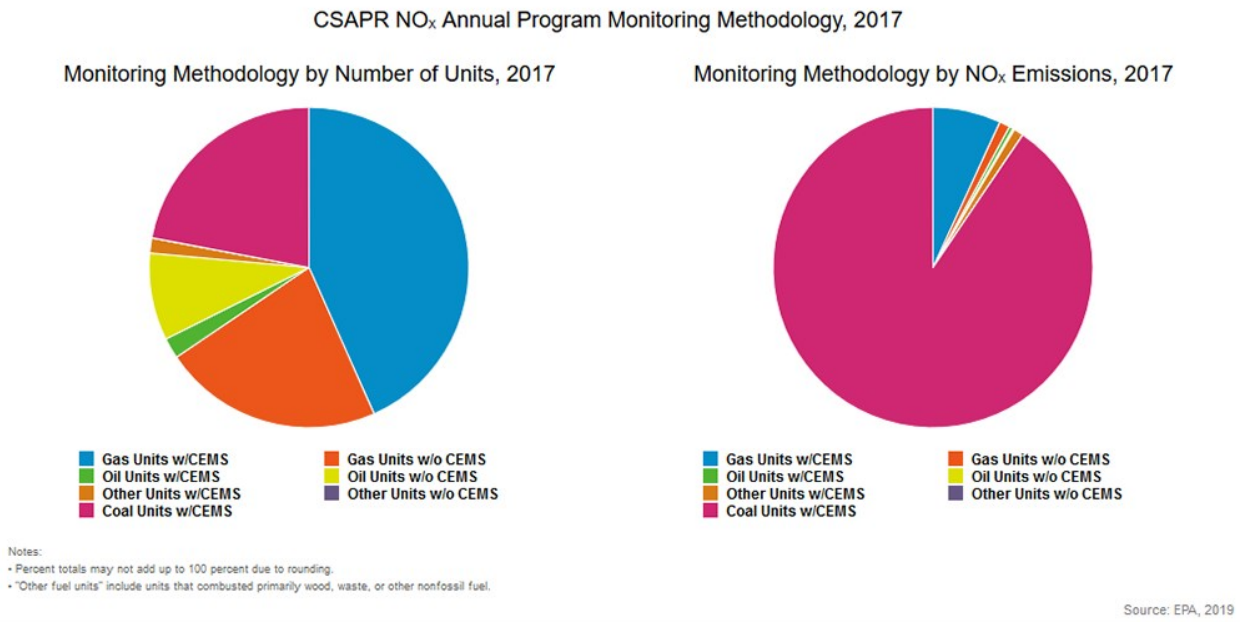


Figure 4. CSAPR NO_X Annual Program Monitoring Methodology, 2017

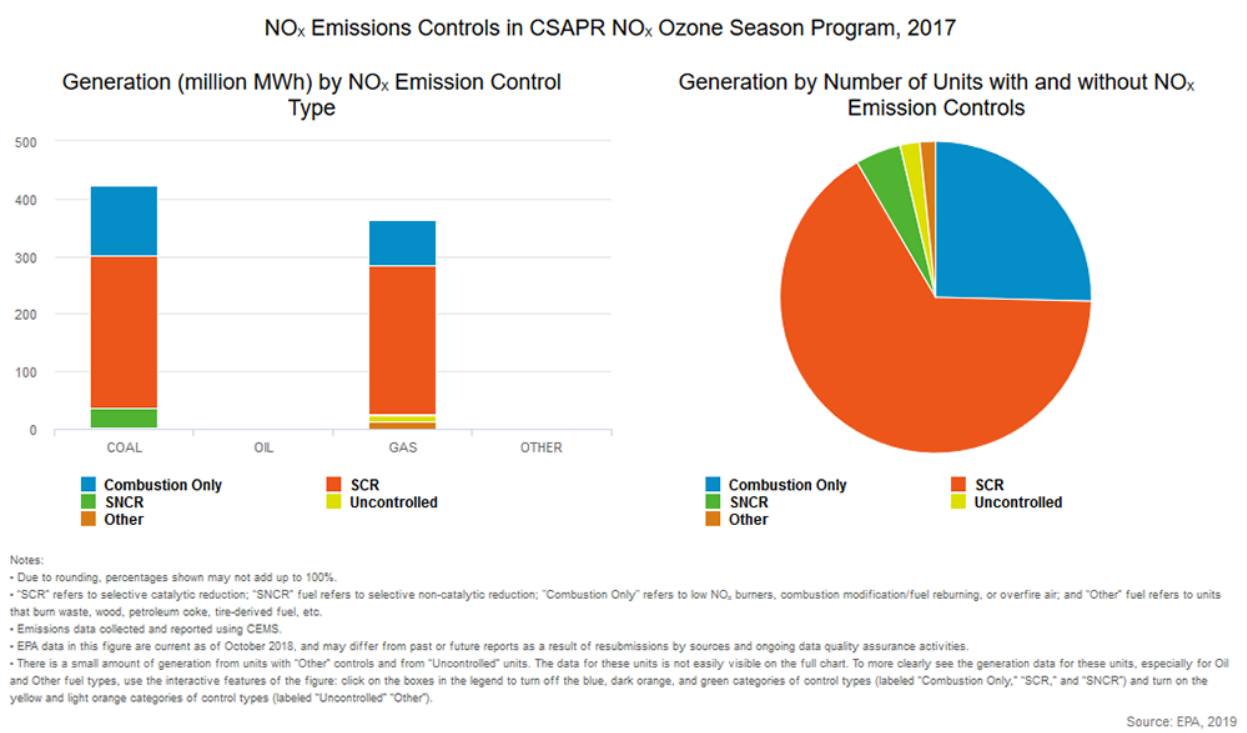


Figure 5. NO_X Emissions Controls in the CSAPR NO_X Ozone Season Program, 2017

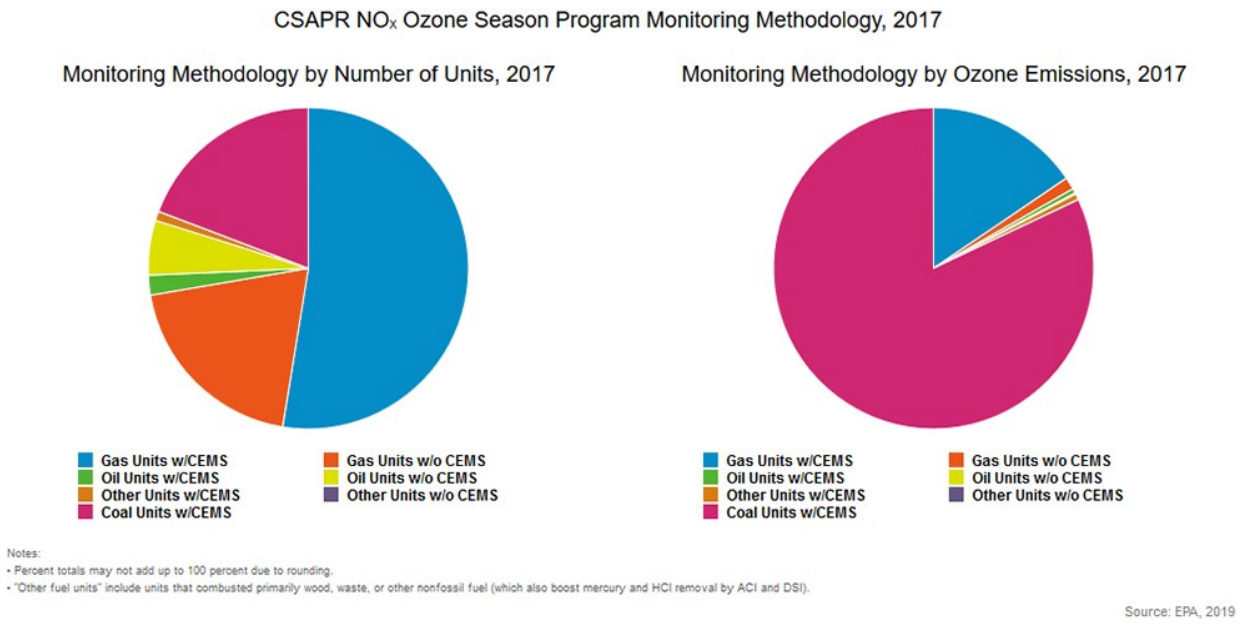


Figure 6. CSAPR NO_X Ozone Season Program Monitoring Methodology, 2017

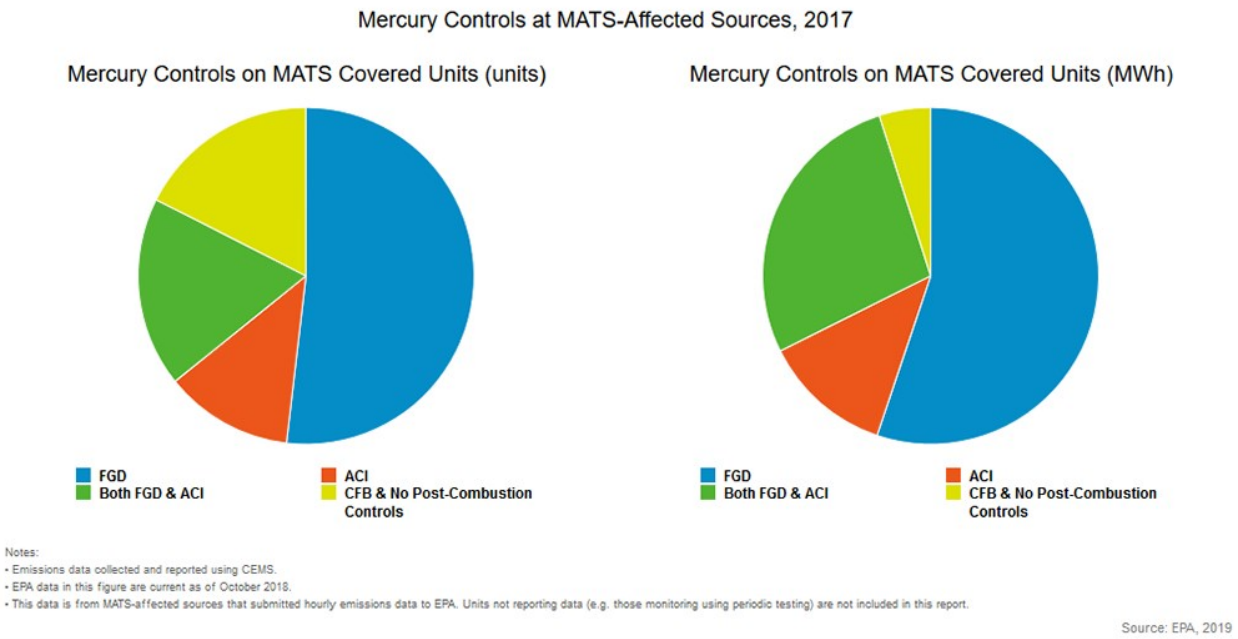


Figure 7. Mercury Controls at MATS-Affected Sources, 2017

Mercury Compliance and Monitoring Methods used by Units Reporting Hourly Data under MATS, 2017

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
530	235	160	370	232	255	43

Notes:
- Emissions data collected and reported using CEMS.
- EPA data in this figure are current as of October 2018.
- This data is from MATS-affected sources that submitted hourly emissions data to EPA and does not show complete data from all MATS-affected sources because many sources received compliance extensions or chose to demonstrate compliance through methods other than continuously monitored emissions.

Source: EPA, 2019

Figure 8. Mercury Compliance and Monitoring Methods used by Units Reporting Hourly Data under MATS, 2017

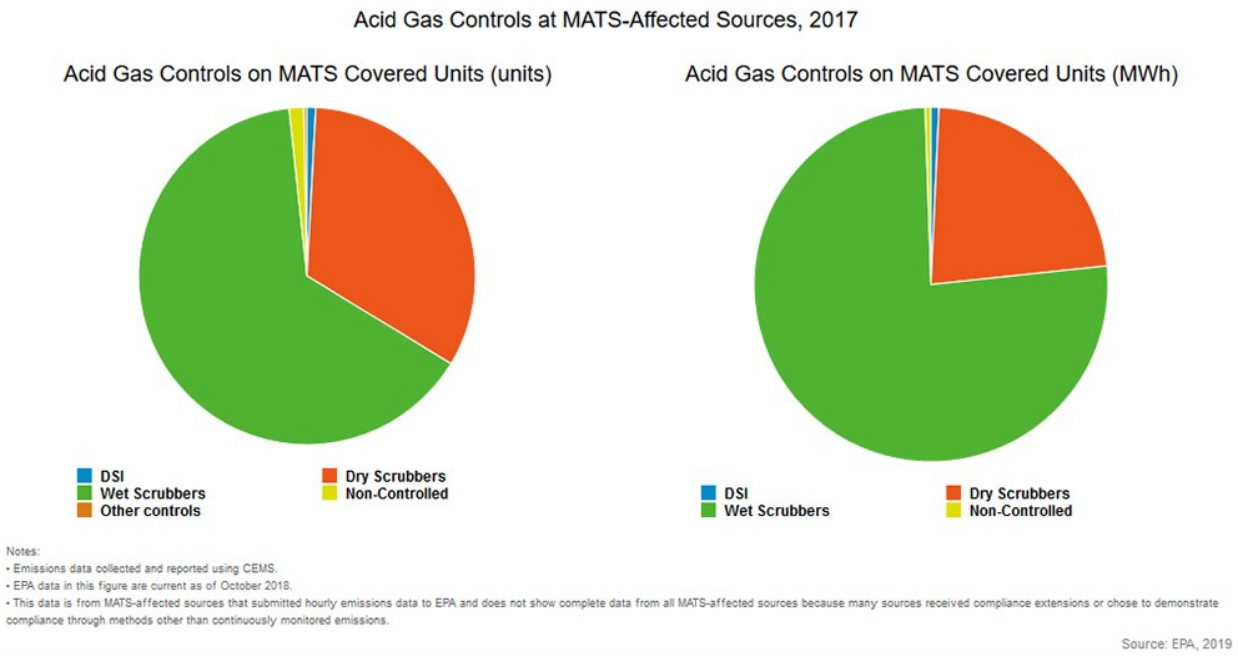


Figure 9. Acid Gas Controls at MATS-Affected Sources, 2017

Acid Gas Compliance and Monitoring Methods used by Units Reporting Hourly Data under MATS, 2017

Acid Gas	Reporting Hourly data		Compliance Method (# of Units)		Monitoring Method
	Number of reporting units	Number of reporting facilities	Electrical Output	Heat Input	CEMS
HCl	4	3	1	3	4
SO2 as a surrogate for HCl	354	168	6	348	354

Notes:
- Emissions data collected and reported using CEMS.
- EPA data in this figure are current as of October 2018.
- This data is from MATS-affected sources that submitted hourly emissions data to EPA and does not show complete data from all MATS-affected sources because many sources received compliance extensions or chose to demonstrate compliance through methods other than continuously monitored emissions.

Source: EPA, 2019

Figure 10. Acid Gas Compliance and Monitoring Methods used by Units Reporting Hourly Data under MATS, 2017

Chapter 5: Program Compliance

This section shows how the Acid Rain Program (ARP) and Cross-State Air Pollution Rule (CSAPR) allowances were used for compliance under the allowance trading programs in 2017. In contrast to ARP and CSAPR, MATS is issued under section 112 of the Clean Air Act and is not an allowance trading program.

Highlights

ARP SO_2 Program

- The reported 2017 SO_2 emissions by ARP sources totaled 1,318,755 tons.
- Over 47 million SO_2 allowances were available for compliance (9 million vintage 2017 and nearly 38 million banked from prior years).
- EPA deducted just over 1.3 million allowances for ARP compliance. After reconciliation, over 46 million ARP SO_2 allowances were banked and carried forward to the 2018 ARP compliance year.
- All ARP SO_2 facilities were in compliance in 2017 (holding sufficient allowances to cover their SO_2 emissions).

CSAPR SO_2 Group 1 Program

- The reported 2017 SO_2 emissions by CSAPR Group 1 sources totaled 653,658 tons.
- Over 4.2 million SO_2 Group 1 allowances were available for compliance.
- EPA deducted over 653,000 allowances for CSAPR SO_2 Group 1 compliance. After reconciliation, over 3.6 million CSAPR SO_2 Group 1 allowances were banked and carried forward to the 2018 compliance year.
- All CSAPR SO_2 Group 1 facilities were in compliance in 2017 (holding sufficient allowances to cover their SO_2 emissions).

CSAPR SO_2 Group 2 Program

- The reported 2017 SO_2 emissions by CSAPR Group 2 sources totaled 99,739 tons.
- Over 1.5 million SO_2 Group 2 allowances were available for compliance.
- EPA deducted just under 100,000 allowances for CSAPR SO_2 Group 2 compliance. After reconciliation, over 1.4 million CSAPR SO_2 Group 2 allowances were banked and carried forward to the 2018 compliance year.
- All CSAPR SO_2 Group 2 facilities were in compliance in 2017 (holding sufficient allowances to cover their SO_2 emissions).

CSAPR NO_X Annual Program

- The reported 2017 annual NO_X emissions by CSAPR sources totaled 585,855 tons.
- Over 1.8 million NO_X Annual allowances were available for compliance.

- EPA deducted just under 586,000 allowances for CSAPR NO_X Annual compliance. After reconciliation, almost 1.3 million CSAPR NO_X Annual allowances were banked and carried forward to the 2018 compliance year.
- One facility was out of compliance with the CSAPR NO_X Annual program and had 44 tons of excess emissions.

CSAPR NO_X Ozone Season Group 1 Program

- The reported 2017 ozone season NO_X emissions by CSAPR sources totaled 7,136 tons.
- Over 42,000 NO_X Ozone Season Group 1 allowances were available for compliance.
- EPA deducted over 7,000 allowances for CSAPR NO_X Ozone Season Group 1 compliance. After reconciliation, over 35,000 CSAPR NO_X Ozone Season Group 1 allowances were banked.
- All CSAPR NO_X Ozone Season Group 1 facilities were in compliance (holding sufficient allowances to cover their NO_X emissions).

CSAPR NO_X Ozone Season Group 2 Program

- The reported 2017 ozone season NO_X emissions by CSAPR sources totaled 294,468 tons.
- Just under 412,000 NO_X Ozone Season Group 2 allowances were available for compliance.
- EPA deducted over 294,000 allowances for CSAPR NO_X Ozone Season Group 2 compliance. After reconciliation, over 117,000 CSAPR NO_X Ozone Season Group 2 allowances were banked.
- All CSAPR NO_X Ozone Season Group 2 facilities were in compliance (holding sufficient allowances to cover their NO_X emissions).

Background Information

The year 2017 was the third 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 first year of compliance for the CSAPR NO_X Ozone Season Group 2 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).

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, changes due to resubmissions by sources, 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
- Air Markets Program Data (AMPD) https://ampd.epa.gov/ampd/

- Emissions Trading https://www.epa.gov/emissions-trading-resources

Figures

Acid Rain Program SO_2 Program Allowance Reconciliation Summary, 2017

Total Allowances Held (1995 - 2017 Vintage)	**47,388,615**	Held by Affected Facility Accounts	30,860,477
		Held by Other Accounts (General and Non-Affected Facility Accounts)	16,528,138
Allowances Deducted for Acid Rain Compliance*	1,339,308		
Penalty Allowance Deductions	0		
Banked Allowances	**46,049,307**	Held by Affected Facility Accounts	29,521,169
		Held by Other Accounts (General and Non-Affected Facility Accounts)	16,528,138

* Allowances deducted for ARP Compliance Includes 20,625 allowances deducted from opt-ins for reduced utilization.

ARP SO_2 Program Compliance Results

Reported Emissions (tons)	1,318,755
Compliance issues, rounding, and report resubmission adjustments (tons)	-72
Emissions not covered by allowances (tons)	0
Total allowances deducted for emissions	1,318,683

Notes:
- Compliance emissions data may vary from other report sections as a result of variation in rounding conventions, changes due to resubmissions by sources, or allowance compliance issues at certain units.
- Reconciliation and compliance data are current as of June 2018 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2019

Figure 1. Acid Rain Program SO_2 Program Allowance Reconciliation Summary, 2017

Cross-State Air Pollution Rule SO_2 Group 1 Program Allowance Reconciliation Summary, 2017

Total Allowances Held (2015 - 2017 Vintage)	**4,263,345**	**Held by Affected Facility Accounts**	**3,656,070**
		Held by Other Accounts (General, State Holding and Non-Affected Facility Accounts)	**607,275**
Allowances Deducted for Cross-State Air Pollution Rule SO_2 Group 1 Program	**653,650**		
Penalty Allowance Deductions	**0**		
Banked Allowances	**3,609,695**	**Held by Affected Facility Accounts**	**3,002,420**
		Held by Other Accounts (General, State Holding and Non-Affected Facility Accounts)	**607,275**

CSAPR SO_2 Group 1 Program Compliance Results

Reported Emissions (tons)	653,658
Compliance issues, rounding, and report resubmission adjustments (tons)	-8
Emissions not covered by allowances (tons)	0
Total allowances deducted for emissions	653,650

Notes:
- Compliance emissions data may vary from other report sections as a result of variation in rounding conventions, changes due to resubmissions by sources, or allowance compliance issues at certain units.
- Reconciliation and compliance data are current as of June 2018 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2019

Figure 2. Cross-State Air Pollution Rule SO_2 Group 1 Program Allowance Reconciliation Summary, 2017

Cross-State Air Pollution Rule SO_2 Group 2 Program Allowance Reconciliation Summary, 2017

Total Allowances Held (2015 - 2017 Vintage)	**1,554,461**	**Held by Affected Facility Accounts**	**1,186,746**
		Held by Other Accounts (General, State Holding and Non-Affected Facility Accounts)	**367,715**
Allowances Deducted for Cross-State Air Pollution Rule SO_2 Group 2 Program	**99,724**		
Penalty Allowance Deductions	**0**		
Banked Allowances	**1,454,737**	**Held by Affected Facility Accounts**	**1,087,022**
		Held by Other Accounts (General, State Holding and Non-Affected Facility Accounts)	**367,715**

CSAPR SO_2 Group 2 Program Compliance Results

Reported Emissions (tons)	99,739
Compliance issues, rounding, and report resubmission adjustments (tons)	-15
Emissions not covered by allowances (tons)	0
Total allowances deducted for emissions	99,724

Notes:
- Compliance emissions data may vary from other report sections as a result of variation in rounding conventions, changes due to resubmissions by sources, or allowance compliance issues at certain units.
- Reconciliation and compliance data are current as of June 2018 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2019

Figure 3. Cross-State Air Pollution Rule SO_2 Group 2 Program Allowance Reconciliation Summary, 2017

Cross-State Air Pollution Rule NO_x Annual Program Allowance Reconciliation Summary, 2017

Total Allowances Held (2015 - 2017 Vintage)	**1,852,814**	**Held by Affected Facility Accounts**	**1,604,243**
		Held by Other Accounts (General, State Holding and Non-Affected Facility Accounts)	**248,571**
Allowances Deducted for Cross-State Air Pollution Rule NO_x Annual Program	**585,869**		
Penalty Allowance Deductions (2018 Vintage)	**88**		
Banked Allowances	**1,266,945**	**Held by Affected Facility Accounts**	**1,018,374**
		Held by Other Accounts (General, State Holding and Non-Affected Facility Accounts)	**248,571**

CSAPR NO_x Annual Program Compliance Results	
Reported Emissions (tons)	585,855
Compliance issues, rounding, and report resubmission adjustments (tons)	58
Emissions not covered by allowances (tons)	-44
Total allowances deducted for emissions	585,869

Notes:
- Compliance emissions data may vary from other report sections as a result of variation in rounding conventions, changes due to resubmissions by sources, or allowance compliance issues at certain units.
- Reconciliation and compliance data are current as of June 2018 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2019

Figure 4. Cross-State Air Pollution Rule NO_X Annual Program Allowance Reconciliation Summary, 2017

Cross-State Air Pollution Rule NO_X Ozone Season Program Group 1 Allowance Reconciliation Summary, 2017

Total Allowances Held (2015 - 2017 Vintage)	**42,554**	**Held by Affected Facility Accounts**	**28,552**
		Held by Other Accounts (General, State Holding and Non-Affected Facility Accounts)	**14,002**
Allowances Deducted for Cross-State Air Pollution Rule NO_x Ozone Season Program Group 1	**7,093**		
Penalty Allowance Deductions	**0**		
Banked Allowances	**35,461**	**Held by Affected Facility Accounts**	**21,459**
		Held by Other Accounts (General, State Holding and Non-Affected Facility Accounts)	**14,002**

CSAPR NO_x Ozone Season Program Group 1 Compliance Results

Reported Emissions (tons)	**7,136**
Compliance issues, rounding, and report resubmission adjustments (tons)	**-43**
Emissions not covered by allowances (tons)	**0**
Total allowances deducted for emissions	**7,093**

Notes:
- Compliance emissions data may vary from other report sections as a result of variation in rounding conventions, changes due to resubmissions by sources, or allowance compliance issues at certain units.
- Reconciliation and compliance data are current as of June 2018 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2019

Figure 5. Cross-State Air Pollution Rule NO_X Ozone Season Program Group 1 Allowance Reconciliation Summary, 2017

Cross-State Air Pollution Rule NO_X Ozone Season Program Group 2 Allowance Reconciliation Summary, 2017

Total Allowances Held (2017 Vintage)	**411,931**	**Held by Affected Facility Accounts**	**382,255**
		Held by Other Accounts (General, State Holding and Non-Affected Facility Accounts)	**29,676**
Allowances Deducted for Cross-State Air Pollution Rule NO_x Ozone Season Program Group 2	**294,488**		
Penalty Allowance Deductions	**0**		
Banked Allowances	**117,443**	**Held by Affected Facility Accounts**	**87,767**
		Held by Other Accounts (General, State Holding and Non-Affected Facility Accounts)	**29,676**

CSAPR NO_x Ozone Season Program Group 2 Compliance Results

Reported Emissions (tons)	294,468
Compliance issues, rounding, and report resubmission adjustments (tons)	20
Emissions not covered by allowances (tons)	0
Total allowances deducted for emissions	294,488

Notes:
- Compliance emissions data may vary from other report sections as a result of variation in rounding conventions, changes due to resubmissions by sources, or allowance compliance issues at certain units.
- Reconciliation and compliance data are current as of June 2018 and subsequent allowance deduction adjustments and penalties are not reflected.

Source: EPA, 2019

Figure 6. Cross-State Air Pollution Rule NO_X Ozone Season Program Group 2 Allowance Reconciliation Summary, 2017

Chapter 6: Market Activity

Cap and trade 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 ARP and CSAPR are cap and trade programs, MATS is not a market-based program; therefore this section does not report on market activity for MATS.

Highlights

Transaction Types and Volumes

- In 2017, more than 970,000 allowances were traded across all five of the CSAPR trading programs.
- Just under one-quarter of the transactions within the CSAPR programs were between distinct organizations. In 2017, over 6 million ARP allowances were traded, the majority (67 percent) between related organizations.

2017 Allowance Prices[1]

- ARP SO_2 allowance prices averaged less than $1 per ton in 2017.
- CSAPR SO_2 Group 1 allowance prices started 2017 at $5.25 per ton and ended 2017 at $2.13 per ton.
- CSAPR SO_2 Group 2 allowance prices started 2017 at $5.25 per ton and ended 2017 at $2.63 per ton.
- CSAPR NO_X annual program allowances started 2017 at $6 per ton and ended 2017 at $2 per ton.
- CSAPR NO_X ozone season program allowances started 2017 at $525 per ton and ended 2017 at $175 per ton.[2]

Background Information

Transaction Types and Volumes

Allowance transfer activity includes two types of transfers: EPA transfers to accounts 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. This category does not include transfers due to allowance retirements. Private transactions include all transfers initiated by authorized account representatives for any compliance or general account purposes.

[1] Allowance prices as reported by SNL Finance, 2017.

[2] These prices reflect CSAPR Update ozone season NO_X allowances. In October 2017, EPA published an update to the CSAPR ozone season allowance trading programs. On October 23rd, 2017, most CSAPR ozone season NO_X allowances were converted to CSAPR Update ozone season NO_X allowances.

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 2017 emissions were below emission budgets for the Acid Rain Program (ARP) and for all five Cross-State Air Pollution Rule (CSAPR) programs. As a result, CSAPR allowance prices 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.

More Information

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

Figures

2017 Allowance Transfers under CSAPR and ARP

	Transactions Conducted	Allowances Transferred	Share of Program's Allowances Transferred	
			Related (%)	Distinct (%)
ARP SO_2	718	6,622,116	67%	33%
CSAPR SO_2 Group 1	355	304,224	85%	15%
CSAPR SO_2 Group 2	137	173,046	84%	16%
CSAPR NO_x Annual	800	388,382	68%	32%
CSAPR NO_x Ozone Season Group 1	18	13,239	100%	0%
CSAPR NO_x Ozone Season Group 2	490	92,804	53%	47%

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, 2019

Figure 1. 2017 Allowance Transfers under CSAPR and ARP

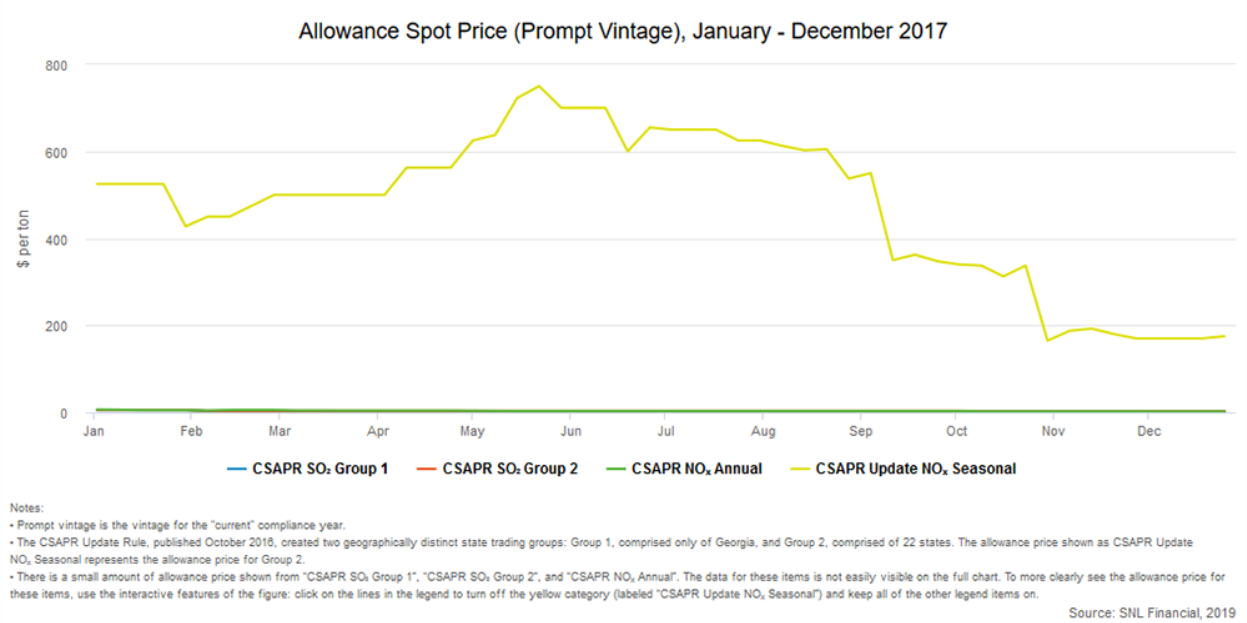


Figure 2. Allowance Spot Price (Prompt Vintage), January–December 2017

Chapter 7: Air Quality

The Acid Rain Program (ARP) and Cross-State Air Pollution Rule (CSAPR) 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 11.8 parts per billion (ppb) to 1.0 ppb (92 percent) between 1980 and 2017.
- The two largest single-year reductions (over 20 percent) occurred in the first year of the ARP, between 1994 and 1995, and between 2008 and 2009, just prior to the start of the CAIR SO_2 program.

Regional Changes in Air Quality

- Average ambient SO_2 concentrations declined in the eastern United States following implementation of the ARP and other emission reduction programs. Regional average concentrations declined 91 percent from the 1989–1991 to the 2015–2017 observation periods.
- Ambient particulate sulfate concentrations have decreased since the ARP was implemented, with average concentrations decreasing by 44 to 78 percent in observed regions from 1989–1991 to 2015–2017.
- Average annual ambient total nitrate concentrations declined 55 percent from 1989–1991 to 2015–2017 in the eastern United States, with the most significant decreases occurring after 2002 coinciding with the implementation of the NO_x Budget Trading Program and CAIR.

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 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 Clean Air Market Programs https://www.epa.gov/airmarkets/programs
- EPA's 2019 National Air Quality Trends Report https://www.epa.gov/air-trends

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1. Katsouyanni, K., Schwartz, J., Spix, C., Touloumi, G., Zmirou, D., Zanobetti, A., Wojtyniak, B., Vonk, J.M., Tobias, A., Pönkä, A., Medina, S., Bachárová, L., & Anderson, H.R. (1996). Short term effects of air pollution on health: a European approach using epidemiologic time series data: the APHEA protocol. *J. of Epidemiol Community Health*, 50: S12–S18.

2. Peel, J.L., Tolbert, P.E., Klein, M., Metzger, K.B., Flanders, W.D., Todd, K., Mulholland, J.A., Ryan, P.B., & Frumkin, H. (2005). Ambient air pollution and respiratory emergency department visits. *Epidemiology*, 16: 164–174.

3. Hong, C., Goldberg, M.S., Burnett, R.T., Jerrett, M., Wheeler, A.J., & Villeneuve, P.J. (2013) Long-term exposure to traffic-related air pollution and cardiovascular mortality. *Epidemiology*, 24: 35–43.

Figures

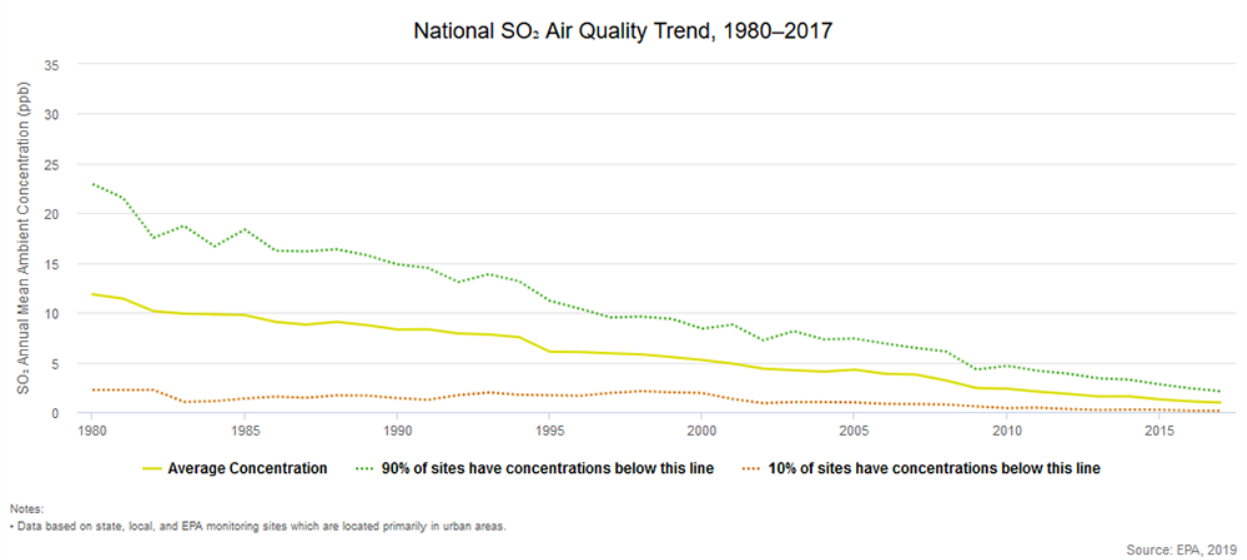

Figure 1. National SO_2 Air Quality Trend, 1980–2017

Regional Changes in Air Quality

Measurement	Region	Annual Average, 2000–2002	Annual Average, 2015–2017	Percent Change	Number of Sites
Ambient Particulate Sulfate Concentration (µg/m³)	Mid-Atlantic	4.8	1.4	-71	13
	Midwest	4.3	1.4	-67	16
	North Central	1.3	0.70	-46	2.0
	Northeast	2.6	0.80	-69	6.0
	Pacific	0.82	0.55	-33	5.0
	Rocky Mountain	0.66	0.40	-39	10
	South Central	2.9	1.5	-48	2.0
	Southeast	4.2	1.3	-69	12
Ambient Sulfur Dioxide Concentration (µg/m³)	Mid-Atlantic	8.0	1.0	-88	13
	Midwest	6.8	1.1	-84	16
	North Central	1.0	0.50	-50	2.0
	Northeast	3.4	0.60	-82	6.0
	Pacific	0.37	0.34	-8.0	5.0
	Rocky Mountain	0.48	0.29	-40	10
	South Central	1.1	0.60	-45	2.0
	Southeast	3.4	0.50	-85	12
Ambient Total Nitrate Concentration (µg/m³)	Mid-Atlantic	3.0	1.4	-53	13
	Midwest	4.1	2.0	-51	16
	North Central	1.2	0.80	-33	2.0
	Northeast	1.9	0.90	-53	6.0
	Pacific	1.8	0.90	-50	5.0
	Rocky Mountain	0.78	0.48	-38	10
	South Central	1.5	0.90	-40	2.0
	Southeast	2.3	1.1	-52	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.

Source: EPA, 2019

Figure 2. Regional Changes in Air Quality

Ozone

Highlights

Changes in 1-Hour Ozone during Ozone Season

- There was an overall regional reduction in ozone levels between 2000–2002 and 2015–2017, with a 19 percent reduction in the highest (99th percentile) ozone concentrations in CSAPR states.
- Results demonstrate how NO_X emission reduction policies have affected 1-hour ozone concentrations in the eastern United States – the region that the policies were designed to target.

Trends in Rural 8-Hour Ozone

- From 2015 to 2017, rural ozone concentrations averaged 65 ppb in CSAPR states, a decrease of 25 ppb (27 percent) from the 1990 to 2002 period.
- The Autoregressive Integrated Moving Average (ARIMA) model shows how the reductions in rural ozone concentrations compare with the implementation of the NBP in 2003 (two-year 14 ppb reduction from 2002) and the start of the CAIR NO_X Ozone Season program in 2009 (two-year 7 ppb reduction from 2007).
- Five of the six lowest observed annual ozone concentrations were between 2013 and 2017. Ozone season NO_X emissions fell steadily under CAIR and continued to drop after implementation of CSAPR in 2015. In addition, implementation of the mercury and air toxics standards (MATS), which began in 2015, achieves co-benefit reductions of NO_X emissions.

Changes in 8-Hour Ozone Concentrations

- The average reduction in both urban and rural ozone concentrations (not adjusted for weather) in the CSAPR NO_X Ozone Season program region from 2000–2002 to 2015–2017 was about 10 ppb (18 percent).
- The average reduction in the meteorologically-adjusted ozone concentrations in the CSAPR NO_X Ozone Season program region from 2000–2002 to 2015–2017 was about 11 ppb (20 percent).

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 United States and are home to about 122 million people.[1] These nonattainment areas were designated in 2004 using air quality data from 2001 to 2003.[2]
    - Based on data from 2015 to 2017, 91 of the eastern ozone nonattainment areas now show concentrations below the level of the 1997 standard, while the remaining area 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 United States and are home to about 80 million people.

These nonattainment areas were designated in 2012 using air quality data from 2008 to 2010 or 2009 to 2011.

  - Based on data from 2015–2017, 73 percent (16 areas) of the eastern ozone nonattainment areas now show concentrations below the level of the 2008 standard. While six areas continue to show concentrations above the 2008 standard, four of those areas made progress toward meeting the standard in the 2015–2017 period. It is reasonable to conclude that ozone season NO_X emission reductions from the NBP, CAIR, and CSAPR have significantly contributed to these improvements in ozone air quality.

- Effective August 3, 2018, EPA designated 52 areas nonattainment for the 2015 8-hour ozone standard based on air quality data from 2014–2016 or 2015–2017. Twenty-two of the 52 areas are in the eastern United States and are home to 76 million people.

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 United States 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, and 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 also 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 CSAPR NO_X ozone season program region and 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 99^{th} percentile of the daily maximum 8-hour ozone concentrations measured at CASTNET sites (as described above).

Meteorologically–Adjusted Daily Maximum 8-Hour Ozone Concentrations

Meteorologically–adjusted ozone trends provide additional insight on the influence of CSAPR NO_X Ozone Season program emission reductions on regional air quality. EPA retrieved daily maximum 8-hour ozone concentration data from CASTNET and daily meteorology data from the National Weather Service for 78 urban areas and 37 rural CASTNET monitoring sites located in the CSAPR NO_X Ozone Season program region. EPA uses these data in a statistical model to account for the influence of weather on seasonal average ozone concentrations at each monitoring site.[3, 4]

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, and CSAPR. 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 United States 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 United States. Implementation began in May 2017 to further reduce ozone season NO_X emissions from power plants in 22 states in the eastern US.

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 Clean Air Market Programs https://www.epa.gov/airmarkets/programs
- EPA's 2019 National Air Quality Trends Report https://www.epa.gov/air-trends

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2. 40 CFR Part 81. Designation of Areas for Air Quality Planning Purposes.

3. Cox, W.M. & Chu, S.H. (1996). Assessment of interannual ozone variation in urban areas from a climatological perspective. *Atmospheric Environment*, 30 (16): 2615–2625.
4. Camalier, L., Cox, W.M., & Dolwick, P. 2007. The effects of meteorology on ozone in urban areas and their use in assessing ozone trends. *Atmospheric Environment*, 41(33): 7127–7137.

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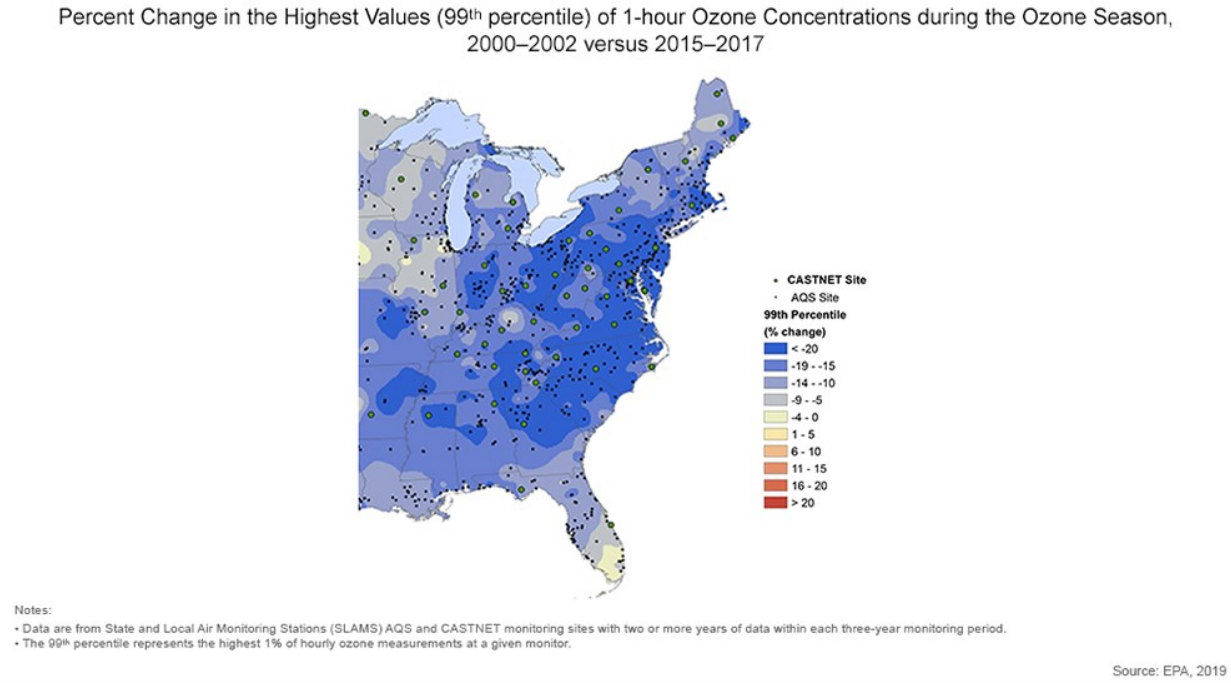

Figure 1. Percent Change in the Highest Values (99th percentile) of 1-hour Ozone Concentrations during the Ozone Season, 2000–2002 versus 2015–2017

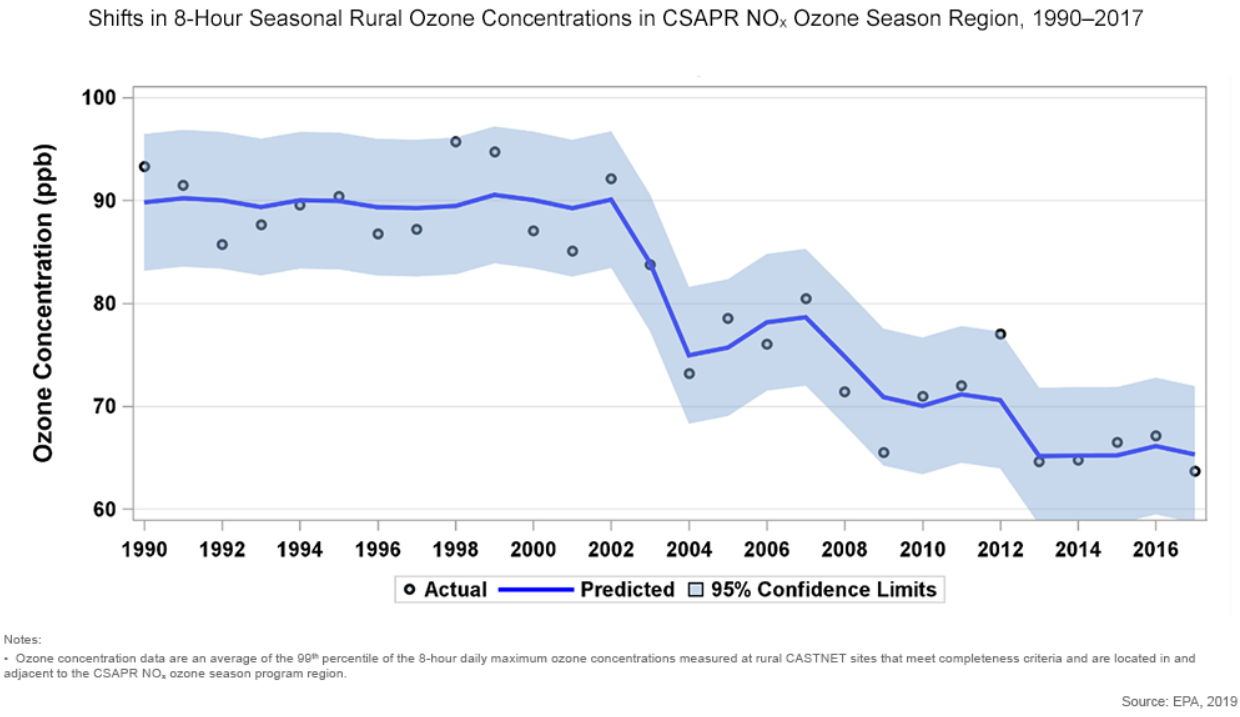

Figure 2. Shifts in 8-hour Seasonal Rural Ozone Concentrations in CSAPR NO_X Ozone Season Region, 1990–2017

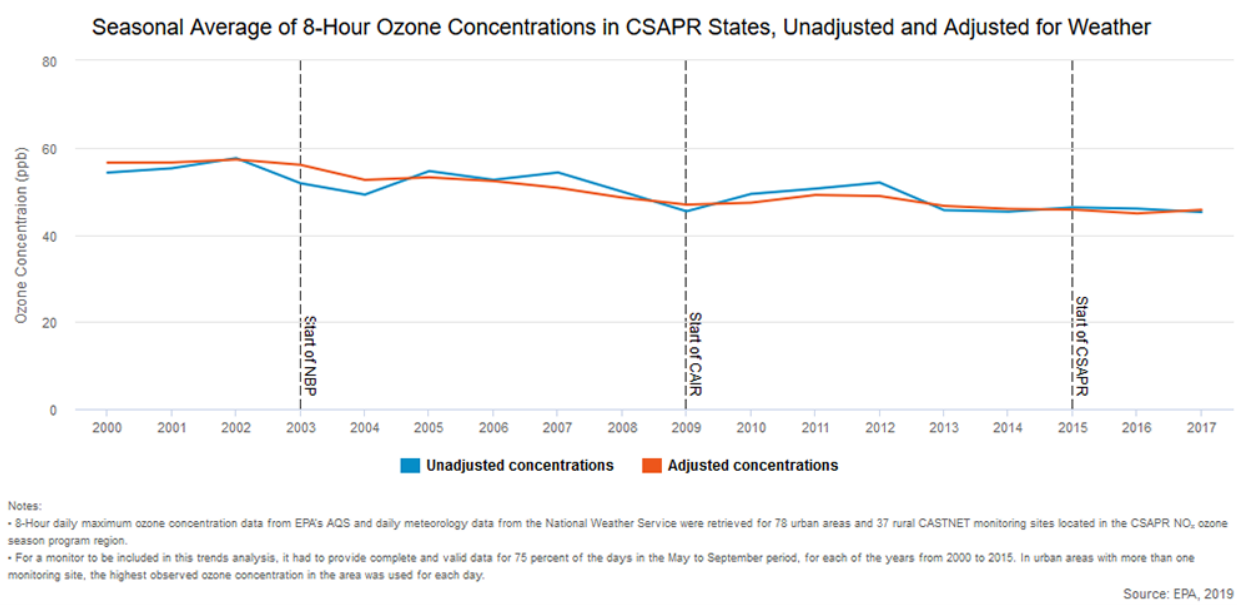

Figure 3. Seasonal Average of 8-Hour Ozone Concentrations in CSAPR States, Unadjusted and Adjusted for Weather

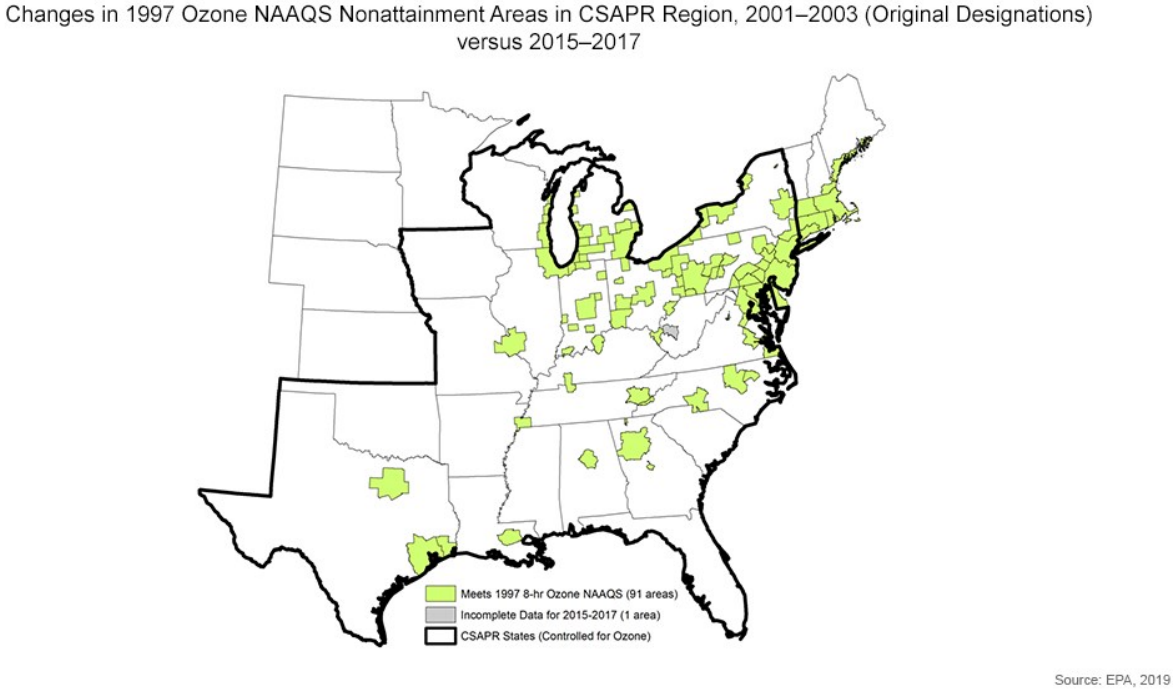

Figure 4. Changes in 1997 Ozone NAAQS Nonattainment Areas in CSAPR Region, 2001–2003 (Original Designations) versus 2015–2017

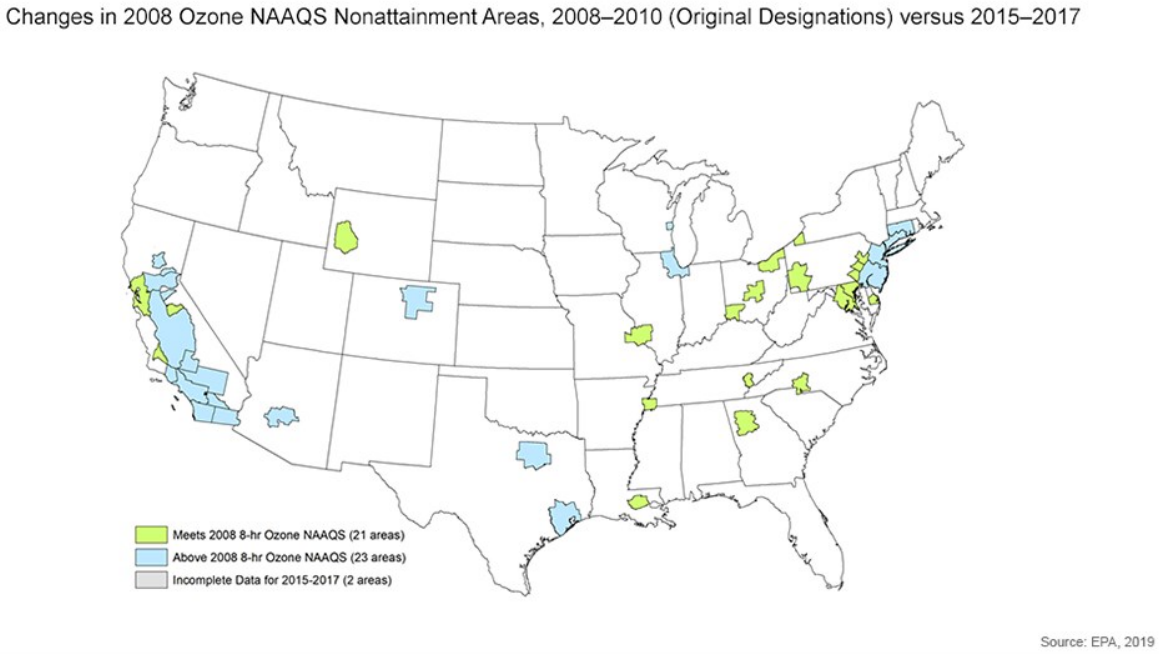

Figure 5. Changes in 2008 Ozone NAAQS Nonattainment Areas, 2008–2010 (Original Designations) versus 2015–2017

Particulate Matter

Highlights

PM Seasonal Trends

- The Air Quality System (AQS) includes average $PM_{2.5}$ concentration data for 244 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 47 and 46 percent in the warm and cool season months, respectively, between 2000 and 2017.

Changes in $PM_{2.5}$ Nonattainment

- 36 of the 39 designated nonattainment areas for the 1997 annual average $PM_{2.5}$ NAAQS are in the eastern United States and are home to about 75 million people.[1,2] The nonattainment areas were designated in January 2005 using 2001 to 2003 data.
    - Based on data gathered from 2015 to 2017, 35 of these eastern areas originally designated nonattainment show concentrations below the level of the 1997 $PM_{2.5}$ standard (15 $\mu g/m^3$), 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 a number of 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]

Particulate Matter 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 $\mu g/m^3$ 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 $\mu g/m^3$. In December 2012, EPA strengthened the annual fine particle standard to 12 $\mu g/m^3$.

CSAPR was promulgated to help downwind states in the eastern United States 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 US, recent data indicate that no areas are violating the 1997 or 2006 $PM_{2.5}$ NAAQS. One area in the eastern US (Allegheny County, PA) is violating the 2012 annual $PM_{2.5}$ 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

- 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 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 Clean Air Market Programs https://www.epa.gov/airmarkets/programs
- EPA's 2019 National Air Quality Trends Report https://www.epa.gov/air-trends

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5. Bell, M.L., Dominici, F., Ebisu, K., Zeger, S.L., & Samet, J.M. (2007). Spatial and temporal variation in $PM_{2.5}$ chemical composition in the United States for health effects studies. *Environmental Health Perspectives* 115: 989–995.

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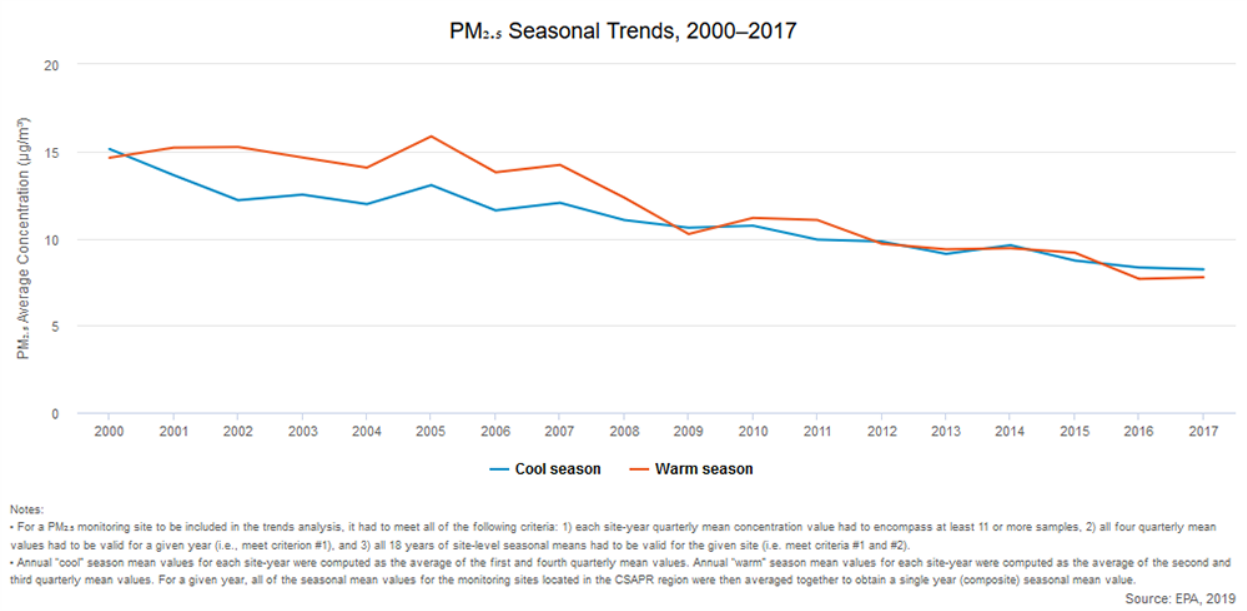

Figure 1. $PM_{2.5}$ Seasonal Trends, 2000–2017

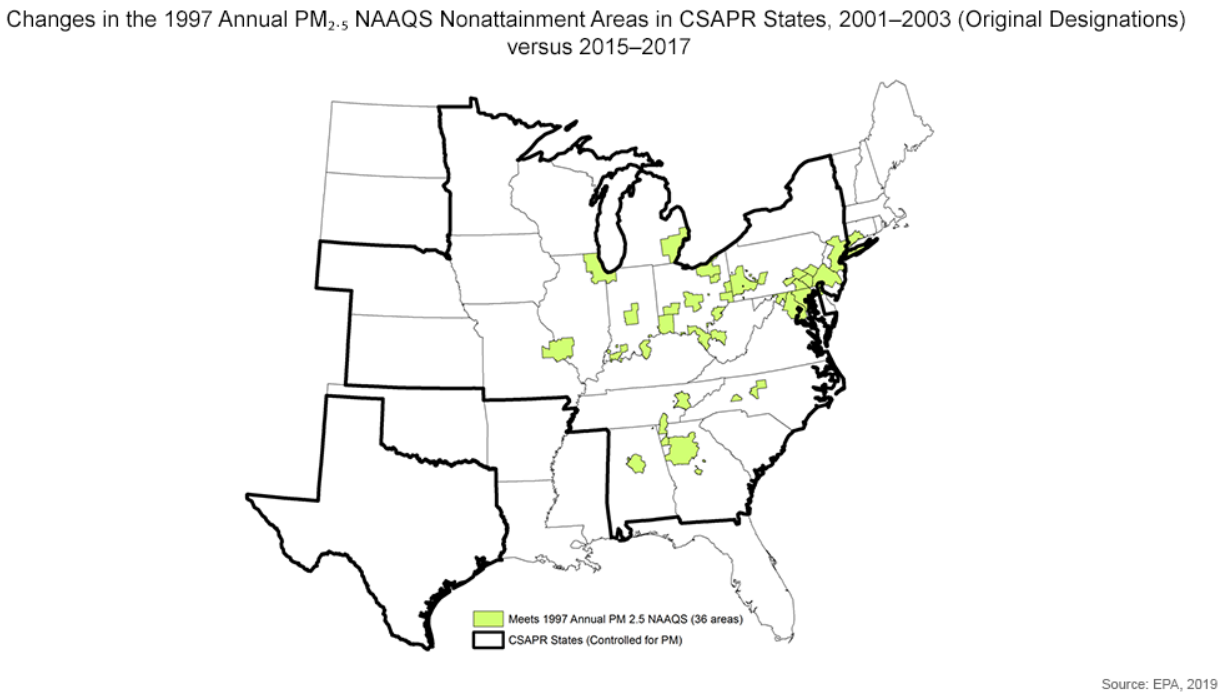

Figure 2. Changes in the 1997 Annual $PM_{2.5}$ NAAQS Nonattainment Areas in CSAPR States, 2001–2003 (Original Designations) versus 2015–2017

Chapter 8: 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 64 percent reduction in wet sulfate deposition from 2000–2002 to 2015–2017.
- Between 2000–2002 and 2015–2017, the Northeast and Mid-Atlantic experienced the largest reductions in wet sulfate deposition of 71 percent and 70 percent, respectively.
- A reduction in SO_2 emissions and 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 21 percent in the Mid-Atlantic and 33 percent in the Northeast but increased 13 percent in the Rocky Mountain region from 2000–2002 to 2015–2017. Increases in wet deposition of inorganic nitrogen in the Rocky Mountain region are attributed to a 57 percent increase in wet deposition of reduced nitrogen (NH_4^+) between 2000 and 2017.
- 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, and manufacturing) contribute to air concentrations and deposition of nitrogen.

Regional Trends in Total Deposition

- The reduction in total sulfur deposition (wet plus dry) has been of similar magnitude to that of wet deposition with an overall average reduction of 69 percent from 2000–2002 to 2015–2017.
- Decreases in dry and total inorganic nitrogen deposition have generally been greater than that of wet deposition, with average reductions of 28 percent and 21 percent, respectively. In contrast, wet deposition from inorganic nitrogen decreased by an average of 10 percent from 2000–2002 to 2015–2017.

Background Information

Acid Deposition

As SO_2 and NO_X gases react in the atmosphere with water, oxygen, and other chemicals, they form acidic compounds that are deposited to the earth's surface in the form of wet and dry acid 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 precipitation) has decreased in much of the eastern United States 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 sources contribute to changes in air concentrations and deposition 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. CASTNET now operates more than 90 regional sites throughout the contiguous United States, 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 United States, 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]

More Information

- Acid Rain https://www.epa.gov/acidrain
- Clean Air Status and Trends Network (CASTNET) https://epa.gov/castnet
- National Atmospheric Deposition Program (NADP) http://nadp.slh.wisc.edu/

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Figures

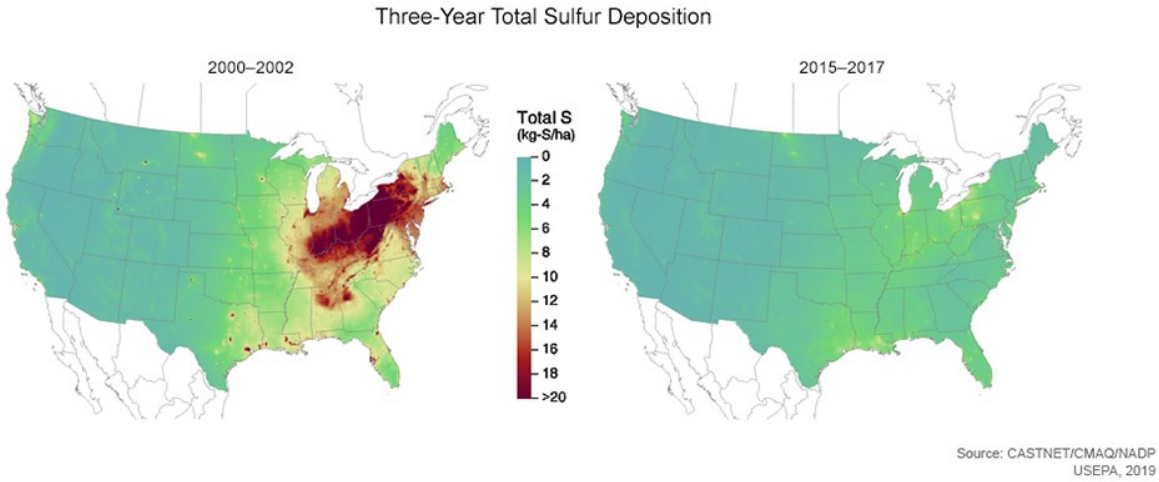

Figure 1. Three-Year Total Sulfur Deposition

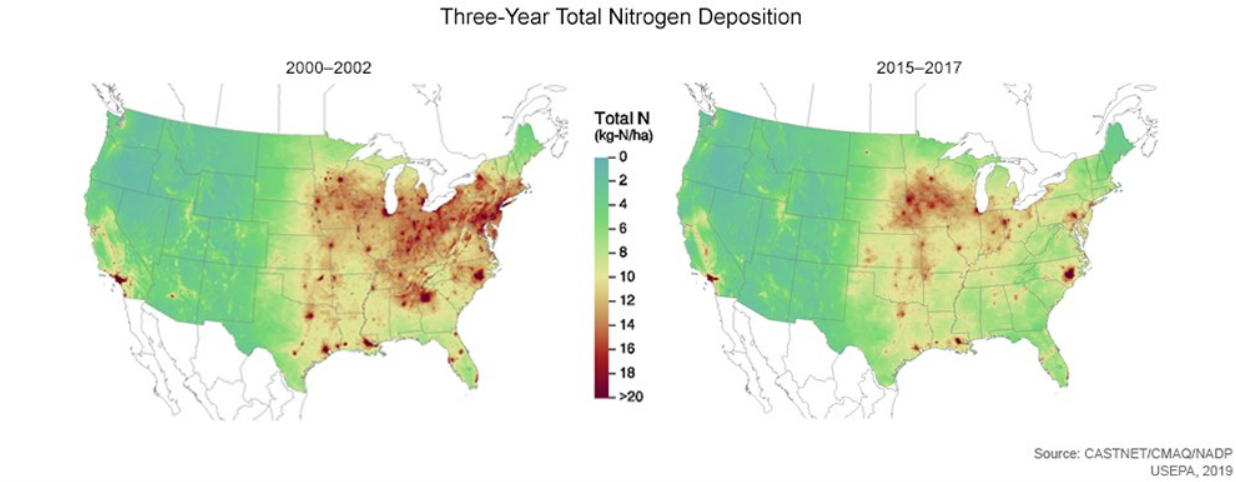

Figure 2. Three-Year Total Nitrogen Deposition

Regional Trends in Deposition - Nitrogen

Measurement	Region	Annual Average, 2000-2002	Annual Average, 2015-2017	Percent Change
Dry Nitrogen Deposition (kg-N/ha)	Mid-Atlantic	9.9	6.2	-37
	Midwest	7.0	5.0	-29
	North Central	4.7	4.7	0
	Northeast	6.1	3.5	-43
	Pacific	2.7	2.2	-19
	Rocky Mountain	2.3	2.0	-13
	South Central	5.8	4.9	-16
	Southeast	6.7	4.5	-33
Wet Nitrogen Deposition (kg-N/ha)	Mid-Atlantic	4.8	3.8	-21
	Midwest	5.9	5.1	-14
	North Central	4.5	4.9	9.0
	Northeast	4.8	3.2	-33
	Pacific	1.0	1.1	10
	Rocky Mountain	1.5	1.7	13
	South Central	4.0	4.2	5.0
	Southeast	4.0	3.5	-13
Total Deposition of Nitrogen (kg-N/ha)	Mid-Atlantic	15	10	-32
	Midwest	13	10	-21
	North Central	9.2	9.5	3.0
	Northeast	11	6.7	-39
	Pacific	3.7	3.3	-11
	Rocky Mountain	3.8	3.7	-3.0
	South Central	9.8	9.1	-7.0
	Southeast	11	8.0	-25
Total Deposition of Oxidized Nitrogen (kg-N/ha)	Mid-Atlantic	11	6.1	-46
	Midwest	8.8	4.9	-44
	North Central	4.6	3.4	-26
	Northeast	8.4	4.2	-50
	Pacific	2.7	1.7	-37
	Rocky Mountain	2.6	1.9	-27
	South Central	6.6	4.9	-26
	Southeast	8.1	4.6	-43
Total Deposition of Reduced Nitrogen (kg-N/ha)	Mid-Atlantic	3.3	3.9	18
	Midwest	4.2	5.2	24
	North Central	4.5	6.1	36
	Northeast	2.5	2.4	-4.0
	Pacific	1.1	1.6	45
	Rocky Mountain	1.2	1.8	50
	South Central	3.2	4.2	31
	Southeast	2.7	3.4	26

Regional Trends in Deposition - Sulfur

Measurement	Region	Annual Average, 2000-2002	Annual Average, 2015-2017	Percent Change
Dry Sulfur Deposition (kg-S/ha)	Mid-Atlantic	11	1.7	-84
	Midwest	8.2	1.8	-78
	North Central	1.8	0.80	-56
	Northeast	5.6	1.3	-77
	Pacific	0.60	0.30	-50
	Rocky Mountain	0.60	0.40	-33
	South Central	2.0	0.90	-55
	Southeast	4.6	1.0	-78
Wet Sulfur Deposition (kg-S/ha)	Mid-Atlantic	6.0	1.8	-70
	Midwest	5.5	2.1	-62
	North Central	2.3	1.4	-39
	Northeast	5.1	1.5	-71
	Pacific	0.60	0.40	-33
	Rocky Mountain	0.70	0.60	-14
	South Central	3.8	2.7	-29
	Southeast	4.8	2.1	-56
Total Deposition of Sulfur (kg-S/ha)	Mid-Atlantic	17	3.5	-79
	Midwest	14	3.9	-72
	North Central	4.1	2.1	-49
	Northeast	11	2.7	-75
	Pacific	1.2	0.80	-33
	Rocky Mountain	1.3	0.90	-31
	South Central	5.8	3.6	-38
	Southeast	9.4	3.1	-67

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.
- Total deposition is estimated from raw measurement data, not rounded, and may not equal the sum of dry and wet deposition.

Source: EPA, 2019

Figure 3. Regional Trends in Deposition

Chapter 9: 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 2017, 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 2017, streams in the central Appalachian region have experienced mixed results due in part to their soils and geology. Only 45 percent of monitored streams show lower sulfate concentrations (and statistically significant trends), while 8 percent show increased sulfate concentrations.
- Nitrate concentrations and trends are highly variable and many sites do not show improving trends between 1990 and 2017, despite reductions in NO_X emissions and inorganic nitrogen deposition.
- In 2017, levels of acid neutralizing capacity (ANC), a key indicator of aquatic ecosystem recovery, have increased significantly from 1990 in lake and stream sites in the Adirondack Mountains, New England, and the Catskill mountains. In the Appalachians, sites with increasing ANC remain low at 21 percent, reflecting a 3 percent increase from 2016.

Ozone Impacts on Forests

- Between 2000–2002 and 2015–2017, the area in the eastern United States with significant forest biomass loss (> 2 % biomass loss) decreased from 34 percent to 5.7 percent for seven tree species combined – black cherry, yellow poplar, sugar maple, eastern white pine, Virginia pine, red maple, and quaking aspen.

- For black cherry and yellow poplar individually (the tree species most sensitive to ground-level ozone), the total land area in the eastern United States with significant biomass loss decreased from 15 percent to 5.2 percent for black cherry, and from 3 percent to 0 percent for yellow poplar between 2000–2002 and 2015–2017.
- For the period 2015–2017, total land area in the eastern United States 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 3.4% for the period of 2000–2002.
- While this change in biomass loss cannot be exclusively attributed to the implementation of the NBP, CAIR, and CSAPR, 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 depleted, base cation-poor 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 a monitoring program that provides information on the impacts of acidic deposition on otherwise pristine lakes and streams: the Long-term Monitoring (LTM) program. This program is designed to track changes in surface water chemistry in the four regions sensitive to acid rain in the eastern United States: 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, etc. 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 many commercial and ecologically important forest tree species throughout the United States.[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 United States 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/airmarkets/clean-air-markets-monitoring-surface-water-chemistry
- Acid Rain https://www.epa.gov/acidrain/

References

1. Burns, D.A., Lynch, J.A., Cosby, B.J., Fenn, M.E., & Baron, J.S. (2011). *National Acid Precipitation Assessment Program Report to Congress 2011: An Integrated Assessment.* U.S. EPA, National Science and Technology Council, Washington, D.C.: 114 p

2. Chappelka, A.H. & Samuelson, L.J. (1998). Ambient ozone effects on forest trees of the eastern United States: A review. New Phytologist 139: 91–108.

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

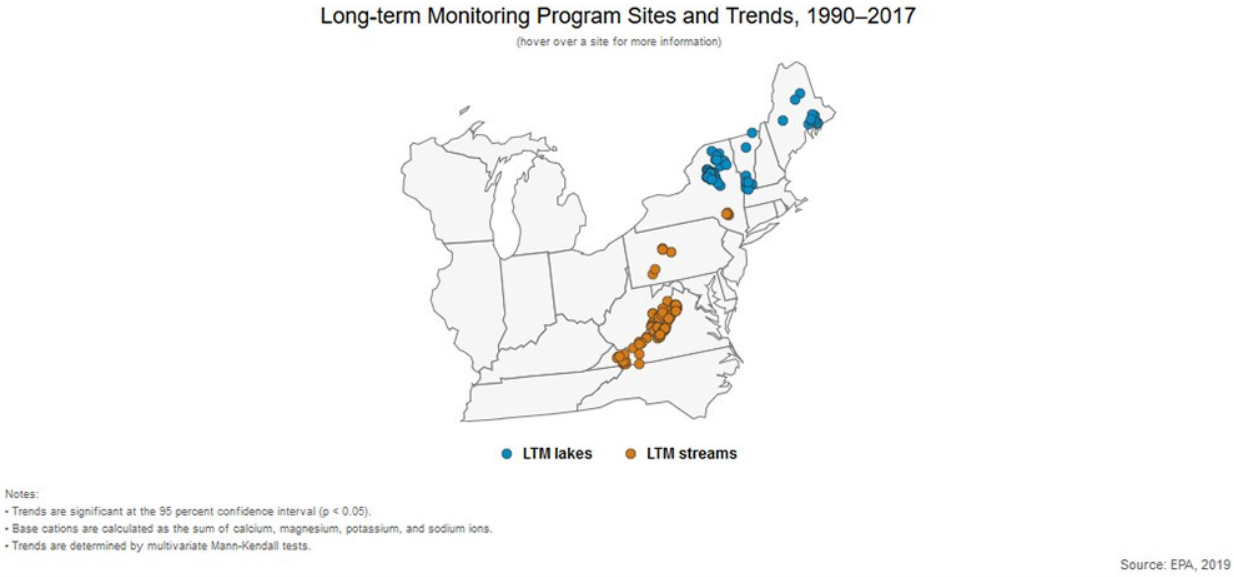

Figure 1. Long-term Monitoring Program Sites and Trends, 1990–2017

Regional Trends in Sulfate, Nitrate, ANC, and Base Cations at Long-term Monitoring Sites, 1990–2017

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	38 lakes in NY*	100%	79%	87%	92%
New England	26 lakes in ME and VT	100%	23%	74%	60%
Catskills/ N. Appalachian Plateau	9 streams in NY and PA**	80%	53%	70%	90%
Central Appalachians	66 streams in VA	45%	77%	21%	29%

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, 2019

Figure 2. Regional Trends in Sulfate, Nitrate, ANC, and Base Cations at Long-term Monitoring Sites, 1990–2017

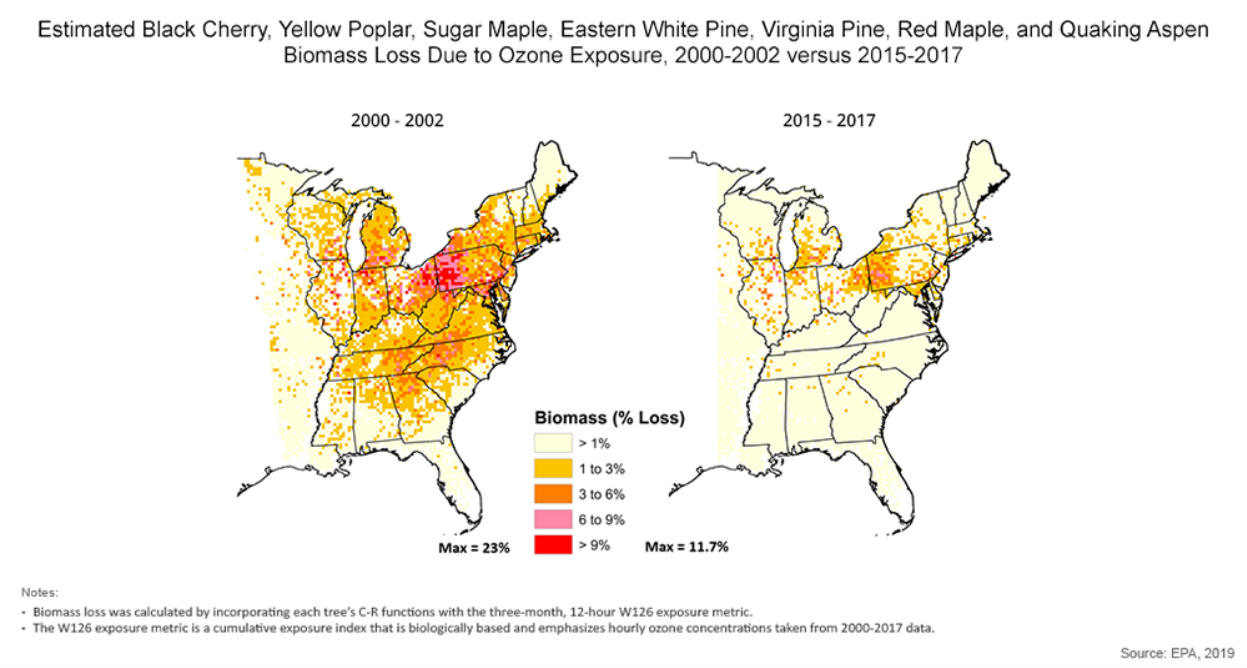

Figure 3. Estimated Black Cherry, Yellow Poplar, Sugar Maple, Eastern White Pine, Virginia Pine, Red Maple, and Quaking Aspen Biomass Loss Due to Ozone Exposure, 2000–2002 versus 2015–2017

Critical Loads Analysis

Highlights

Critical Loads and Exceedances

- For the period from 2015 to 2017, seven percent of all studied lakes and streams still received levels of combined total sulfur and nitrogen deposition exceeding their calculated critical load. This is an 80 percent improvement over the period from 2000 to 2002 when 37 percent of all studied lakes and streams exceeded their calculated critical load.
- Emission reductions achieved between 2000 and 2017 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 in 2017 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 resulting from SO_2 and NO_X emissions are sufficient to protect 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 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 6,275 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/airmarkets/monitoring-surface-water-chemistry
- National Acid Precipitation Assessment Program (NAPAP) Report to Congress https://ny.water.usgs.gov/projects/NAPAP/

References

1. Dupont, J., Clair, T.A., Gagnon, C., Jeffries, D.S., Kahl, J.S., Nelson, S.J., & Peckenham, J.M. (2005). Estimation of critical loads of acidity for lakes in the northeastern United States and eastern Canada. *Environmental Monitoring and Assessment,* 109:275–291.

2. Sullivan, T.J., Cosby, B.J., Webb, J.R., Dennis, R.L., Bulger, A.J., & Deviney, Jr. F.A. (2007). Streamwater acid-base chemistry and critical loads of atmospheric sulfur deposition in Shenandoah National Park, Virginia. *Environmental Monitoring and Assessment,* 137: 85–99.

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

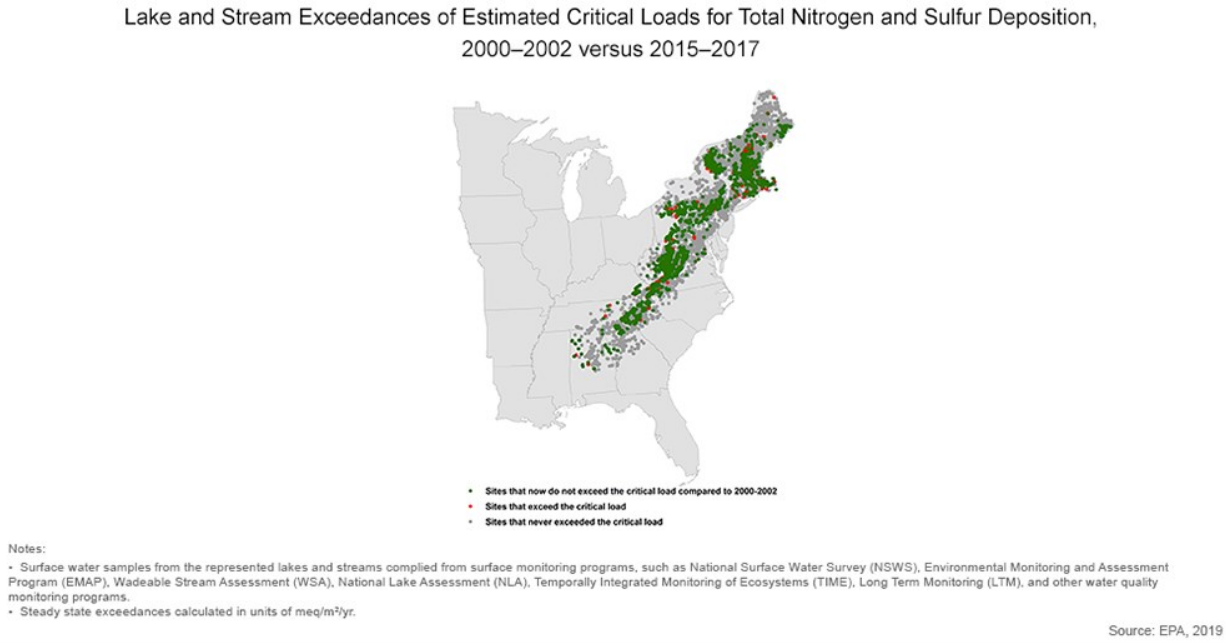

Figure 1. Lake and Stream Exceedances of Estimated Critical Loads for Total Nitrogen and Sulfur Deposition, 2000–2002 versus 2015–2017

Critical Load Exceedances by Region, 2000–2002 versus 2015–2017

Region	Number of Water Bodies Modeled	Water Bodies in Exceedance of Critical Load				Percent Reduction
		2000-2002		2015-2017		
		Number of Sites	Percent of Sites	Number of Sites	Percent of Sites	
New England (CT, MA, ME, NH, RI, VT)	2,195	580	26%	121	6%	79%
Adirondack (NY)	312	163	52%	37	12%	77%
Northern Mid-Atlantic (NY, NJ, PA)	1,146	301	26%	44	4%	85%
Southern Mid-Atlantic (KY, MD, VA, WV)	1,740	968	56%	198	11%	77%
Southern Appalachian Mountains (AL, GA, SC, TN)	882	298	34%	70	8%	76%
Total Units	**6,275**	**2,310**	**37%**	**470**	**7%**	**80%**

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.

Source: EPA, 2019

Figure 2. Critical Load Exceedances by Region, 2000–2002 versus 2015–2017