Air and Energy National Research Program

Strategic Research Action Plan, 2019 – 2022

External Review DRAFT

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List of Acronyms

ACE	Air, Climate, and Energy
A-E	Air and Energy
AFO	Animal feeding operation
AQD	Air Quality Decisions
AQMEII	Air Quality Model Evaluation International Initiative
ASTHO	Association of State and Territorial Health Officials
BMP	Best management practice
CAA	Clean Air Act
CBP	Chesapeake Bay Program
CDC	Centers for Disease Control
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMAQ	Community-Multiscale Air Quality Model
CO	Carbon monoxide
CRADA	Cooperative Research and Development Agreement
CSS	Chemical Safety for Sustainability
CWA	Clean Water Act
DOE	Department of Energy
DOI	Department of Interior
E3R	Extreme Events and Emerging Risks
EA	Environmental Assessments
ECOS	Environmental Council of States
EIS	Environmental Impact Statements
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency
ERIS	Environmental Research Institute of the States
FEM	Federal Equivalent Method
FRM	Federal Reference Method
FWPCA	Federal Water Pollution Control Act
FY	Fiscal year
GCRA	Global Change Research Act
HABs	Harmful algal blooms
HAPs	Hazardous air pollutants
HEI	Health Effects Institute
HHRA	Human Health Risk Assessment
HSRP	Homeland Security Research Program
HTAP	Hemispheric Transport of Air Pollution
LRTAP	Long-range Transboundary Air Pollution
MACT	Maximum achievable control technology
MESA	Multi-Ethnic Study of Atherosclerosis
NAAQS	National ambient air quality standards
NADP	National Atmospheric Deposition Program
NEHA	National Environmental Health Association
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NGM	Next-Generation Methods
NHLBI	National Heart, Lung, and Blood Institute
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NOAA	National Oceanic and Atmospheric Administration
NSR	New Source Review
NTAA	National Tribal Air Association
O_3	Ozone
OAR	Office of Air and Radiation
OECA	Office of Enforcement and Compliance Assurance
OLEM	Office of Land and Emergency Management
ORD	Office of Research and Development
OTAQ	Office of Transportation and Air Quality
OW	Office of Water
Pb	Lead
PFAS	Per-and Polyfluoroalkyl Substances
PM	Particulate matter
PSD	Prevention of Significant Deterioration
RCRA	Resource Conservation and Recovery Act
SBIR	Small Business Innovative Research
SDWA	Safe Drinking Water Act
SGCR	Subcommittee on Global Change Research

SHC Sustainable and Healthy Communities
SIP State Implementation Plan
SO_2 Sulfur dioxide
SOA Secondary organic aerosol
SSWR Safe and Sustainable Water Resources
STAR Science to Achieve Results
StRAP Strategic Research Action Plan
TDEP Total Deposition
TSC Tribal Science Council
UNFCCC United Nations Framework Convention on Climate Change
USFS United States Forest Service
USGCRP U.S. Global Change Research Program
VOCs Volatile organic compounds

Executive Summary

This *Air and Energy (A-E) Strategic Research Action Plan, 2019–2022* (A-E StRAP) outlines research to address the U.S. Environmental Protection Agency's (EPA's) strategic objectives and mandates to improve air quality, reduce the number of areas currently in nonattainment of the national ambient air quality standards (NAAQS), and protect public health and the environment. Approximately 120 million people in the United States live in counties that do not meet the NAAQS for at least one of the six criteria air pollutants, even as emissions of these pollutants have been reduced by more than 70 percent over the past 45 years. Other emerging air pollutants, growing impacts from sources such as wildfires, and changes to the nation's energy portfolio and in environmental conditions more broadly (for example., land use change, transportation, climate change) further complicate our understanding of the measures needed to improve air quality now and into the future. These increasingly complex problems require innovative thinking and sustainable solutions to ensure that EPA can protect human health and the environment. Research conducted by the A-E Research Program provides partners in EPA program and regional and regional offices, states, and tribes and other stakeholders with the knowledge base and the tools to make more informed decisions and to better understand the benefits and potential consequences of those decisions.

The A-E Research Program is structured to provide research that addresses EPA priorities and mandates, meets partners' and stakeholders' needs, fills knowledge gaps, and complements broader efforts across the Federal government and the scientific community. The research portfolio has been developed with considerable input from EPA partners in the regional and program offices, states, tribes, and other outside stakeholder groups. The research planning also reflects interactions with the five other national research programs within EPA's Office of Research and Development to address cross-cutting scientific issues. The A-E research objectives are:

Research Objective 1: Assess Impacts — Improve understanding of the processes regulating human and ecosystem exposures and of the effects associated with air pollutants at individual, community, regional, national, and global scales.

Research Objective 2: Expand Approaches to Prevent and Reduce Emissions — Develop and evaluate new approaches to prevent and reduce air pollution now and in the future, particularly sustainable, cost-effective, and innovative multi-pollutant and sector-based approaches.

Research Objective 3: Advance Measurement and Modeling — Improve the human exposure and environmental modeling, monitoring, metrics, and information that are needed to address emerging and future risks and inform air quality decision making at the national, state, tribal, and local levels.

Research Objective 4: Inform Decisions — Deliver state-of-the-art science and tools to inform implementation of the NAAQS and other air quality regulations and policies at the national, state, tribal, and local levels.

The A-E Research Program will achieve these objectives and address specific scientific challenges by developing and implementing research activities under three inter-related topics: (1) Science for Air Quality Decisions; (2) Extreme Events and Emerging Risks; and (3) Next-Generation Methods to Improve Public Health and the Environment. Many scientific issues cut across the entire A-E portfolio. One issue in particular, wildland fires, draws from all three programmatic research topics.

This A-E StRAP describes the research topics, overall structure, and purpose of the A-E Research Program. The A-E Research Program will continue to engage with EPA partners as we work to identify the specific products that will be developed to achieve the research area objectives and outputs identified in the StRAP. This engagement will continue through implementing the research to ensure that the products and innovative tools delivered by A-E scientists will inform our partners' and stakeholders' work to improve and protect air quality, reduce the number of nonattainment areas across the United States, improve public health and the environment, and meet broader EPA legal and statutory mandates.

Introduction

Despite decades of improvement in United States air quality, protecting human health and the environment from the impacts of air pollution remains a challenge for the 21st Century. Approximately 120 million people in the United States live in counties that do not meet the national ambient air quality standards (NAAQS) for at least one criteria pollutant, even as emissions of the six criteria air pollutants[1] have been reduced by more than 70 percent over the past 45 years. This challenge is complicated by interactions between air quality, global trends, and existing and emerging energy options. The U.S. Environmental Protection Agency (EPA) Office of Research and Development's (ORD) Air and Energy (A-E) Research Program provides the science and engineering needed to inform actions that will improve air quality and address the environmental impacts of energy development and use. The A-E Strategic Research Action Plan (StRAP) is one of six research plans, one for each of EPA's national research programs in ORD. The six research programs are:

- Air and Energy (A-E)
- Chemical Safety for Sustainability (CSS)
- Homeland Security Research Program (HSRP)
- Human Health Risk Assessment (HHRA)
- Safe and Sustainable Water Resources (SSWR)
- Sustainable and Healthy Communities (SHC)

EPA's six strategic research action plans lay the foundation for EPA's research programs to provide focused research that meets the Agency's legislative mandates and the goals outlined in the EPA and ORD Strategic Plans (U.S. EPA, 2018a, b). The StRAPs are designed to guide an ambitious research portfolio that delivers the science and engineering solutions the Agency needs to meet its goals now and into the future, while also cultivating an efficient, innovative, and responsive research enterprise.

Research to Support the EPA Strategic Plan

EPA has been protecting public health and the environment from air pollution for almost half a century. This record of success has been built on a strong scientific foundation to inform policy decisions and to solve problems. Today, improving the nation's air quality remains a major EPA priority, especially for those who reside in communities unable to fully meet air pollution standards or who may be at increased risk due to health or socio-demographic reasons. Equally pressing is the Agency priority to anticipate and prepare for future environmental conditions, which have significant negative implications for human health and the environment. For example, changes in environmental conditions can affect human health through extreme weather events, including extreme high temperatures, changing allergen profiles, and potentially increased incidences of water-borne and vector-borne disease due to floods and higher water temperatures. Anticipated increases in the frequency and intensity of extreme weather events will likely place additional stresses on ecosystems, infrastructures, and economies, each of which affects public health.

[1] Criteria pollutants are those pollutants for which NAAQS have been established, which include particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and lead (Pb). (http://www.epa.gov/air/airpollutants.html).

As part of its mission to protect human health and the environment, EPA is dedicated to improving air quality in the United States. In support of this mission, the *FY 2018-2022 EPA Strategic Plan* (U.S. EPA, 2018a) identifies the Agency's strategic goals and objectives as summarized in Figure 1. The A-E research portfolio is designed to address the current and future needs of partners and stakeholders as they develop and implement policies to achieve goals and objectives outlined in the Agency strategic plan. The EPA goals and objectives relevant to the A-E Research Program are summarized in Table 1 and briefly discussed below.

Figure 1. ***EPA Strategic Plan (FY 2018-2022)***

Goal 1, Objective 1.1, "Improve Air Quality," prioritizes key activities to support attainment of the NAAQS[2] and implementation of stationary and mobile source regulations, as well as national and multi-state programs. The A-E Research Program directly supports this core mission by continuing to develop, evaluate, and apply methods and models to support air quality management programs and by providing foundational science to inform decision making.

EPA Goal 2, "Cooperative Federalism," focuses on close communication with Agency regional and program office partners, state and local agencies, and external stakeholders. ORD has been working to strengthen its direct relationship with states through the Environmental Council of the States (ECOS) and the Environmental Research Institute of the States (ERIS), and with tribes through the Tribal Science Council (TSC) and other tribal organizations such as the National Tribal Air Association (NTAA). The A-E team has met with these groups to discuss our research program and to better understand their research needs. For example, Appendix 2 summarizes state research needs identified by ECOS. In

[2] Section 109 of the Clean Air Act (CAA) identifies two types of national ambient air quality standards – ***primary standards*** *provide public health protection, including protecting the health of "sensitive" populations such as children, older adults, and persons with pre-existing disease such as asthma or cardiovascular disease and* ***secondary standards*** provide public welfare protection, including protection against decreased visibility and damage to animals, wildlife, soils, water, crops, vegetation, and buildings. Unless otherwise stated, in this document the term NAAQS will refer to both primary and secondary standards.

addition, over the past year, ORD implemented a Memorandum of Understanding with several public health organizations, such as the National Environmental Health Association (NEHA) and the Association of State and Territorial Health Officials (ASTHO), to better engage the states and disseminate research to decision makers.

EPA Goal 3, Objective 3.3, "Prioritize Robust Science," emphasizes research and scientific analyses to inform policymaking. For air quality, this objective states that the Agency will do the following over the next five years:

- *Deliver state-of-the-art tools for states and tribes to use in identifying effective emission reduction strategies to meet national ambient air quality standards (NAAQS) and enhance air quality measurement methods used to ascertain compliance with the NAAQS.*
- *Assess human and ecosystem exposures and effects associated with air pollutants on individual, community, regional, national, and global scales.*[3]
- *Develop and evaluate approaches to prevent and reduce pollution, particularly sustainable, cost-effective, and innovative multi-pollutant and sector-based approaches.*
- *Provide human exposure and environmental modeling, monitoring, metrics, and information needed to inform air quality decision making at the federal, state, tribal, and local level*.

Table 1. Highlights of EPA Strategic Plan Goals and Objectives Relevant to the A-E Research Program

EPA Goal	EPA Objective
Goal 1 — Core Mission: Deliver real results to provide Americans with clean air, land, and water, and ensure chemical safety	**Objective 1.1 — Improve Air Quality:** Work with states and tribes to accurately measure air quality and ensure that more Americans are living and working in areas that meet high air quality standards
Goal 2 — Cooperative Federalism: Rebalance the power between Washington and the states to create tangible environmental results for the American people	**Objective 2.1 — Enhance Shared Accountability:** Improve environmental protection through shared governance and enhanced collaboration with state, tribal, local, and federal partners using the full range of compliance assurance tools
	Objective 2.2 — Increase Transparency and Public Participation: Listen to and collaborate with impacted stakeholders and provide effective platforms for public participation and meaningful engagement
Goal 3 — Rule of Law and Process: Administer the Law as Congress intended, to refocus the Agency on its statutory obligations under the law	**Objective 3.3 — Prioritize Robust Science:** Refocus the EPA's robust research and scientific analysis to inform policy making

[3] Beyond effects associated with ambient air exposures, consideration of potential human and ecosystem exposures and effects associated with deposition of air pollutants to water and land are also evaluated.

The Agency's mission to protect human health and the environment includes implementing air quality standards. To support this mission, a major emphasis of the A-E Research Program is on better understanding the impacts of air pollutants on human health and the environment and improving ambient air pollutant monitoring, air quality models, and emissions measurement methods to inform air quality management decisions. In addition, to support climate resiliency goals of state and local agencies, as well as tribes and community organizations, EPA needs research to understand the effects of extreme events on air quality, water quality, and, ultimately, human health and the environment. Most of the research identified in this A-E StRAP is targeted at immediate needs of the EPA partners, but there are also elements that are exploratory and anticipatory in nature and will lead to capabilities in the future. For example, looking ahead to anticipate the needs of EPA partners and stakeholders under Goal 1, the A-E research portfolio aims to gain insights into potential benefits of multi-pollutant air quality management approaches and to understand how the energy system may evolve as technologies advance, the environment changes, and new policies are developed.

A critical component of developing the A-E StRAP is soliciting input from EPA programs and regions, state and tribal partners, and stakeholders. Input from our partners and stakeholders provides a clear message that much of the current research and anticipated direction of the A-E Research Program continues to address their needs and is responsive to the new EPA Strategic Plan.

Statutory and Policy Context

The A-E Research Program primarily responds to issues addressed in the Clean Air Act (CAA), as revised, with additional responsibilities under the Energy Independence and Security Act (EISA) of 2007, the Global Change Research Act (GCRA) of 1990, the Federal Water Pollution Control Act (FWPCA), and the National Environmental Policy Act (NEPA) as summarized in Table 2.

Table 2. Air and Energy Research Program Supports Decisions Mandated by Legislation

Legislation	Acronym	Website
Clean Air Act	CAA	https://www.gpo.gov/fdsys/granule/USCODE-2010-title42/USCODE-2010-title42-chap85
Energy Independence and Security Act	EISA	https://www.gpo.gov/fdsys/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf
Global Change Research Act	GCRA	https://www.gpo.gov/fdsys/pkg/STATUTE-104/pdf/STATUTE-104-Pg3096.pdf
Federal Water Pollution Control Act	FWPCA	https://www.epa.gov/sites/production/files/2017-08/documents/federal-water-pollution-control-act-508full.pdf
National Environmental Policy Act	NEPA	https://www.epa.gov/laws-regulations/summary-national-environmental-policy-act

Title I of the CAA lists a broad portfolio of research to be conducted by EPA related to air pollution and its health and environmental effects. Section 7403 of the CAA has ten subparts that list the research and development responsibilities of EPA related to the prevention and control of air pollution. The CAA states that EPA shall conduct research "related to the causes, effects (including health and welfare

effects), extent, prevention, and control of air pollution." The CAA further requires that this include "research, testing, and development of methods for sampling, measurement, monitoring, analysis, and modeling of air pollutants" and research on "the short-term and long-term effects of air pollutants … on human health." Further research listed under the CAA includes efforts to "improve understanding of the short-term and long-term causes, effects, and trends of ecosystems damage from air pollutants on ecosystems." These research requirements set the scope of the A-E Research Program.

Under Section 204 of the EISA, EPA is responsible for reporting to Congress, on a triennial basis, on the impacts to date and the likely future impacts on environmental and resource conservation issues from the Renewable Fuel Standard requirements. The A-E Research Program is responsible, in partnership with EPA's Office of Transportation Air Quality (OTAQ) within the Office of Air and Radiation (OAR), for preparation of these reports.

Under requirements of the GCRA, EPA is one of thirteen federal agencies listed as members of the Subcommittee on Global Change Research (SGCR; originally called the Committee on Earth and Environmental Sciences in the GCRA). EPA contributes to the SGCR's responsibilities to develop a national global change research plan, annual reports to Congress, and a mandated quadrennial assessment of the causes and impacts of global change (the National Climate Assessment). Along with the CAA mandate to conduct research on the impacts of air pollution on human health and ecosystems, the A-E Research Program conducts research that contributes to meeting the requirements of the GCRA, specifically related to the effects of global change on air quality, water quality, and ecosystems.

Because the long-term potential impacts of air pollutants in the context of global change rely upon tools developed and used by A-E, the program also responds to the requirements of Section 302(g) of the FWPCA to address threats to ecological and economic well-being of coastal areas associated with those pollutants, including flooding that is affected by sea level rise.

NEPA requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions. Using the NEPA process, agencies evaluate the environmental and related social and economic effects of their proposed actions. Agencies also provide opportunities for public review and comment on those evaluations.

The policy context for the A-E Research Program closely follows the legislative context of the statutes summarized above. The program provides scientific and technical information to support efforts by EPA program and regional partners, state and local agencies, and tribes to develop and implement policies required under the CAA, EISA, GCRA, FWPCA, and NEPA. These policies include review and implementation of the NAAQS, development and review of ambient and source emission measurement methods, evaluations of emission control technologies, assessment of hazardous air pollutant health risks after application of maximum achievable control technology (MACT) standards, and development of Environmental Impact Statements (EIS) and Environmental Assessments (EA).

Environmental Problems and Program Purpose

Ambient air pollution has significant adverse consequences on human health and the environment. Research conducted and supported by ORD has demonstrated that exposure to air pollution can cause a range of human health and environmental welfare effects. These include, for example, respiratory (e.g., asthma) and cardiovascular problems that can lead to disease and death in humans, and environmental

impacts such as visibility impairment, deposition-driven eutrophication, and acidification in surface waters.

Research conducted and supported by EPA has informed and enabled the nation's efforts to curtail air pollution emissions and greatly improve air quality for more than 45 years. As illustrated in Figure 2, aggregate national emissions of the six criteria air pollutants have been reduced by over 70 percent from 1970 to 2017. This progress occurred while the United States economy continued to grow, as indicated by more than a 262 percent increase in gross domestic product. Moreover, Americans drove more miles, and population and energy use increased. Despite this success and the enormous public health benefits that have come from these reductions, in 2016 there were still over 120 million Americans (U.S. EPA, 2018a, p. 8) living in counties that do not meet current NAAQS for one or more criteria air pollutants.

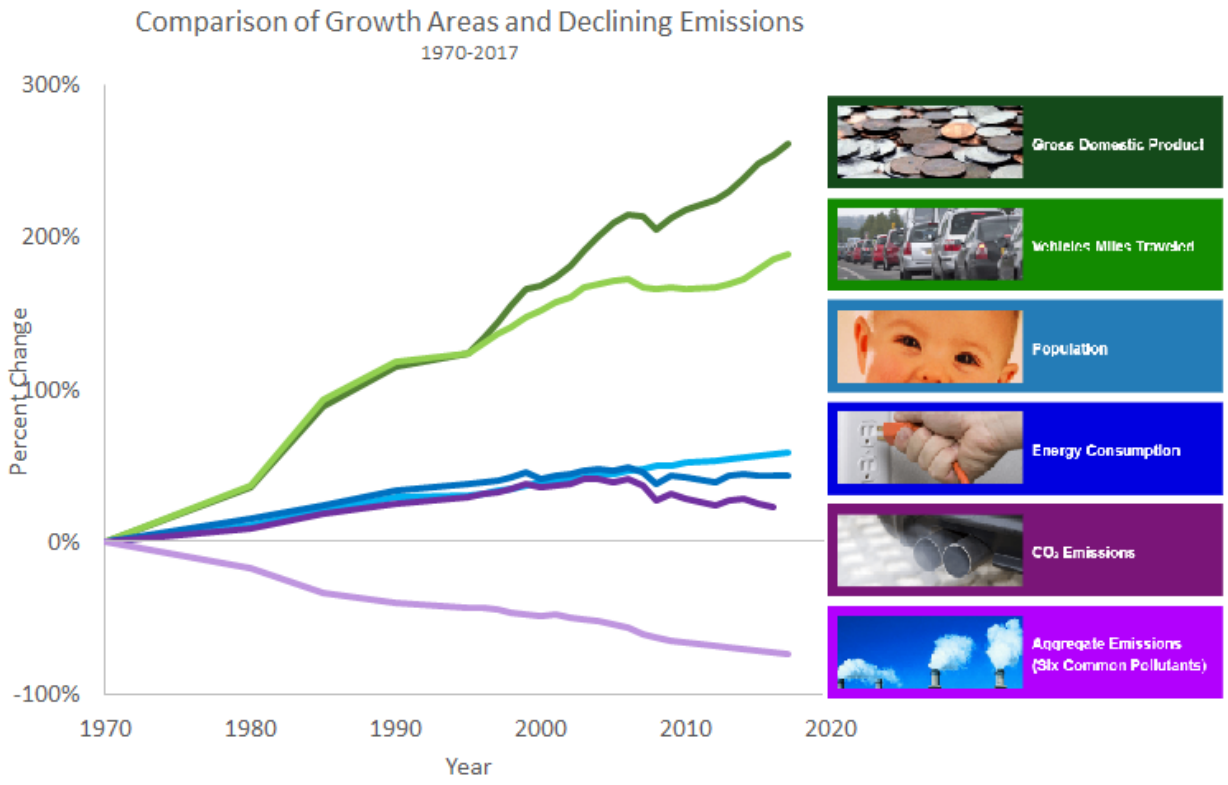

Figure 2. Comparison of Growth Areas and Declining Air Emissions, 1970-2017.[4]

In addition to the existing challenges of improving air quality to meet the NAAQS, the environment is always changing in response to different stressors. The observed increases in frequency and magnitude of extreme events (such as heat waves and extreme precipitation) driven by changes in atmospheric

[4] Source: EPA Air Trends Report (U.S. EPA, 2018c); figure available on-line at: https://gispub.epa.gov/air/trendsreport/2018/#growth_w_cleaner_air

conditions are affecting air quality, water resources, agriculture, wildlife, ecosystems, contaminated sites, waste management practices, and the built environment (e.g., energy, water, and transportation infrastructure) (USGCRP, 2017). These changing environmental conditions are threatening air quality and may ultimately lead to detrimental human health and environmental impacts. For example, higher average and peak temperatures are leading to higher concentrations of some air pollutants and increasing stressors such as heat and allergens that may worsen asthma and other health outcomes (USGCRP, 2016). In addition, the acres of wildlands that have burned annually are estimated to have doubled in recent years (National Interagency Fire Center, 2016), and the contribution from these fires to annual emissions of fine particulate matter (PM2.5) was estimated to be more than 30 percent in 2014 (U.S. EPA, 2016). Research on the health and environmental impacts of extreme events, as well as research on potential adaptation measures, will help inform states, local governments, and tribes on how to plan for and respond to changing environmental conditions and natural disasters.

To achieve and sustain healthy air quality for all Americans, EPA must continue advancing the scientific understanding of air emissions, atmospheric processes, exposure, and effects. Such advances require an in-depth understanding of the relationship between energy and the environment and of the impact of changes in the mix of energy sources and technologies. Energy production and use represents the major source of air pollution emissions; it also impacts water quality and demand, generates liquid and solid waste, and affects ecosystems and the services they provide. The decades-long transition toward natural gas and renewable resources, increasing electrification of industrial processes, and changes in the transportation sector will all affect air pollution emissions and their subsequent health and environmental effects. The health and environmental effects, whether positive or negative, of emissions related to energy production are very likely to be different than what has been experienced in the past. Understanding the environmental trade-offs in the use of different energy sources is crucial to developing and implementing future approaches to improve air quality and reduce the impacts of changing environmental conditions.

The challenges that span the nexus of air, energy, and changing environmental conditions, as well as the major related research needs identified by EPA partners and stakeholders, guide both the **Problem Statement** that governs EPA's A-E strategic research, as well as its **Program Vision.**

Problem Statement

Air pollution adversely affects people's health and harms the economy and the environment. While the nation has made substantial progress in improving air quality, millions of people still live in areas that do not meet national standards and air pollutants continue to damage our health and our environment. The gains of past decades are challenged by changing environmental conditions. To address these problems, we need to expand understanding, information, and tools that enable air-quality managers to: (1) identify and characterize air pollution sources; (2) assess air pollutant exposures and associated health and environmental impacts; and (3) implement effective strategies to reduce air pollution and its risks.

Program Vision

Advance the science needed to achieve clean air and attain the national ambient air quality standards, which will protect human health and ecosystems throughout the United States.

The A-E Research Program builds on the foundation of past accomplishments to deliver the knowledge, tools, and data needed for the future. A-E research efforts support policies that have had far-reaching

positive impacts across the nation, including reducing health risks from air pollution, helping state and local governments and tribes to build resilient and sustainable communities, and protecting the natural environment upon which life depends, even as our population and economy has grown.

Program Design

The A-E StRAP provides both a vision and a blueprint for advancing the science for clean air and environmentally-responsible energy options. It focuses research to achieve the legislative mandates outlined in the relevant statutes briefly discussed above, and on meeting the Agency goals and priorities identified in the EPA and ORD strategic plans. The A-E Research Program works closely with its Agency partners and external stakeholders, including state and local agencies, tribes, sister federal agencies, nonprofit organizations, and industrial and academic scientists, to identify and conduct research to address the highest priority issues across the United States in order to meet the Agency strategic measures as shown in Figure 3.

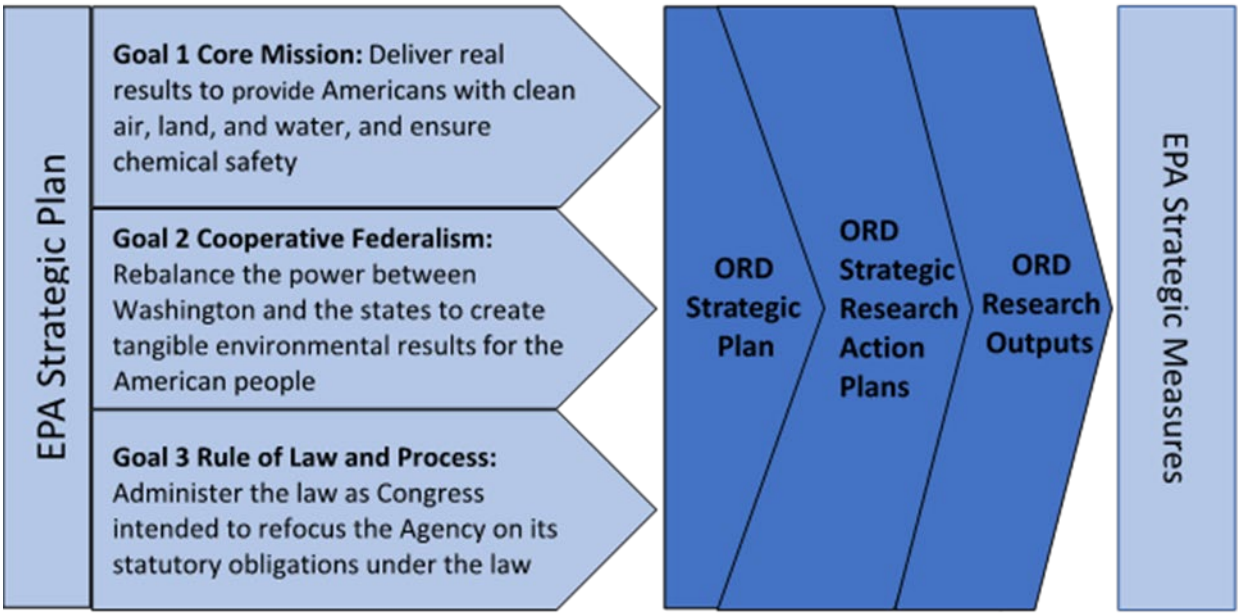

Figure 3: ORD's Strategic Research Action Plans are driven by EPA's Strategic Goals and Objectives to contribute to EPA's Strategic Measures

The A-E Research Program strategically integrates intramural and extramural research efforts to create a robust portfolio. Scientists representing a wide range of disciplines work together to improve our understanding of complex environmental problems. Internally, the A-E Research Program engages with scientists across multiple ORD laboratories and centers. Innovative research collaborations with EPA regional offices (for example, through the Regional Applied Research Effort [RARE] program and the Regional Research Partnership Program [R2P2]) allow A-E researchers opportunities to work with Agency partners on a number of applied science projects to address high-priority, region-specific science needs.

Extramural research funded through grants and contracts complements and expands the intramural research program by providing invaluable engagement between the Agency and the nation's leading scientists and engineers. Integral to ORD's efforts to address environmental research priorities, extramural research engages the scientific community to help address important scientific knowledge gaps and to strategically respond to current and emerging environmental and public health challenges.

The Science to Achieve Results (STAR) grants program is a key extramural component of the A-E Research Program. Previous awards have engaged academic researchers on a broad range of issues advancing our understanding of atmospheric chemistry, air quality modeling and measurements, epidemiology, toxicology, and climate-related impacts. In addition, since 1999 the A-E Research Program has funded a number of university-based research centers through larger, multi-year grants. These research centers have contributed to a greater understanding of the health impacts of particulate matter (PM), determined how specific sources of air pollution cause different health effects, and answered questions about the health impacts from exposure to multiple air pollutants. Beginning in 2016, the A-E Research Program funded three Air, Climate, and Energy (ACE) Centers to identify new integrated and multidisciplinary solutions for protecting air quality and public health in the midst of a changing climate and evolving energy technologies.

Another key component of extramural research is public-private partnerships, which can provide high-quality, impartial science on the health effects of air pollution. By serving as a neutral party, a public-private partnership can sponsor independent science to inform decision-making. Such partnerships are typically formed as nonprofit entities that receive balanced funding from the government and from a regulated industry. In recent years, one well-regarded partnership has advanced scientific understanding in areas such as: multipollutant science; impacts of policies and regulations; and, potential impacts of emerging fuels and technologies.

To a more limited extent, the A-E Research Program has entered into research partnerships through Cooperative Research and Development Agreements (CRADAs). Small businesses have also been funded to develop and commercialize novel environmental technologies that support EPA's mission through the Small Business Innovation Research (SBIR) Program. A-E researchers are also exploring the use of open-source challenges and prize competitions, citizen science and crowd-sourcing, social science, and other emerging, innovative avenues to investigate and address environmental science problems.

Building on the 2016-2019 Program

This plan builds upon and continues to advance the research outlined in the *2016-2019 Air, Climate, and Energy (ACE) StRAP*. Guided by the previous plan, A-E researchers have moved the state of the science forward and provided benefits to public health and the environment, as evident in the following examples:

- **Multi-Ethnic Study of Atherosclerosis (MESA) Air Pollution Study** – In 2004, EPA awarded a STAR research grant to the University of Washington to study how air pollution affects the development of cardiovascular disease in healthy people. The MESA prospective cohort study investigated cardiovascular impacts among more than 6,000 participants over a 10-year period. The researchers reported in 2016 that long-term exposure of people to everyday air pollution accelerates the progression of coronary artery disease. The results are significant from both clinical practice and policy perspectives, emphasizing long-term prevention of exposure to air pollution as a strategy to

mitigate or delay the onset of cardiovascular disease.

- **Helping States Reduce Non-Attainment Areas –** Many areas within the United States still face challenges meeting one or more NAAQS. Fundamental science gaps remain in understanding the unique chemistry and meteorology specific to these locations. These science gaps hinder states' ability to improve air quality. Advanced monitoring research, in collaboration with states, helps develop effective solutions by providing valuable insights into the complex interactions between emissions, chemistry, and meteorology in these nonattainment areas. Partnering with state agencies, short-term intensive field studies were designed to address ozone issues in states bordering Lake Michigan and the Long Island Sound and to understand high wintertime $PM_{2.5}$ concentrations around Salt Lake City, Utah. The insights gained in these studies are helping states improve air quality and public health.

- **Community-Multiscale Air Quality Model (CMAQ)** – CMAQ is a powerful computational tool for air quality management. The EPA continuously updates CMAQ to reflect fundamental advances in physical science research. Revised versions of CMAQ, regularly issued by EPA[5], allow users in states, regional planning organizations, and international organizations to simulate air quality in and around metropolitan areas, identify air pollution hot spots, and develop potential remediation strategies using the most current science. CMAQ links meteorological and emissions models to simultaneously model multiple air pollutants, which helps air quality managers determine the best pollution management strategies for their communities, regions, and states. For example, state and local decision makers used CMAQ data to maintain and achieve clean air that prevented an estimated 2,000 premature deaths per year and 50,000 cases of respiratory ailments in children nationwide (U.S. EPA, 2014). CMAQ also informed analyses conducted to estimate climate impacts on air quality and health for the Climate and Health Assessment (USGCRP, 2016) and the Fourth National Climate Assessment[6] being developed by the USGCRP.

- **Reducing the Environmental Public Health Burden of Wildfires** – Within the last decade, wildfires have increased in frequency and intensity and now burn more than 7 million acres annually within the United States, which is 40 percent more than in previous decades. Wildland fires[7] are a national challenge impacting public health and the environment, as well as the economy. EPA has provided leadership on this issue by conducting research to improve affected communities' understanding of wildland fire emissions. EPA has also provided improved air quality modeling of wildland fire plume rise, transport, and chemical evolution. States impacted by wildland fires require this information to make timely decisions. EPA also conducted toxicological studies to differentiate how the different

[5] CMAQ v5.2.1 was released in March 2018. Learn more at: https://www.epa.gov/cmaq.

[6] Learn more about the Fourth National Climate Assessment (NCA4) at https://www.globalchange.gov/nca4.

[7] Wildland fires occur in relatively natural, undeveloped areas that may include agricultural areas (for example, rangelands) and suburban forests near residential areas. Structures, if any, are widely scattered in these areas. *Wildfires* are any fires started by an unplanned ignition caused by lightning, volcanoes, other acts of nature, unauthorized activity, or accidental, human-caused actions, or a prescribed fire that has developed into a wildfire. *Prescribed fires* are any fires intentionally ignited by management actions in accordance with applicable laws, policies, and regulations to meet specific land or resource management objectives. Prescribed fires include agricultural burning for crop management, as well as fires used for forest management (See 40 CFR 50.1) (See 40 CFR 50.1)

phases of combustion impact human health and how wildland-fire smoke impacts human health compared with a typical urban environment. This research informed the development of an updated *Wildfire Smoke: A Guide for Public Health Officials* (U.S. EPA, 2016b), as well as an innovative Smoke Sense mobile application. The Smoke Sense application provides information on air quality and provides users with strategies to protect their health from wildland fire smoke exposure.[8]

- **Evaluating Urban Resilience** – Urban infrastructures are highly interconnected. There are many systems that supply us with our daily needs, including housing, food, water, energy, safety, communication, and more. If one of these systems is negatively affected, all the others can be impacted and become vulnerable. To decrease vulnerabilities and increase resilience, we must understand how our systems' vulnerabilities affect each other and how the systems are affected by changing environmental conditions and extreme weather events. Working with state and local planners and managers, EPA developed a comprehensive, transparent, and flexible tool that cities can use to identify the greatest risks, successes, and priorities for decreasing urban vulnerability and increasing resilience to climate change (U.S.EPA, 2017). Case studies were conducted with Washington, DC and Worcester, MA. The tool provided visualizations that helped interpret case study results and assisted city managers in implementing climate change adaptation activities. This approach can be applied to a variety of different cities to help target and prioritize adaptation planning.

Input from EPA program and regional office partners provides a clear message that much of the current research and anticipated direction of the A-E Research Program continues to address Agency needs and is responsive to the new EPA strategic plan. The A-E Research Program will continue to:

- Enhance tools for states, local agencies, and tribes to inform emissions reduction strategies
- Improve methods and models for multi-scale air quality management
- Improve monitoring and modeling tools to characterize the relationship between ambient air quality, deposition, and multimedia ecosystem impacts
- Improve monitoring methods for source emissions, ambient air, and human/ecological exposures, including use of air pollution sensors
- Improve monitoring methods for source emissions, ambient air, and human/ecological exposures, including use of air pollution sensors
- Advance methods to evaluate risks and inform decision making in a changing environment
- Expand capabilities to understand risks related to extreme events and emerging air pollutants, such as per-and polyfluoroalkyl substances (PFAS)
- Enhance understanding of wildland fire impacts on air quality, exposures, health, and ecosystems
- Improve energy-system scenarios development and evaluation

[8] A-E researchers are conducting a citizen science study using the Smoke Sense application to determine the extent to which exposure to wildland fire smoke affects health and productivity and to evaluate health risk communication strategies during smoke days. Learn more at: https://www.epa.gov/air-research/smoke-sense-study-citizen-science-project-using-mobile-app.

- Expand translation of research and the format of deliverables so that they are useful for EPA partners and key external stakeholders

To more efficiently and effectively address critical research questions and more clearly align with the FY*2018-2022 EPA Strategic Plan*, the A-E Research Program is updating its structure to organize research into the following three inter-related topics:

1. Science for Air Quality Decisions
2. Extreme Events and Emerging Risks
3. Next-Generation Methods to Improve Public Health and the Environment

Many scientific issues cut across these three A-E topics. Figure 4 is a conceptual diagram illustrating the intersection of the topics, using wildland fires as an example of an integrated science focus that draws from each topic. The topics and specific research areas within each topic are described in more detail in the Research Topics section below.

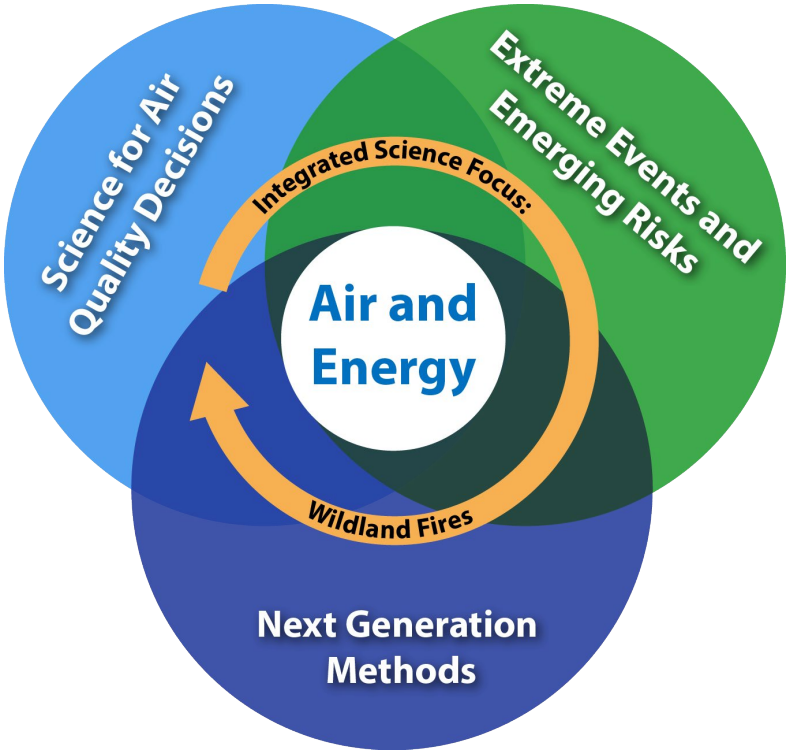

Figure 4. Air and Energy research topics.

Solutions-Driven Research

ORD is renewing and expanding our commitment to producing research that addresses real-world problems and helps EPA program and regional office partners, state and local agencies, as well as tribal organizations, to make timely decisions based on science. This commitment includes exploring ways to improve research processes through the application of a solutions-driven research framework. Solutions-driven research emphasizes:

1) Planned partner and stakeholder engagement throughout the research process, starting with problem formulation and informing all elements of research planning, implementation, dissemination, and evaluation
2) A focus on solutions-oriented research outputs identified in collaboration with partners and stakeholders
3) Coordination, communication, and collaboration both among ORD researchers and between researchers and partners to develop integrated research that multiplies value to partners and stakeholders
4) Application of research outputs in cooperation with partners and stakeholders to solve complex environmental problems, and to test the feasibility, appropriateness, meaningfulness, and effectiveness of the research-driven solutions

ORD will also study how we engage with our stakeholders and partners and how we design and conduct our research to inform solutions to their most pressing environmental problems. By doing this, we are engaging in translational science, which will continually improve and increase the value of our research to our partners and stakeholders. Translational science is a widely practiced approach developed by the National Institutes for Health (https://ncats.nih.gov/) to "understand the scientific and operational principles underlying each step of the translational process," which moves science along the path from lab research to practical solutions in real world circumstances.

ORD is adopting a 3-pronged strategy for solutions-driven research:

1) Apply principles of solutions-driven research broadly across ORD's six national research programs
2) Conduct pilot translational science projects that apply and evaluate methods of solutions-driven research to planning, conducting, applying, and evaluating integrated research that addresses a well-defined and unmet need of partners and stakeholders
3) Conduct case studies of previous and current research activities that embody the principles of solutions-driven research, which will help inform a list of best practices

Risk communication is a central factor in solutions-driven research, allowing people to understand their risks and adopt protective behaviors, as well as informing risk management decisions. ORD will emphasize advances in the science of risk communication and will apply best practices for communicating risk to different audiences across the six national research programs.

Consistent with Objective 3.3 in EPA's Strategic Plan, ORD will work with our partners and stakeholders to identify the most important environmental and public health problems they face and then provide the high-quality science they need to address those problems[9]. ORD will continue to support our research outputs after they are delivered to our partners and stakeholders, and in doing this, ORD will evaluate the usefulness and effectiveness of our research in helping solve environmental and public health problems.

[9] U.S. EPA. 2018. FY 2018-2022 EPA strategic plan. February 12. https://www.epa.gov/sites/production/files/2018-02/documents/fy-2018-2022-epa-strategic-plan.pdf

Integration Among Research Programs

EPA's six research programs work together to identify and address science challenges. Coordination efforts can range from formal integration across the programs, to collaboration among EPA scientists working on related issues. There are many opportunities for integration among the programs, and the research programs will continue to work together to identify additional opportunities. Based on feedback from EPA program and regional partners, state and local agencies, tribes, other federal agencies, and ORD scientists, the A-E Research Program is coordinating with other EPA national research programs in several areas. These include:

Wildland Fires

Wildland fires are a persistent and pervasive multimedia issue. Wildland fires affect air and water quality in and around the locations of fires, as well as more broadly. A changing environment also increases the likelihood and severity of wildfires and changes the optimal window for the prescribed burning season. Research in this area involves multiple ORD research programs, specifically A-E, SSWR, SHC, HSRP, and CSS. A-E research will focus on improving our understanding of wildland fire impacts on public and environmental health and informing approaches to reduce associated risks. This will include improving models and measurement methodologies to assess emissions and determine impacts, determining what ecosystems and human populations are susceptible and vulnerable to wildland fires, developing approaches to mitigate risks to human health and ecosystems, and developing health risk communication strategies. Because wildland fires can also affect drinking water quality through increased sedimentation, mobilization of heavy metals and other pollutants, and shifts in treatment processes and associated effects, A-E and SSWR will work together to address this cross-media issue. This cross-cutting project will provide information needed by utilities to anticipate and respond to wildfire impacts, with SSWR emphasizing drinking water resources and small drinking water systems. HSRP will also contribute to ORD's work on wildland fires by researching fate and transport of contaminants during wildland fires, for example, fire in asbestos-contaminated areas.

Nutrients

The cross-ORD Nutrient effort led by SSWR is focused on reducing the nutrient loadings that can cause adverse environmental impacts (e.g., degradation of drinking, source, and recreational waters from harmful algal blooms). The nutrient research effort uses an approach that spans multiple types of water bodies and groundwater resources, and coordinates across media (water, land, and air) and various temporal and spatial scales. This effort develops and applies scientific information and tools for partners and stakeholders to develop cost-effective approaches to nutrient reduction. This research addresses statutory obligations under the CWA, SWDA, and CAA and is designed to support EPA's Office of Water (OW), OAR, Office of Land and Emergency Management (OLEM), regions, and cross-Federal Agency efforts. ORD's nutrient research priorities are: (1) assessing and managing harmful algal blooms; (2) providing the science needed to set effective nutrient-related water quality goals; (3) providing tools, technologies, and best practices to predict, monitor, manage, and assess effectiveness of efforts to reduce nutrients; and (4) synthesizing information and developing tools that address atmospheric nutrient deposition impacts (e.g.,, eutrophication and acidification) on terrestrial and aquatic resources. A-E research directly supports the last priority by characterizing deposition of airborne nitrogen compounds to watersheds and waterbodies that may contribute to harmful algal blooms.

PFAS

The cross-ORD PFAS research program develops and applies scientific information and tools so that partners and stakeholders can make informed decisions to protect public health and the environment from harm associated with PFAS. It supports cross-EPA and cross-federal agency efforts to address PFAS. This research addresses statutory obligations under the Safe Drinking Water Act (SDWA), the Clean Water Act (CWA), CAA, the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The four goals of ORD's PFAS action plan are: (1) understanding human health and ecological effects of PFAS; (2) understanding PFAS occurrence, fate and transport, and exposure; (3) reducing, removing, and remediating PFAS in the environment; and (4) supporting stakeholders in protecting public health and the environment. A-E research will focus on developing and applying sampling and analytical methods as well as modeling approaches to assess the emissions, fate, and transport of PFAS in the atmosphere.

Resilience

The cross-ORD resilience effort is focused on preparing for and recovering from disasters, including extreme weather events. This work helps meet the safety and resilience goals of EPA regions and programs and ORD's state, tribal, and community stakeholders. Adequate preparation for and recovery from disasters requires a complete picture of an affected system. During a disaster, certain events can cause cascading problems that may be missed by examination from the perspective of a single-media program, highlighting the importance of integration on this issue across ORD's research programs. ORD's resilience research will deliver metrics, methods, and tools that EPA partners and stakeholders can use to assess their own vulnerability to, preparedness for, and response and recovery from environmental releases and other conditions due to extreme weather and other disasters. ORD's research will advance the assessment of trends in and development of future scenario products for disasters for EPA clients (A-E), and address resilience and preparedness with respect to immediate emergency response (HSRP), long-term planning for resilient communities (SHC), contaminated site remedies (SHC), and watersheds and water infrastructure (SSWR).

A-E and the other national research programs have additional research activities that complement each other by focusing on different facets of related public health and environmental problems. These efforts are briefly summarized in Appendix 3.

Lead

Lead (Pb) is a priority research issue given its prevalence in the environment, harmful neurological and other health effects and impacts on the most vulnerable, particularly children. Lead is one of the six criteria air pollutants for which EPA has established NAAQS. The CAA requires that the Agency periodically review the science upon which the NAAQS are based and the standards themselves. EPA completed its most recent review of the Pb NAAQS in 2016.[10] Priority areas of lead research for our partners in the Office of Air and Radiation include new information related to assessments and biomodelling research. This work is carried out by our colleagues in the Human Health Risk Assessment (HHRA) Research Program. In addition, our colleagues in the Sustainable and Healthy Communities

[10] Learn more about the most recent review of the Lead NAAQS at: https://www.epa.gov/lead-air-pollution/national-ambient-air-quality-standards-naaqs-lead-pb.

(SHC) Research Program are incorporating the air pathway into their multimedia modeling efforts on lead. While air exposures are not a high priority as a national problem, there can be local exposures from specific sources. A-E will work collaboratively with our colleagues in HHRA and SHC to ensure impacts from lead in the air are addressed by ORD.

Research Program Objectives

The overall goal for the A-E Research Program is to advance the science and provide information critical for improving air quality and addressing impacts that are influenced by changes to the nation's energy portfolio, technological advances, and environmental conditions. Moreover, the A-E Research Program is aimed at providing strategies and solutions to reduce exposures and risks from air pollution. The A-E Research Program is structured to provide research results that fulfill EPA mandates and priorities, meet the needs of partners and stakeholders, fill knowledge gaps within broader efforts across the Federal government, and complement research being conducted by the larger scientific community.

The program is strategically divided into four broad research objectives that flow from the *FY 2018-22 EPA Strategic Plan*. The work supported through the A-E Research Program addresses EPA's goal of improving the nation's air quality and emphasizes efforts to focus on the highest priorities identified by partners and stakeholders.

The following research objectives encompass the breadth and diversity of the A-E Research Program's portfolio:

> **Research Objective 1: Assess Impacts** — Improve understanding of the processes regulating human and ecosystem exposures and of the effects associated with air pollutants at individual, community, regional, national, and global scales.
>
> **Research Objective 2: Expand Approaches to Prevent and Reduce Emissions** — Develop and evaluate approaches to prevent and reduce air pollution now and in the future, particularly sustainable, cost-effective, and innovative multi-pollutant and sector-based approaches.
>
> **Research Objective 3: Advance Measurement and Modeling** — Improve the human exposure and environmental modeling, monitoring, metrics, and information that are needed to address emerging and future risks and inform air quality decision making at the national, state, tribal, and local levels.
>
> **Research Objective 4: Inform Decisions** – Deliver state-of-the-art science and tools to inform implementation of the NAAQS and other air quality regulations and policies at the national, state, tribal, and local levels.

Consistent with the principles and characteristics of all ORD research programs, the A-E Research Program objectives and challenges outlined below will provide effective and innovative solutions to environmental problems. As described below, each research objective addresses a range of science challenges to further focus the expertise and research activities of technical staff to meet the overall strategic vision of the program.

Objective 1: Assess Impacts

Research Objective: *Improve understanding of the processes regulating human and ecosystem exposures and of the effects associated with air pollutants at individual, community, regional, national, and global scales.*

The effects of air pollutants on public health and the environment occur at multiple scales and result from exposures to a mixture of pollutants in the atmosphere. In addition to other factors, exposures and human and environmental effects are also impacted by complex interactions between climate and air quality.

One of EPA's primary responsibilities is to set, periodically review, and, if appropriate, revise the NAAQS for pollutants commonly found in outdoor air that are emitted from numerous diverse sources and are considered harmful to public health and the environment. Currently, EPA has established NAAQS for six criteria air pollutants – carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide. The establishment and review of the NAAQS is a complex undertaking, involving synthesis of the extensive science on human and ecosystems impacts of air pollution. The A-E Research Program works closely with the Human Health Risk Assessment (HHRA) Research Program in carrying out the research needed to inform the NAAQS reviews.

The effects of a changing environment on air and water quality are characterized by complex synergies between human and natural systems. Social and economic factors also impact the nature and degree of exposures and the resulting health and ecological effects that may occur. For example, many states have experienced an increase in intensity and duration of wildfires with serious impacts on human health, ecosystems, and air quality. People living near and downwind from fires may be affected by smoke exposures, with impacts that vary by what and how materials are burning, their individual susceptibility and vulnerability, the duration and level of exposure, and other factors.

Factors that put people or ecosystems at risk from exposure to air pollution (e.g., lifestage, pre-existing disease, genetics/epigenetics, and socioeconomics) must be considered to fully assess impacts, inform air quality management decisions, and target risk communication strategies aimed at reducing exposures to and risks from air pollution. These factors are also important as communities assess how best to adapt to extreme weather events that are expected to increase over time.

New and innovative methods and models are needed to assess the multiple chemical and non-chemical interactions that ultimately impact public health and welfare. To inform their decision making, stakeholders and partners need quantitative assessments that describe exposures and potential human and ecosystem effects associated with air pollutants and that also describe the impacts of changing environmental conditions on human health, air quality, and water quality. There are also unprecedented quantities of health and exposure data resulting from new technologies and the growing popularity of citizen science and individualized medicine, and innovative approaches are needed to enhance the assessment of this vast amount of data. The A-E Research Program has a strong commitment to translate the science it produces to better inform decisions, development of regulations, policies, and advisories to reduce risks associated with air pollution.

Science Challenges:

- *Address key uncertainties and data gaps to inform future reviews of the NAAQS*

- *Develop innovative approaches for assessing human and environmental exposures and effects of pollutants in the atmosphere*
- *Advance understanding of the potential impacts of emerging and future risks to human health, air quality, water quality, ecosystems, and built infrastructure*
- *Identify the biological, environmental, social, behavioral, and economic characteristics that put populations and ecosystems at increased risk of effects from exposure to air pollutants and the associated impacts of a changing climate*
- *Identify the social, behavioral, and economic factors that may hinder the ability of communities and individuals to prepare and implement adaptation strategies for changes in climate*
- *Characterize the multipollutant exposures, effects, and integrated impacts of dynamic environmental conditions on health, air and water quality, and ecosystems*

Objective 2: Expand Approaches to Prevent and Reduce Emissions

Research Objective: *Develop and evaluate new approaches to prevent and reduce air pollution, now and in the future*, *particularly sustainable, cost-effective, and innovative multi-pollutant and sector-based approaches.*

When making environmental decisions, decision makers are challenged by the complex environmental, economic, and social interactions of various management options. These challenges highlight the need for innovative approaches that include economic and social factors to maximize public health benefits while preventing and reducing emissions, meeting environmental standards, and gaining improvements in air quality, human health, and the environment.

As a result of this complexity, there is a growing need for cost-effective, multipollutant strategies that prevent air pollution without unintended environmental, economic, or social consequences. Decision makers are exploring approaches that simultaneously address multiple pollutants as an alternative to the one-pollutant-at-a-time approach. For example, sector-based approaches can more holistically assess environmental concerns and develop focused solutions specific to energy production, transportation, and other sectors. To ensure the best outcomes for public health and the environment, we must understand the full life-cycle health and environmental impacts of technology and management options in each sector, as well as the economic, social, and cultural factors that can impact uptake and sustained use of these options.

Another important aspect of air quality management is that emissions of air pollution in one location can have impacts in other locations – at local, regional, national, and international scales. Expanding our understanding of long-range transport of air pollutants from international sources is an important consideration to inform U.S.-based policies to improve domestic air quality. For example, A-E researchers are working with an international task force on Hemispheric Transport of Air Pollution (HTAP) to improve methods to quantify global influences on regional air quality. A-E researchers are also working with HTAP to evaluate and better understand air pollution control options and their impacts at the intercontinental to global scales. This includes collaborative efforts between North American and European regional-scale air quality modeling efforts through the Air Quality Model Evaluation International Initiative (AQMEII). These efforts will inform the Convention on Long-range Transboundary Air Pollution (LRTAP) and other international efforts to reduce air pollutants and related impacts.

Identifying the most cost-effective and sustainable approaches to achieve environmental outcomes also requires consideration of economic and social factors. The success of a strategy to prevent or reduce pollution depends not only on the effectiveness of the technical approach, but also on social, behavioral, and economic factors that affect the willingness of people or institutions to adopt the strategy.

Science Challenges:

- *Advance the science of air pollution dynamics and chemistry to improve the assessment of related health and ecological effects and to support the management of air pollution problems across different scales of time and space.*
- *Develop methods and obtain data to conduct life-cycle analyses of alternative pollution reduction and energy sources. This will inform decisions made by EPA and other local, regional, national, and international organizations to ensure more sustainable and cost-effective environmental protection.*
- *Evaluate control technologies and identify best practices for more efficient integrated and sustainable pollution reduction and prevention solutions, while taking into account relevant social, behavioral, and economic factors.*

Objective 3: Advance Measurement and Modeling

Research Objective *Improve human exposure and environmental modeling, monitoring, metrics, and information needed to address emerging and future risks and to inform air quality decision making at the national, state, tribal, and local levels.*

Expanding our knowledge of the sources of air pollutants, how they are transported through the environment, and how people and ecosystems are exposed will lead to more effective and targeted air quality management solutions. As environmental conditions change over time, air pollution transport and exposures will be affected. Measurement and modeling sciences are key to understanding current air pollution exposures and emerging and future risks.

Environmental monitoring technology is rapidly evolving, showing great advances from year to year. The availability of new advanced monitoring technologies, spanning from lower-cost, emerging sensors to high-end complex instruments, is increasing. In many cases, these newer technologies are used to complement traditional regulatory monitoring methods. Lower-cost technologies are growing in popularity with a wide range of users who are interested in near-real time information at finer local scales. The rapid advance of lower cost sensors, although not currently targeted at regulatory applications, has created more efficient ways for EPA, industry, state and local agencies, and tribes to track leaks and emissions, conduct research, identify hotspots, and prioritize where to monitor with more sophisticated instrumentation. These new technologies have great potential for a number of applications, such as improving information to enhance characterization of human exposures and ground-truthing estimates from satellites and models with ground-level measurements. Uncertainty in their performance over time remains high, however, and requires greater focus on evaluation and data quality. Questions also remain about how communities and individuals will use lower-cost sensors and how data may be used to inform decisions.

Advances in air quality modeling and the integration of modeling simulations with observational data, including ambient measurements, are needed to better understand air quality at a very local scale. This

is because variations occur from neighborhood to neighborhood, and localized solutions may prove to be highly effective. This research would include expanding knowledge of near-source impacts and control strategies, including near-road environments, complex multi-source environments, and rail yards, ports, and other transportation facilities. Improvements are also needed in modeling and measurement capabilities to quantify and predict wildland fire impacts on air quality that can be used to reduce risks to affected communities and individuals. Additional air quality modeling challenges are presented by complex terrain and high elevations with valley inversions in winter, stratospheric contributions to tropospheric ozone, and international pollutant transport. Changes at the global scale can also affect air quality, and research is needed to improve the models that connect these global scale changes to regional and local air quality. Additionally, environmental conditions continue to evolve as the climate changes. EPA partners, states, tribes, communities, and individuals are interested in understanding how changing temperatures will affect air quality, watersheds, and ecosystems, including what the potential health and environmental impacts will be and where and to what extent these impacts are likely to occur. Advances in monitoring and modeling methods, providing greater temporal and spatial detail, near real-time local data, and plausible future scenarios can provide the information needed to better prepare and adapt to future changes. EPA has an important role to play in providing understandable and useful information to help a wide range of stakeholders prepare and implement adaptation strategies.

Science Challenges:

- *Pursue and evaluate innovations in monitoring and modeling to:*

  (1) better characterize air pollution interactions across global, regional, local, and neighborhood scales as well as various time scales;

  (2) inform strategies to address emerging environmental problems caused by changing atmospheric conditions; and

  (3) enhance exposure assessments and science to inform decisions that reduce air pollution-related risks associated with various sources
- *Evaluate preparedness and adaptation strategies to mitigate air pollutant and climate impacts to protect at-risk populations, communities, and ecosystems.*

Objective 4: Inform Decisions

Research Objective: *Deliver state-of-the-art science and tools to inform decision making for implementation of the NAAQS and other air quality regulations and policies at the national, state, tribal, and local levels*.

Decision makers across the country need accurate, timely, and reliable information and tools to make sound decisions about environmental and public health protection. The A-E Research Program recognizes the need to regularly engage with its partners and stakeholders and to effectively translate and deliver robust and relevant research results to inform assessments, policy design, and implementation activities, including implementation of the NAAQS.

States and tribes have the lead responsibility for implementing many air quality regulations. EPA provides science and tools to assist these partners and other stakeholders in identifying, characterizing, and understanding their air pollution problems. EPA also provides science and tools to evaluate and

implement alternative management strategies to improve air quality and public health. The scope of the tools and information developed by the A-E Research Program includes air quality models, data on emissions of air pollution from a wide range of air pollution sources, measurement methods for detection of air pollutants, and targeted studies of health and environmental impacts of air pollutants under varying environmental conditions.

Science Challenges

- *Provide EPA partners, states, tribes, and others with scientifically-robust, user-friendly information based on state-of-the-science measurement technologies and modeling methods to support implementation of air quality regulations and policies.*
- *Deliver information and methods to inform decisions by states, tribes, communities, and individuals to prepare for, and adapt to, emerging and future risks of air pollution.*

Research Topics

The four research objectives described above serve as the framework for identifying research topics to focus the scope and nature of the A-E Research Program over the next four years. The vision and program structure described in this A-E StRAP build on the previous 2016-2019 ACE StRAP and support the Agency priorities as outlined in the *FY 2018-2022 EPA Strategic Plan*.

The A-E Research Program is updating its organization to improve integration across multiple scientific disciplines and better leverage resources to more efficiently and effectively address critical research needs, as well as enhance translation and accessibility of science to inform the decisions of Agency partners and stakeholders. The program will be centered around three interconnected research topics consisting of eight research areas, plus an integrated science research area focused on wildland fires that cuts across all three research topics. The topics and research areas are shown in Table 3. The research topics focus on meeting the research needs of EPA's partners and stakeholders, filling knowledge gaps, and leveraging and complementing related efforts supported by ORD's other national research programs, other federal agencies, and the broader scientific community. Proposed high-level, strategic A-E outputs that are responsive to partners' needs are summarized by topic and research area in Appendix 1. Outputs are deliverables with the research results synthesized and/or translated into the format needed by the end user(s). Research to address partners' needs and contribute to the development of these outputs is described in the research area descriptions below. The A-E research portfolio outlined in this strategic plan closely coordinates intramural and extramural efforts to provide a balance of fundamental and applied science to deliver outputs that are effectively developed and translated to solve environmental problems.

Table 3. Overview of Air and Energy Research Program Structure

Topic	Research Areas	
Science for Air Quality Decisions	#1: Approaches to support air quality management for multiple pollutants at multiple scales	#9: Wildland Fires (Integrated Science Focus)
	#2: Approaches for characterizing source emissions, air quality, exposure, and mitigation strategies	
	#3: Public Health and Environmental responses to air pollution	
Extreme Events and Emerging Risks	#4: Public health and environmental exposures and responses to emerging air pollutants and extreme weather events	
	#5: Methods to evaluate environmental benefits and consequences of a changing energy system	
	#6: Methods to enable resilience to future environmental stressors	
Next-Generation Methods to Improve Public Health and the Environment	#7: Emerging approaches to improve air quality and exposure characterization	
	#8: Novel approaches to assess human health and ecosystem impacts and risks	

Topic 1: Science for Air Quality Decisions (AQD)

Research under this topic will continue to provide science to inform decisions made by partners and stakeholders to improve the nation's air quality, reduce the number of nonattainment areas, implement and enforce stationary and mobile source regulations, and expand public health and welfare protections. Science to inform air quality decisions directly relates to achieving all four of the A-E Research Program Objectives discussed in the previous section. The A-E Research Program will provide data, tools, and information to inform strategies to reduce air pollutant emissions, exposures, and related risks to public health and the environment. The research conducted within the AQD topic area will build upon and extend work conducted under the 2016-2019 ACE StRAP with necessary modifications considering scientific and policy advancements that have been made over the past four years. These efforts will also be closely connected, as appropriate, with work completed within the other two research topics discussed below.

The evolution of the A-E Research Program includes a broader public health context focused on delivering effective, relevant, and robust science to better explain and reduce uncertainties in observed public and environmental health effects of air pollutants, and may offer more effective support for adapting to climate change. The research under this topic will encompass a range of scientific disciplines to produce integrated and comprehensive outputs that remain responsive, timely, and useful. The A-E Research Program will continue to conduct research to assess multipollutant exposures and health effects in field and laboratory settings. This work will include evaluating simple and complex mixtures of particles, criteria gases, and organic compounds. Researchers will develop, evaluate, modify, and apply models and methods to assess human and environmental exposures and impacts of air pollution and associated climate-related changes at individual, community, regional, national, and international scales. This work is the core that supports NAAQS development, review, and implementation. These efforts are essential and will be continued through a range of intramural and

extramural research activities (e.g., grants supported through the STAR program), as well as collaborative efforts with other federal agencies, EPA program and regional partners, states, local agencies, tribes, and other stakeholder groups.

Research Area 1: Approaches to Support Air Quality Management Programs for Multiple Pollutants at Multiple Scales

The A-E Research Program will continue to develop, evaluate, and apply methods and models to support air quality management programs. This work includes enhancing capabilities to conduct multipollutant air quality assessments at local, regional, national, and global scales and further developing multimedia and multi-stressor models to address complex environmental issues.

The Community Multiscale Air Quality (CMAQ) modeling system[11], a core component of the A-E Research Program, combines meteorological, emissions, and air-chemistry transport and deposition models that can be used to explore the estimated short- and long-term impacts of different policy and regulatory options, including actions to attain the NAAQS and long-term impacts of the changing environment. CMAQ has served as a powerful and trustworthy computational tool for EPA's programs and regions, states, and tribes to evaluate different air pollution scenarios for two decades.

Developed and maintained by EPA scientists based on more than three decades of air pollution research, the CMAQ modeling system continues to evolve scientifically to better represent how complex mixtures of air pollutants are formed, transported, and eventually removed from the atmosphere. A-E researchers lead efforts to conduct and apply fundamental physical science research that improves CMAQ's representation of complex atmospheric chemistry and dynamics. Also, as a result of CMAQ being publicly available, a vibrant global user community has fostered collaborations with state, federal, industrial, and academic institutions in the United States and around the world to assess and improve the model's functionality.

Currently, CMAQ developers are broadening its scope to enhance its ability to consider atmospheric phenomena from the global scale to the neighborhood scale. These efforts are important for understanding the impacts of human activities and intervention strategies at all levels. Examples of specific areas of on-going research include the following: improving the quantification of the contributions of local and regional sources versus background contributions (such as trans-Pacific transport of air pollution) to non-attainment areas, which will inform efficient and effective NAAQS attainment strategies; improving representation of secondary organic aerosol (SOA); enhancing our understanding of the removal processes of atmospheric pollutants; improving knowledge of boundary layer meteorology; and expanding our understanding of wildland fire impacts on local- to continental-scale pollution.

Atmospheric deposition of nitrogen, sulfur, and other pollutants is an important exposure pathway to consider as we improve our understanding of air pollutant impacts on ecosystems and water quality, including the impacts of agricultural sources such as animal feeding operations (AFOs). A-E researchers are improving the characterization of emissions from animal and crop agricultural operations including improving our understanding of ammonia (NH_3), PM, and volatile organic compound (VOC) emissions

[11] Learn more about CMAQ: The Community Multiscale Air Quality Modeling System at https://www.epa.gov/cmaq.

form AFOs related to manure application as well as NH_3 and oxides of nitrogen (NO_x) soil emissions from fertilizer applications. These researchers are also working collaboratively with EPA regional and program office partners and colleagues in the USDA to evaluate best management practices (BMPs) for mitigation. Furthermore, through the National Atmospheric Deposition Program (NADP) Total Deposition (TDEP) Science Committee, A-E researchers and colleagues advance the science of measuring and modeling atmospheric wet, dry, and total deposition of nitrogen, sulfur, and mercury. The CMAQ model is used to predict the exposure of plants, animals, soil, and water to air pollutants. For example, atmospheric deposition is the second largest source of nitrogen to the Chesapeake Bay watershed. Researchers used CMAQ to model nitrogen deposition and the results were used by the Chesapeake Bay Program (CBP) to understand the reduction of atmospheric nitrogen loading over the past few decades.[12]

EPA regions, as well as state and local agencies and tribes, often use models in the permitting review process to estimate air pollutant concentrations at specified ground-level receptors surrounding particular sources. A-E researchers will continue to work closely with OAR to develop and refine air dispersion models to assess local-scale impacts of a variety of sources. For example, ORD collaborates with OAR on the AERMOD modeling system[13] which informs State Implementation Plan (SIP) revisions and analyses required for the New Source Review (NSR) and Prevention of Significant Deterioration (PSD) permitting programs. AERMOD also informs risk and technology reviews for sources of hazardous air pollutants (HAPs) required under section 112(d)(6) of the CAA. A-E scientists conduct meteorological wind tunnel studies to develop data sets and improve algorithms that enhance AERMOD's fine-scale modeling simulation of building downwash, accounting for the influence that buildings and other structures have on the flow and dispersion of air pollutant plumes.

EPA program and regional office partners, as well as states, local agencies, and tribes, have also expressed a strong interest in better understanding air pollutant exposures in near-road environments. The R-LINE model[14] is currently under development by ORD to improve our understanding of temporal and spatial variability of mobile source-related pollutants near major roadways. In addition, A-E researchers are exploring opportunities to improve characterization using measurements and modeling of complex roadway configurations, including the effects of noise and vegetative roadside barriers, elevated roadways and bridges, and depressed roadways.

Source and ambient measurements provide empirical observations of complex phenomena and basic ground-truthing to evaluate models. A-E researchers will continue to explore opportunities to use a combination of ground-based, satellite, and aircraft/ship-based measurements to assess and improve the accuracy of modeling systems and enhance our understanding of factors that influence the distribution and fate of air pollutants.

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[12] CBP is a unique regional partnership focused on restoration and protection of this important estuary. CBP partners include federal and state agencies, local governments, non-profit-organizations, and academic institutions. Learn more at https://www.chesapeakebay.net/discover.

[13] Information on preferred and recommended air quality dispersion models including the AERMOD modeling system is available at https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models.

[14] The R-Line model is a research grade dispersion model that is currently being developed by ORD, and will allow partners and stakeholders to evaluate air quality impacts in the near-road environment (https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models).

Complex nonattainment areas provide unique challenges for air quality managers. The A-E Research Program will continue to support efforts that improve the characterization of criteria pollutants in such areas (e.g., ground-level ozone photochemical formation in near-shore environments). More broadly, the program will also conduct research to enhance assessments of long-range transport of air pollutants, particularly related to wildland fire plumes, and to advance methods that estimate background contributions to PM and ozone.

EPA partners and stakeholders are often asked to evaluate multimedia exposures and are interested in improved assessment methods to better understand the multitude of linkages across air, water, and land boundaries to estimate potential public health and environmental impacts that would not otherwise be understood using single-media models. Beyond using CMAQ and other focused air quality tools to understand synergies and tradeoffs associated with various mitigation and pollution prevention strategies, A-E researchers are developing a multimedia and multi-stressor modeling system to inform actions that protect human health and welfare. This work includes connecting and improving a variety of models to characterize the cumulative effects of pollutants across media. The work also includes advancing air-surface exchange characterization in regional air quality models and the existing "one-environment" modeling paradigm to address air quality impacts from changes in drivers, such as land use and climate changes.

Building on the successes of the modeling systems discussed above, A-E researchers will develop and evaluate a new paradigm for air quality modeling using an updated architecture to increase computational efficiency and applicability as discussed in Research Topic 3 below.

Program, regional, state, and/or tribal needs

EPA partners and state, local, and tribal air quality managers need reliable information to inform decisions on effective and efficient ways for improving air quality. Collectively, the results of the research in this area will provide robust and comprehensive datasets and modeling tools that can be applied across different spatial scales to: (1) characterize the role of background air pollution on NAAQS attainment and implementation; (2) support the development of major energy and transportation sector rules; (3) inform permitting decisions; (4) assess risks posed by criteria and hazardous air pollutants (HAPs); and (5) develop local and regional-scale air quality and related climate data products.

Research Area 2: Approaches for Characterizing Source Emissions, Air Quality, Exposure, and Mitigation Strategies

Developing, evaluating, and applying methods that improve characterization of source emissions, air quality, and exposures will continue to be essential components of the A-E Research Program. This work supports critical Agency programs, including applications for implementation and compliance with relevant air pollution standards. Work within this research area will include laboratory and collaborative field studies.

Federal Reference Methods (FRMs) and Federal Equivalent Methods (FEMs) are used to inform NAAQS attainment/nonattainment decisions and are used for a wide range of analyses. Designating FRMs and

FEMs is a core element of A-E's ambient air measurements program.[15] Accuracy, durability, ease of use, and cost-drivers are major factors.

In addition, A-E researchers will continue to collaborate with OAR to update and, where possible, develop improved methods to measure hazardous air pollutants (HAPs) in ambient air. This work will include considering updates to methods for toxic organic pollutants in ambient air.

To better inform decision makers, A-E researchers will continue to develop, evaluate, and apply models and methods that improve spatial and temporal characterization of human and environmental exposures for individual and mixtures of air pollutants. Research and data collection efforts will be directed at improving our understanding of exposure-related factors that influence the magnitude and duration of air pollutant exposures and at expanding the knowledge base of factors that contribute to regional differences.

Beyond considering impacts of ambient air quality, the health impacts of indoor air pollutants are also of interest. A-E researchers are developing an indoor air chemistry model that will provide guidance on how to reduce exposures, improve our understanding of how ambient air pollutants infiltrate indoors, and provide solutions for reducing air pollutant exposures within buildings. Additionally, residential wood combustion used to provide energy for cooking, heat, and/or light impacts both indoor and outdoor air quality, human health, and the environment. Characterizing emissions from woodstoves and cookstoves continues to be a research priority expressed by partners. A-E research under the 2016-19 StRAP made considerable progress in understanding health effects associated with exposure to cookstove emissions and, as a result, this aspect of cookstove research is anticipated to be less of a focus under this StRAP. Overall, the research will look to evaluate best practices and alternative technologies for cleaner energy systems that reduce emissions and reduce public health and environmental impacts.

Program, regional, state, and/or tribal needs

Regarding source emissions, EPA partners, state and local agencies, and tribes are interested in advanced methods to measure source or near-source emissions, especially for high-priority sectors and broad source categories (e.g., industrial operations, oil and gas facilities, refineries, mobile sources including on- and off-road vehicles, wildland fires, agricultural sources, residential wood combustion) and pollutants (e.g., condensable PM, 1,3-butadiene, acrolein, ethylene oxide, chloroprene). Improved source emissions data are critical for reducing uncertainties in national emissions inventories and informing the development, implementation, and enforcement of regulations. A-E researchers will continue to advance air measurement technologies to better characterize source emissions. For example, the A-E Research Program is furthering development of fenceline and mobile technologies to improve characterization of previously undetected leaks from industrial and oil and gas facilities.

EPA partners, state and local agencies, and tribes are also interested in better data to inform effective mitigation strategies. A-E researchers will continue to assess innovative control technologies to support implementation of the most efficient management strategies that prevent and reduce air pollutant emissions.

[15] A list of designated FRMs and FEMs and documents supporting EPA's program to approve these methods is available at: https://www.epa.gov/amtic/air-monitoring-methods-criteria-pollutants.

Collectively, the efforts in this research area will strengthen emissions inventories, advance model development, and inform NAAQS reviews and development of standardized implementation plans for use by state, tribal, and local air agencies. Source, ambient, and personal measurement technologies are evolving rapidly. These advances are shaping a new paradigm for monitoring, as discussed in Research Topic 3 below.

Research Area 3: Public Health and Environmental Responses to Air Pollution

This research area emphasizes science to assess single and multi-pollutant exposures and resulting human and ecological effects to inform policy and public health practices. This research area continues efforts initiated under the 2016-2019 ACE StRAP and reflects the evolution of research on air pollution, a growing emphasis on implementation-related research, and enhancing the translation of the science to better inform decision makers and the public about measures that may be taken to reduce the impacts of air pollution on public health and welfare.

A core component of this research area is focused on improving our understanding of human and ecosystem exposure and effects. This work informs future NAAQS reviews and advances assessments of multi-pollutant exposures.[16] The A-E Research Program works closely with the HHRA research program in carrying out research needed for the NAAQS reviews.[17] The results of A-E research will contribute directly to the Integrated Science Assessments (ISAs)[18] developed in the HHRA program to inform the NAAQS reviews conducted by EPA's OAR.

A-E researchers continue to evaluate the health and ecological impacts of exposures to individual pollutants within complex, multi-pollutant mixtures. This improves our understanding of how impacts can be modified by co-exposures to other pollutants or by non-pollutant stressors (e.g., extreme temperatures, demographics, social stressors). Furthermore, the identification of factors that put people or ecosystems at risk from exposure to air pollution (e.g., life-stage, pre-existing disease, genetics/epigenetics, social, cultural, behavioral, and other factors that confer vulnerability) must be considered to fully assess impacts and inform air quality and public health management decisions. A subset of these factors may be identified as key *modifiable* factors and may be important to consider in policy decisions or as effective targets for behavioral and intervention strategies. In addition, A-E researchers are improving the understanding of potential confounding and exposure measurement error in air pollution epidemiological studies to clarify the effects of various pollutants within a mixture of air pollutants. A-E researchers will continue to develop integrated approaches, incorporating evidence from epidemiological, human clinical, and toxicological studies, to improve our understanding of the biological mechanisms that impact susceptibility and key exposure factors. Researchers will use this understanding to devise solutions that can address the problem of air quality-related health burden.

[16] Multipollutant exposures may include simple and complex mixtures of particles, criteria pollutant gases, and selected HAPs.

[17] The CAA establishes two types of NAAQS, primary (health-based) and secondary (welfare-based) standards. The statute requires review every five years of the science upon which the NAAQS are based and the standards themselves. The NAAQS review process identifies key uncertainties and knowledge gaps that will help to guide A-E priorities on human and ecological effects research to inform future NAAQS reviews.

[18] ISAs are reports that represent a concise evaluation and synthesis of the most policy-relevant science to inform the reviews of the NAAQS. Learn more at: https://www.epa.gov/isa.

As illustrated in Figure 2, emissions of criteria air pollutants have declined significantly over recent decades as a result of implementation of the CAA by EPA, state and local agencies, and tribes. To inform future NAAQS reviews, the A-E Research Program will improve our understanding of whether adverse effects continue to be observed at concentrations below current standards, what the shape of the concentration-response and exposure-response functions are at these lower concentrations, and how uncertainties in health impacts may vary with pollutant concentration.

An additional area of active research is enhancing our understanding of exposure durations of concern and the possible cumulative effects of multiple short-term, intermittent exposures and the relationship of these exposures to longer-term exposures and risks. A-E research efforts will focus on expanding our understanding of health effects associated with short-term peak exposures, such as those related to wildfires, traffic-related sources, or other episodic events, as well as improving our understanding of health effects associated with seasonal-length exposures, such as those related to wintertime wood-burning emissions.

To inform reviews of the secondary NAAQS, A-E researchers are expanding measurements and modeling for atmospheric nitrogen and sulfur to reduce uncertainty in the relationship between air quality, deposition, and ecosystem services. The science conducted under the A-E Research Program will expand our understanding of the linkages between atmospheric pollutants and ecological endpoints by developing deposition budgets of nutrients and acidity for critical loads assessments.[19] This research has and will continue to directly inform reviews of the NAAQS and the risk and exposure assessment activities performed by OAR as they consider options for the secondary NAAQS. This A-E research will be coordinated with complementary research being conducted by the SSWR research program.

The changing environment has modified weather patterns, which in turn have influenced the concentrations and spatial patterns of ambient air pollutants. A-E researchers will continue to improve our understanding of the relationships between climate change, air quality, and human and ecological impacts. This work will include, but not be limited to, advancing the understanding of: (1) temperature changes on ozone and PM concentrations; (2) changes in pollen and allergic disease patterns; and (3) the impacts of wildland fires and precipitation changes.

The work in this research area will include the translation of results to inform public health and well-being practices. Studies will examine the interaction between behavior and social and economic factors to more thoroughly understand how these factors may influence health and well-being outcomes. Translating the science for use in public health communication and community empowerment is an area that will involve collaborations between EPA and other federal agencies, such as the Centers for Disease Control (CDC) and the National Heart, Lung, and Blood Institute (NHLBI), as well as state and local agencies and tribes. This broadened focus will address ways to lower exposure or mitigate the biological responses at individual, community, or ecosystem levels, and, ultimately, to evaluate whether such interventions have benefits as measured by indicators of health, well-being, or economics.

[19] 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 aquatic biological resources.

Program, regional, state, and/or tribal needs

Scientific information produced by A-E researchers in this area will inform improved strategies by which governmental agencies, communities, and individuals can take actions to increase public awareness of air pollution-related exposures and risks and support public health decisions to reduce adverse public health and environment effects.

Topic 2: Extreme Events and Emerging Risks (E3R)

Actions to ensure the nation meets the environmental goals mandated by Congress often require near-term decisions that have long-term consequences. Air quality management strategies, such as those that require installation of large-scale air pollution control systems or adoption of emission reduction technologies in vehicles, can take years, if not decades, to implement and achieve the anticipated benefits. As an example, changes in atmospheric conditions are altering the frequency and magnitude of extreme precipitation events; understanding these changes is crucial to the long-term effectiveness of water treatment systems and waste management sites, which are designed to last for 50 or more years.

The effectiveness of these decisions over the long-term therefore requires an awareness of how the future may unfold and how those changes will affect atmospheric conditions, including air quality and weather patterns. The Extreme Events and Emerging Risks research topic is designed to inform decisions about the potential changes over the long-term, which will allow EPA and its stakeholders to prepare for future conditions and enable the long-term effectiveness of near-term decisions. Work conducted under E3R is related to achieving all four of the A-E Research Program objectives discussed above.

It is clear from recent experience that future conditions are not likely to mirror those observed in the past. Environmental conditions are changing, as we have seen with increases in drought, extreme precipitation events (as experienced in Houston in 2017 during Hurricane Harvey), and more and higher high-temperature events. These are outside the range experienced in the past, whether in frequency, magnitude, or both, and such conditions are increasingly likely to become the norm. The United States' dynamic economy and past successes in reducing emissions mean that future air pollutant types and sources of concern will change as technologies are developed and deployed.

Changes in atmospheric emissions and concentrations affect air quality, water quality (through deposition and changes in precipitation patterns), flood and fire frequency and magnitude, and coastal and forest ecosystems. These changes can affect air quality management effectiveness, vulnerabilities of water treatment and waste management infrastructure, and, ultimately, public health and ecosystems. The focus of the A-E Research Program on these issues is to improve and expand our understanding of the potential long-term connections between changes in atmospheric emissions and composition on these and other outcomes of importance to environmental protection, as required under the CAA.

Recognizing that future conditions will change, we do not know with precision when, where, and how they will change. As we look further into the future, the inherent uncertainties about conditions will increase. The A-E Research Program is developing and expanding approaches that can enhance insights into what future conditions might be, based on trends in technological development, advances in

understanding how the Earth's climate is changing, and methods for supporting decision making in the face of uncertainty and surprises.

The A-E Research Program will build upon its past successes in developing information needed by EPA partners and stakeholders, including scenarios (and associated data) of changes in energy production and use, land use, population, and other environmental stressors. The products of this work are also of value to researchers in other ORD programs, other federal agencies, the academic community, industry, and local, state, regional, and tribal organizations. The A-E Research Program's experience with developing tools and approaches to inform decisions will continue, in collaboration with EPA partners and community users of these tools.

Research Area 4: Public health and ecosystem exposures and responses to emerging air pollutants and sources

To maintain and improve air quality, EPA's Office of Air and Radiation (OAR) needs to keep abreast of emerging pollutants and sources. This information can evolve as new technologies come into the market and as we increase our understanding about previously overlooked natural and industrial processes that emit known pollutants. For example, the potential for exposure-related effects of per- and polyfluoroalkyl substances (PFAS) can only be effectively evaluated if we have a solid understanding of their sources and emission levels.

Program, regional, state, and/or tribal needs

OAR and multiple EPA regional offices have expressed growing concerns about the potential for atmospheric exposures to PFAS and the need to understand the sources, fate, and effects of airborne PFAS. In response, A-E researchers will develop methods to measure atmospheric concentrations, potential chemical transformations and transport, and health and environmental impacts of exposure to PFAS in the atmosphere. A-E researchers will coordinate efforts with those of other ORD research programs to develop a cross-media understanding of this emerging pollutant group and their potential impacts on health and the environment, with a focus on vulnerable populations. This research is part of a larger PFAS research effort involving the CSS, SSWR, and SHC Research Programs that collectively is aimed at developing effective risk assessment, management, and mitigation strategies.

To reduce uncertainty in national emission inventories, OAR needs data on emissions of methane from U.S. reservoirs. A-E researchers will apply the tools and methods developed for measuring open (non-stack) sources of organic compounds to increase our understanding of previously under-reported biogenic methane emissions from reservoirs and how water level changes, nutrient content, and ambient conditions can affect the timing and rate of emissions.

Research Area 5: Methods to evaluate environmental benefits and consequences of a changing energy system

OAR, states, and tribes need detailed projections of potential future air pollutant emissions to analyze NAAQS attainment strategies. To address this need, A-E researchers will develop scenarios of energy-system evolution to gain insights into the potential effects of fundamental changes, such as vehicle electrification, increased use of natural gas, and growth of renewable energy. STAR researchers are also analyzing future energy, transportation, and agricultural scenarios to evaluate impacts on emissions, air quality, and the economy. These insights will inform decisions on issues such as air quality management

strategies that will account for multiple possible future situations, thereby increasing the long-term effectiveness of those plans. By using commonly-used energy system modeling frameworks, A-E's researchers will more effectively collaborate with others and develop results that have broad applicability. Researchers will work with experts at the Department of Energy (DOE), in the energy industry, and in the academic community to develop tools, models, and scenarios that can inform environmental program decision makers at local, state, regional, and national scales, in both government and the private sector.

As required by the Energy Independence and Security Act, A-E researchers will develop the triennial Report to Congress on the environmental impacts of biofuel production and use. [20] The biofuels report is a specific example of research to understand the life-cycle environmental impacts of different mixes of energy technologies. The A-E Research Program has the lead for conducting such evaluations, which include impacts to air quality, water quality and quantity, ecosystem health, biodiversity, invasive species, and soil quality. A-E researchers work with experts from other ORD research programs, EPA partner offices, and local, state, and tribal stakeholders to develop life-cycle evaluations of energy system scenarios.

Program, regional, state, and/or tribal needs

To develop effective air quality management strategies, state and local agencies, tribes, and EPA need information about the key uncertainties and data gaps that affect future air quality. One of the more important of these issues is understanding how the nation produces and uses energy. Although the production and use of energy provides the nation and the world with enormous benefits, it also has considerable environmental consequences. The "energy system" – the mix of technologies that produce energy and convert it to desired end uses (e.g., transportation, heat, light, manufacturing) – is in the midst of fundamental change. That change has significant implications for air pollutant emissions, water consumption, and other environmental endpoints.

Research Area 6: Methods to enable resilience to future environmental stressors

Included in EPA's FY19 Performance Measures[21] is a commitment to provide integrated data, models, information, and other decision-support tools for state, tribal, and community partner resiliency, for incorporation into their planning processes. The A-E Research Program will build on recent successes, such as the Adaptation Design Tool (developed in partnership with the National Oceanic and Atmospheric Administration) and the multi-sector approach to evaluating urban resilience to future environmental stressors. Working with researchers from across ORD's research programs and with experts in other federal and state agencies, A-E researchers will continue developing approaches to understand potential future land use change, how heat and other extremes can affect public health and ecosystems, and the potential for flooding of water treatment infrastructure and Superfund and waste management sites.

A core component of this work continues to include working with the potential users to co-develop methods and tools. Workshops, webinars, and other means of engagement with community

[20] *Biofuels and the Environment: The Second Triennial Report to Congress* was completed in June 2018 (https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=341491).
[21] https://www.epa.gov/sites/production/files/2018-03/documents/fy19-cj-13-performance-measures.pdf

representatives have generated ideas about how information can be most effectively developed and communicated and have increased the understanding of the science at the community level.

Program, regional, state, and/or tribal needs

Underlying these tools are foundational efforts to develop scenarios and associated data that can be used by partners, stakeholders, and other ORD research programs. For example, the land use and population scenarios developed by A-E researchers include data on how population and land use distributions may change. These data can be used to evaluate potential changes in magnitude of urban heat island effects or changes in water runoff associated with new streets and other impervious surfaces, among other impacts. In addition, understanding how potential future changes in patterns of average and extreme air temperature and precipitation are crucial factors needed to estimate the potential for future environmental impacts. These estimates are needed to evaluate the long-term effectiveness of air quality management strategies by taking into account estimates of future susceptibility to wildfires and their associated environmental consequences, air quality exceedances, and changes in health impacts of air pollutant exposures during extreme temperature events.

Topic 3: Next-Generation Methods to Improve Public Health and the Environment (NGM)

The A-E Research Program conducts and adapts research that advances science and technology to help our partners and stakeholders solve complex environmental problems. Scientific advances can help lower the cost and improve the effectiveness and efficiency of providing environmental protection.

Next-generation methods to improve public health and the environment are directly related to achieving all four of the A-E Research Program objectives discussed in the previous section. Innovative methods and approaches are under development specifically to meet objective 3 to advance measurement and modeling. This work will also address the remaining A-E objectives to improve assessment of impacts (objective 1), develop approaches to prevent and reduce emissions (objective 2), and inform decisions at national, state, tribal, and local levels (objective 4). The development and evaluation of advanced next-generation fenceline monitoring methods combined with facility-specific, real-time, and lower-cost sensors networks will provide innovative support to further these objectives.

The current state of environmental monitoring for regulatory compliance with the NAAQS is quite expensive and labor and time intensive to produce quality data. New, lower-cost sensor technologies on the market show promise for widespread collection of real-time data, but their performance is still in question. EPA partners and stakeholders have continuously expressed the need for ORD support in understanding the performance of lower-cost sensor technologies and how to assess the quality of the data they produce. A-E research is vital to understanding how this growing technology revolution can be guided to produce reliable data so the information and technologies are of sufficient quality for the uses and decisions of interest.

Similarly, in the era of "big data," the issue of data management and interpretation is at the forefront, including efforts to help users visualize and make sense of air quality information through maps, interactive apps, or other approaches. Advancing data fusion methods to combine data from monitors, sensors, satellites, and model output will improve estimates of air pollution exposure. Opportunities for public/private partnerships will be important to the A-E Research Program, as they combine private

sector expertise in data science with EPA experience in air quality measurement and translation and communication of scientific information.

While technological advances and national air pollution policies have reduced emissions from motor vehicles, electricity generation units, and industrial sources, many regions remain in non-compliance with the NAAQS for particle matter and ozone. These non-attainment regions present modeling challenges due to the combination of emission sources, complex meteorological conditions, wildland fires, and long-range transport of air pollution from rising emissions in developing economies of the world. States responsible for producing new NAAQS attainment demonstrations and updated regional haze plans need robust tools that enable consistent examination of the air pollution phenomena on local-to-global scales. A-E research to develop, evaluate, and apply this advanced AQ modeling system will also advance the science of air quality modeling and understanding of critical processes across global to local scales.

In the area of human health, changes in medical care through technological advances, as well as changes in health data management, have created opportunities for environmental health research not possible previously. Also, the move toward individualized medicine is a future where research on air sensor technologies merges with public health research. The A-E Research Program will capitalize on these changes to develop innovative methods for understanding the impacts of local air quality on health and for evaluating approaches to reduce public health risks associated with exposures to air pollutants.

Innovative research approaches create opportunities for making progress in improving air quality and public health. EPA is exploring the use of open-source challenges, citizen science, social science, and other non-traditional avenues to investigate and address environmental science problems. For example, the A-E Research Program used an open-source challenge to promote the development of wildland fire smoke monitoring systems. The initial challenge awarded funds for successful prototypes and was followed by a Small Business Innovative Research (SBIR) solicitation to further advance this technology. The A-E Research Program, together with its partners, will continue to capitalize on challenges and the SBIR program, whenever possible, to advance next-generation methods.

Research Area 7: Emerging approaches to improve air quality and exposure characterization

Looking to the near future, the A-E Research Program anticipates that portable sensors, integrated sensor networks, and other advanced next-generations systems will more routinely provide near real-time, continuous data to evaluate emissions and to detect and measure pollutants in ambient air. Smaller, lower-cost air sensor monitoring devices may be broadly deployed to capture a much more spatially-detailed picture of relative ambient air quality in a neighborhood, city, or larger area. Similarly, innovations in source monitoring can significantly reduce monitoring costs, provide more timely information, and provide opportunities for industry to address leaks and emissions before they become serious problems. With appropriate data management and analysis, this new world of monitoring data will provide a more complete understanding of air quality, leading to more timely identification and understanding of air pollution problems. Advances in sensor technologies will support assessments of air pollution emissions, with the opportunity to improve overall implementation of CAA regulations.

Many new air sensor technologies are entering the market, but the quality and reliability of the data they produce is unknown. A-E researchers will continue to develop and test new technologies for measuring air pollutants (PM, ozone, VOCs, others) in a variety of ambient and indoor environments and

from a range of industrial and other sources. Communities across the country are working with STAR researchers to better understand how air sensor technologies perform in real world conditions and how the general public interacts with the devices and interprets the data. In addition, multiple projects underway with state and regional partners and the private sector are demonstrating technology performance in ambient and source monitoring and are providing opportunities to evaluate and manage large quantities of data. The A-E Research Program will develop analytical and data management tools to enable local, state, regional, and national managers to evaluate the effectiveness of air pollution reduction strategies using sensor data on an ongoing basis.

In partnership with EPA programs, regions, states, tribes, and local governments, the A-E Research Program will consult with academic experts, federal colleagues, and technology manufacturers to consider performance standards and testing protocols for non-regulatory applications of ambient air sensor devices. The information developed will help air quality managers and the public understand which sensors are appropriate for their monitoring purpose and will encourage innovation in the marketplace.

Advances in computer science, new sources of air pollution measurement data, and the means to interface with other models and data are opening the way for a new generation of air quality models. Modeling challenges are broad and range from incorporating the influence of long-range transport of air pollutants and climatic trends, to understanding fine-scale variations in pollution due to local meteorology, terrain, and emission sources. A next generation of models will draw on multiple sources of data – from sensors, more sophisticated air monitoring instruments, and satellites – enabling greater accuracy of model predictions. Also, advanced modeling approaches will be able to assess air quality over multiple geographic scales – from local to global.

A-E researchers are developing a next-generation air quality model that integrates multi-scale and multi-pollutant capabilities in an updated architecture to increase computational efficiency and applicability. Expanded capabilities include addressing ecosystem impacts and linking to new global meteorology models. Research and data collection efforts will also be directed at (1) improving our understanding of exposure-related factors that influence the magnitude and duration of air pollutant exposures, (2) developing methods to advance the data fusion techniques to integrate ground-level measurements, personal measurement data, satellite data, and (3) modeling results to reduce uncertainties in exposure assessments.

Program, regional, state, and/or tribal needs

State, local, and tribal agencies are responsible for air quality monitoring in their jurisdictions, and they are pursuing the use of lower-cost air sensor monitoring technologies. Air pollution monitoring is costly and technically challenging, leaving many gaps in spatial and temporal coverage. Air agencies are starting to use new, real-time advanced monitoring approaches and lower-cost devices to identify pollution hotspots, to determine locations for siting regulatory monitors, for community awareness about air quality, and for other purposes. However, air quality managers and other stakeholders are frequently turning to EPA to address questions about the reliability of the technologies, the ability to measure challenging pollutants such as speciated VOCs, the quality of the data produced, how to manage and analyze the data, and how to interpret what the data mean for health. OAR places a very

high priority on A-E research and support for understanding sensor technology performance for source emissions and in ambient and indoor air.

States, tribes, and local governments also rely on EPA for air quality models they can use to understand changes in air quality, predict future air quality, and evaluate strategies for air pollution management. OAR underscored the need for an updated air quality modeling platform that could potentially lead to faster assessments of air quality impacts across multiple scales and then be used to inform air quality planning. EPA regions emphasized the need for next-generation models that represent transport from the global to local scale. These modeling tools are essential to demonstrate compliance with the NAAQS and to inform decision makers at the state and tribal levels if their policy choices will be effective, as discussed in Research Topic 1 above.

Research Area 8 - Novel approaches to assess human health and ecosystem impacts and risks

Advances in measurement technology, coupled with state-of-the-art information systems, are enabling the development of new methods to assess impacts and evaluate risks. For example, the move to electronic health records affords epidemiologists in the STAR research centers and the A-E intramural program the opportunity to examine how changes in air quality can affect populations, while protecting the privacy of the patients. Examining trends in health conditions related to air quality provides important information for state and local health departments across the country to more effectively communicate risks to the public and reduce impacts to public health. This research also will inform colleagues in the HHRA research program as they review the state-of-the-science on specific air pollutants for decisions on NAAQS.

As a collaborative effort to promote human health, federal colleagues in the Department of Health and Human Services lead the Million Hearts Initiative, which focuses on reducing the number of heart attacks and strokes in the United States. Based on earlier health research from EPA and others around the world, Million Hearts now advises those who have had a heart attack or stroke to avoid exposure to $PM_{2.5}$.[22] Future research using air sensors and individual health monitors will help evaluate strategies to reduce personal exposure and risk.

Next-generation methods for assessing health and ecosystem risks will help decision makers understand the likely impacts of extreme events, such as the increase in frequency and intensity of wildland fires. Current approaches are proving inadequate for addressing wildland fires in the 21st Century. EPA will work with federal and other partners on innovative approaches to assess and mitigate the risks from fires. Initial work is addressing air and water quality. For example, fires and subsequent soil erosion affect water quality, including natural water treatment processes, infiltration and flow of groundwater supplies, and overall ecosystem health. Researchers will integrate wildfire models with ecosystem models to enable a comprehensive assessment of public health and ecosystem impacts. To improve smoke forecasting and protect human health, A-E researchers will integrate ecosystem models (that estimate the growth of plant biomass) with smoke models to predict the size and direction of smoke plumes from wildland fires.

[22] Learn more about the Million Hearts Initiative efforts to share information about air quality and cardiovascular effects at https://millionhearts.hhs.gov/tools-protocols/tools/particle-pollution.html.

Program, regional, state, and/or tribal needs

State, local, tribal, and federal organizations face complex environmental challenges as the population grows, new technologies emerge, land-use patterns change, and extreme weather events occur more frequently. To make sound health and environmental policy decisions, decision makers need assessments of the extent and likelihood of potential risks to human health and ecosystems. For example, EPA regions identified several needs related to wildland fires, including: better understanding of the health risks of wildland fire smoke exposure over short- and longer-term time periods; understanding the long-range transport of air pollutants from fires and the impact on air quality; and the development of forecasting to aid state air agencies in determining approvals for prescribed burns. A-E will work closely with partners and stakeholders to design research that produces innovative approaches to better understand risks and support decision-making.

Cutting Across All Research Topics: Wildland Fires

The three research topics and associated research areas described above are interconnected and rely on multiple scientific disciplines working collaboratively to provide research results that address EPA priorities and mandates. Many scientific issues cut across the entire research portfolio of the A-E Research Program. One of these issues is wildland fires.

Wildland fires are a persistent and pervasive multimedia issue that is increasing in prominence within the United States. Wildland fires affect air quality in and around the locations of fires, as well as more broadly downwind. Emissions from conventional sources of air pollution have been reduced, yet our changing environment has increased the likelihood and severity of wildfires and has changed the optimal window for the prescribed burning season. A-E research will focus on improving our understanding of wildland fire impacts on public and environmental health and will inform approaches to reduce associated risks. While specific deliverables addressing wildland fires may be included in the Research Areas summarized above, Research Area 9 discussed below is intended to integrate and synthesize wildland fire-related work that draws on the research conducted under the three A-E Topics, as well as related and collaborative research efforts being conducted in other ORD national research programs, specifically SSWR, SHC, HSRP, and CSS.

Research Area 9: Wildland fires

Research over the next several years will provide improved understanding of wildland fire impacts on public health and the environment and will inform approaches to reduce exposures and risks associated with wildland fires. This integrated approach will help us better understand the growing importance of wildland fires, identify vulnerable ecosystems and populations, and develop effective risk communication and mitigation strategies.

The United States has a long history of managing wildland fires, with responsibility for managing and responding to these fires spread across federal, state, and local government agencies, as well as tribes. To enhance our understanding of public health and environmental impacts of wildfires and to inform decision making at different levels, A-E research will:

- Improve models and measurement methodologies to assess emissions and determine impacts on air and water quality and ecosystems

- Determine what ecosystems and human populations and lifestages are susceptible and vulnerable to wildland fires
- Develop and evaluate approaches (e.g., best practices for prescribed fires) to mitigate risks to human health and ecosystems
- Develop and evaluate health-risk communication strategies to promote health-protective behaviors

Across the Federal government, a range of agencies are involved in fire science. Developing effective tools to inform air and water quality management decisions to minimize fire impacts requires a concerted, integrated effort within EPA and across the Federal government. A-E researchers will continue to build collaborations with the U.S. Forest Service (USFS), Department of the Interior (DOI), NOAA, the National Aeronautics and Space Administration (NASA), CDC, and others to fill specific science gaps. These efforts will also be coordinated with related state, local, and tribal activities.

Program, regional, state, and/or tribal needs

Major focus areas for A-E researchers will include: (1) advancing capabilities to assess human health and ecological impacts of wildland fires; (2) improving tools and technologies to quantify and predict wildland fire impacts; (3) better characterization of source emissions; (4) improved understanding of wildland fire impacts on the indoor environment and human exposures; and (5) informing activities to effectively minimize adverse public and environmental impacts and risks.

Anticipated Research Accomplishments and Projected Impacts

By its nature, the A-E Research Program requires a strategic plan that comprises a breadth of activities across a wide array of science and program issues to meet current Agency priorities and stakeholders' research needs, while also being flexible and responsive as new needs emerge. As science and technology evolve rapidly, opportunities arise for new technical approaches to address environmental problems and science questions, as well as whole new ways of approaching these problems. In addition, there are major changes involving social media, access to information, and public attitudes toward environment and health.

The A-E Research Program will have the greatest impact when its research and deliverables are developed in collaboration with partners and stakeholders from inception to completion, embracing the concept of solutions-driven research. ORD deliverables specifically designed to be useful in the hands of partners and stakeholders are termed "outputs." Examples of proposed A-E outputs for FY2019 to 2022 are listed in Appendix 1. The A-E Research Program will engage the relevant partners and stakeholders, as appropriate, throughout the research process to ensure that outputs and related products adequately address partner and stakeholder needs. This includes working together to determine the format of outputs and products that would be most useful for partners and stakeholders and the most effective approaches for communicating A-E science.

In addition to advance-StRAP planning on multiyear cycles, ORD recognizes that EPA partners and stakeholders must respond to emerging, unforeseen needs that can benefit from ORD research and technical expertise. In these situations, ORD works with partners to balance the relative importance of these emerging needs with other research activities that might need to be offset and to ensure agreement in any changes in research direction within available resources.

The A-E Research Program will continue to evolve to meet its mandated obligations supporting regulations and policies while it looks to the future, embracing sustainability, innovation, community engagement, and anticipating the air and energy issues ahead. In that spirit, the A-E Research Program will review its three research topic areas each year. Examples of anticipated accomplishments for each research topic are briefly described below.

Science for Air Quality Decisions (AQD)

EPA's requirement to periodically review and, if appropriate, revise the NAAQS demands a robust scientific understanding of exposures to, and effects of, criteria air pollutants. A critical component of the A-E Research Program is focused on addressing key uncertainties and data gaps identified in previous NAAQS reviews to inform future reviews. This work will include: (1) expanding our understanding of the role of individual pollutants within the mixture of air pollutants; (2) advancing the identification of characteristics that put subgroups within the general human population and ecosystems at increased risk of experiencing effects associated with air pollutant exposures and the impacts of a changing environment; and (3) improving our understanding of possible health and welfare impacts at lower ambient concentrations and/or related to repeated short-term, intermittent, peak exposures.

Science that informs effective national, state, local, and tribal air pollution control strategies to support implementation of the NAAQS and other regulatory drivers requires continued efforts to improve ambient and source measurements, emissions inventories, and modeling tools. As noted in the EPA Strategic Plan, "EPA's work to control emissions of air pollutants is critical to continued progress in reducing public health risks and improving the quality of the environment." This work includes: (1) developing or approving new FRMs and FEMs for criteria pollutants; (2) advancing and evaluating control technologies; (3) standardizing test guidelines for assessing source emissions and profiling emissions among a mixture of sources to inform emissions inventories and source apportionment studies; and (4) advancing modeling tools to improve the characterization of air pollutant impacts on air and water quality and community and individual exposures at relevant local, regional, and hemispheric scales, and under changing climatic conditions.

In addition, the A-E Research Program includes a broader public health focus to deliver effective, relevant, and timely science that provides insights into factors that may better explain and reduce uncertainties in observed public and environmental health effects of air pollutants and may offer more effective support for responses to extreme weather events. These efforts will include enhancing the translation of the science to better inform decision makers, as well as the public, about measures that can reduce the impacts of air pollution on public health and the environment.

Extreme Events and Emerging Risks (E3R)

EPA, state and local agencies, and tribes have growing concerns about PFAS and the potential for people to be exposed to these compounds through emissions to, and transport through, the atmosphere. A-E researchers will develop methods to measure emissions and ambient air concentrations of PFAS and will expand computational models to simulate the physical transport, chemical transformation, and ultimate exposure pathways of these compounds. The A-E Research Program will also investigate the potential levels of exposure resulting from airborne PFAS and the health and environmental effects associated with these exposures.

The effectiveness of environmental protection actions at the national, state, and local scales often depends upon assumptions of how the future will unfold. A-E researchers will develop scenarios of important environmental stressors, including land use change, population change, and frequency and magnitude of extreme weather events, that can be used to evaluate alternative strategies for air quality management, impacts to human and ecosystem health, and other core environmental endpoints.

Building resiliency to changing environmental conditions and extreme weather events relies on analysis methods and decision processes that incorporate substantial uncertainties into estimates of vulnerability and risk. A-E researchers will work with planners and decision makers in communities and states to develop and evaluate frameworks for identifying vulnerabilities to extreme events and evaluating strategies for improving resilience. In collaboration with SSWR and SHC researchers, A-E scientists will develop approaches for estimating risk and incorporating those estimates into the decision process, even as those estimates may change as new information becomes available over the long term.

Changes in the nation's energy system have implications for air pollutant emissions and other environmental impacts. Because of the substantial uncertainties about how such changes will unfold, A-E researchers will develop scenarios of possible adoption of technologies and the associated changes in air quality and other environmental stressors. A-E researchers will examine changes in the types of energy used in the transportation sector and changes in how people and goods are moved. In collaboration with experts from EPA's OAR-OTAQ, A-E researchers will develop and publish the third triennial report to Congress on the environmental impacts of biofuel production and use.

Next-Generation Methods to Improve Public Health and the Environment (NGM)

Smaller, lower-cost air monitoring devices are on the market and can be useful to states, local agencies, tribes, and the public, but the quality of the data generated is largely unknown. A-E researchers will continue to evaluate these new technologies and will work with EPA partners and external stakeholders to develop performance standards and testing protocols for these devices. Future use of devices with known performance characteristics will assist states and local agencies, tribes, and the public in using sensors appropriately for a variety of purposes, and it will help provide more a detailed understanding of air pollution concentrations, sources of air quality problems, and implications of air quality management strategies.

Solving air quality problems requires the use of models to understand air pollution phenomena such as the long-range transport of pollutants and fine-scale changes in pollution in small geographic areas. ORD's next generation of modeling and measurement fusion work will combine modeling with data from sensors, traditional air monitoring instruments, and satellites, to better represent ambient air pollution concentrations. This new air quality model will be more computationally efficient, able to simulate behavior of multiple pollutants at multiple scales, and capable of linking with new global meteorological models. These capabilities will benefit federal, state, and local air agencies as they more effectively evaluate options for attaining the NAAQS.

Complex environmental problems call for the development of new methods to assess impacts and evaluate risks. For example, the increase in frequency and intensity of wildland fires is resulting in more widespread impacts to ground and surface water quality and overall ecosystem-health challenges. To better understand the likelihood and extent of such impacts, A-E researchers will integrate wildland fire models from the U.S. Forest Service with EPA's ecosystem models. Advances in modeling capabilities

will inform more comprehensive assessments of health and ecosystem impacts, enabling environmental managers to identify vulnerable areas and take appropriate management actions.

Conclusion

Clean air is vital to our country – to sustaining the health of people and the ecosystems on which we depend. There are still over 100 million people in the United States who live in counties that do not meet current air quality standards, which impairs their health and results in economic impacts due to lost work, school days, and productivity. Although we have seen significant improvements in air quality over the past several decades by reducing emissions from point and mobile sources nationwide, we cannot assume that progress will continue. Air pollution issues persist at the local level requiring innovative developments in tools and data. In addition, changing environmental conditions are likely to make meeting air quality objectives more difficult.

EPA will respond to the challenge of improving air quality throughout the United States now and into the future. The A-E Strategic Research Action Plan provides the framework for advancing science priorities over the next four years to support EPA, state and local government, and tribes so they may improve air quality. This plan was developed through extensive engagement with other EPA research programs, with EPA partners in the program and regional offices, states, tribes, and other external stakeholders. This integrative and inclusive approach will continue as we work to implement the research envisioned in this plan. A key feature of an inclusive approach involves working together to design research outputs that translate and effectively communicate science to solve complex environmental public health problems.

This strategic plan is guided by over-arching Agency objectives to meet air quality standards and focuses on assessing the impacts of air pollution, preventing and reducing emissions, advancing measurement and modeling, and delivering state-of-the-art tools to inform decision making. The research guided by this plan will provide information needed by government agencies, the private sector, and the public to take actions to maintain and improve air quality for all, particularly in those areas that currently do not meet air quality standards.

References

National Interagency Fire Center. (2016). *Total Wildland FIres and Acres (1960-2015).* Retrieved from http://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html

U.S. EPA. (2014). *Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards Final Rule – Regulatory Impact Analysis.* EPA-420-R-14-005. Retrieved from https://nepis.epa.gov/Exe/ZyPDF.cgi/P100ISWM.PDF?Dockey=P100ISWM.PDF

U.S. EPA. (2016a). *U.S. EPA National Emissions Inventory (NEI) 2014.* Retrieved from https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data

U.S. EPA. (2016b). *Wildfire Smoke: A Guide for Public Health Officials.* Retrieved from https://www3.epa.gov/airnow/wildfire_may2016-revised.pdf

U.S. EPA. (2018a). *FY 2018-2022 EPA Strategic Plan.* Washington, DC: U.S. EPA. Retrieved from https://www.epa.gov/planandbudget/strategicplan

U.S. EPA. (2018c). *Our Nation's Air 2018, https://gispub.epa.gov/air/trendsreport/2018.*

U.S.EPA. (2017). *Evaluating Urban Resilience to Climate Change: A Multi-Sector Approach (Final Report).* EPA/600/R-16/365F. Retrieved from https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=322482

U.S.EPA. (2018b). *ORD Strategic Plan 2018-2022.*

USGCRP. (2016). *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* Washington, DC: U.S. Global Change Research Program.

USGCRP. (2017). *Climate Science Special Report: Fourth National Climate Assessment, Volume I.* Washington, DC: U.S. Global Change Research Program. doi:10.7930/J0J964J6

Appendices

Appendix 1: Summary Table of Proposed Outputs for the Air and Energy Research Program (FY2019-2022)

The following table lists proposed, high-level, strategic Outputs (including proposed delivery timeframes) for the Air and Energy (A-E) National Research Program, organized by Topic and Research Areas. This list is not comprehensive but rather illustrative of the breadth of the A-E portfolio. It should be noted that the Outputs may change as new scientific findings emerge. Outputs are also contingent on budget appropriations. Final Outputs, including expected delivery years and sequence, will be determined during the next phase of research implementation planning. The A-E Research Program will continue to engage with EPA partners throughout the research implementation phase as we identify the specific products that will be developed to achieve the research area objectives and Outputs identified in the StRAP.

Research Area	Program, Regional, State and/or Tribal Need	Output Title
Topic 1: Science for Air Quality Decisions		
1. Approaches to support air quality management programs for multiple pollutants at multiple scales	Improved estimates of short- and long-term impacts of different policy and regulatory options through updated air quality models to inform actions to attain the NAAQS and to expand understanding of the long-term impacts of the changing environment; in particular, the inclusion of source apportionment will enable estimates of individual state and/or sector contributions	1. FY19- Release of CMAQ v5.3 and instrumented versions supporting source apportionment
	Enhanced ability to quantify background criteria pollutant contributions, including those from long-range, international transport, to non-attainment areas; to improve the quantification of the contributions of local and regional sources versus background contributions (such as from international transport) to inform periodic NAAQS reviews required by the CAA and strategies to attain the NAAQS and Regional Haze goals	2. FY20- Development of advanced approaches to estimate background contributions of particulate matter and ozone
	Improved capabilities to evaluate complex nonattainment areas to better understand air quality at a very local scale to inform NAAQS attainment strategies (for example, ground-level ozone photochemical formation in near-shore environments such as near Lake Michigan and the Long Island Sound)	3. FY21- Enhanced monitoring and modeling approaches to inform local decisions in nonattainment areas, in partnership with states

Research Area	Program, Regional, State and/or Tribal Need	Output Title
2. Approaches for characterizing source emissions, air quality, exposure, and mitigation strategies	Enhanced methods to better characterize drivers of exposures and risks from indoor sources of air pollutants including cookstoves to inform best practices and alternative technologies for cleaner energy systems that reduce emissions and related public health and environmental impacts	4. FY20- Summary report of advancements to characterize emissions, exposures, and related health impacts associated with cookstove use
	Methods to Identify and characterize previously undetected leaks from sources; for example, improving detection and identification of VOCs that contribute to ozone formation in nonattainment areas or that are identified as hazardous air pollutants (HAPs) and regulated under section 112 of the CAA including the Petroleum Refinery Maximum Achievable Control Technology (MACT) standard	5. FY21- Progress update on new approaches (aerial and ground-mobile) used to measure source emissions, including fenceline measurement technologies
	Reliable ambient measurements of criteria air pollutants to inform NAAQS attainment/nonattainment decisions and to guide NAAQS implementation actions; developing/updating methods to measure HAPs in ambient air to inform residual risk reviews required under Section 112 of the CAA	6. FY22- Summary of updated ambient air measurement technologies including: a. Federal Reference Method and Federal Equivalent Methods - technology designations and methods development approved for FY19-FY22 b. Methods Development for HAPs

Research Area	Program, Regional, State and/or Tribal Need	Output Title
3. Public health and environmental responses to air pollution	Improved characterization of the relationships between ambient concentrations, deposition, and ecosystem impacts to inform NAAQS reviews for secondary standards such as NO_2, SO_2, and PM and to improve understanding of air pollution impacts on water quality	7. FY19- Synthesis of progress to improve characterization of deposition budgets for North America and identification of remaining critical knowledge gaps related to nitrogen deposition and assessments of critical loads
	Increased understanding of the factors which may influence susceptibility and vulnerability to air pollutants; expanded analytical approaches to improve exposure estimates for healthy and at-risk populations and lifestages to inform reviews of the primary NAAQS which provide public health protection, including protecting the health of sensitive populations such as children, older adults, and individuals with pre-existing heart and lung disease and to inform regulatory and policy actions to reduce risks to these populations	8. FY20- Summary of advancements in understanding health impacts of air pollutants in healthy and at-risk populations and lifestages and identification of remaining critical knowledge gaps
	Enhanced knowledge of the potential health impacts of multi-day pollution events (such as wildfires) in relationship to single day events and longer-term exposures to improve characterization of public health impacts, to inform effective and consistent public health messages, and inform actions to reduce risks	9. FY20- Synthesis of enhanced understanding of peak/intermittent/short-term/cumulative exposures and relationship to longer term exposures; development of health messages, in collaboration with partners, to communicate risks
	Expanded understanding of the health impacts of exposures to lower concentrations of criteria air pollutants including shapes of concentration-response and exposure-response functions and how uncertainties in health impacts may vary with concentration to inform future reviews of the NAAQS	10. FY21- Grantee report summarizing results of multiple epidemiology studies evaluating health impacts of lower ambient concentrations of criteria pollutants

Research Area	Program, Regional, State and/or Tribal Need	Output Title
	Increased capabilities to assess multiple chemical and non-chemical interactions, including long-term temperature changes; advanced understanding of public health and welfare benefits associated with various air quality management options to inform NAAQS reviews and air quality management options to attain the NAAQS and to expand understanding of the long-term impacts of the changing environment	11. FY22- Summary of advancements in interactions of environmental changes on PM, ozone, wildfires and associated human health impacts
Topic 2: Extreme Events and Emerging Issues		
4. Public health and ecosystem exposures and responses to emerging air pollutants and sources	Ability to measure "new" chemicals (for example, PFAS) emitted from sources and in ambient air to better understand the sources, fate, and public health and environmental effects of air pollutants previously poorly characterized or that result from new technologies or industrial processes	12. FY20- Development of laboratory methods for priority PFAS compounds emitted to the atmosphere
	National-scale survey of methane emissions from reservoirs in the United States to reduce uncertainty in inventory estimates by improving the characterization of previously under-reported biogenic methane emissions and how water level changes, nutrient content, and ambient conditions may affect the timing and rate of emissions; this research will address a key gap in monitoring data for the Greenhouse Gas Emissions Inventory United Nations Framework Convention on Climate Change (UNFCCC) reporting requirements	13. FY21- Summary report on advancements to characterize methane emissions from reservoirs
	Understanding pollutant transfer cycle for "new" chemicals of emerging concern (for example, PFAS) to enhance characterization of atmospheric concentrations, potential chemical transformations and transport, and related exposures and health and environmental impacts	14. FY22- State-of-the Science: synthesis of research on airborne PFAS emissions, fate, and impacts and identification of remaining critical knowledge gaps

Research Area	Program, Regional, State and/or Tribal Need	Output Title
5. Methods to evaluate environmental benefits and consequences of changing energy systems	Improved capabilities to project future emission estimates to inform development of NAAQS attainment strategy analyses	15. FY21- Report on air quality under future energy scenarios
	Required assessment under the Energy Independence and Security Act for environmental impacts of biofuels	16. FY21- Third Biofuels Report to Congress (RTC)
	Expanded understanding of future system-wide scenarios of energy use and air pollution emission trends associated with changing transportation technologies to gain insights into potential effects of fundamental change, such as vehicle electrification, increased use of natural gas, and grow of renewable energy sources to analyze NAAQS attainment strategy options	17. FY22- Progress update on environmental consequences of emerging transportation technologies and practices
6. Methods to enable resilience to future environmental stressors	Development of tools and information to advance understanding of the potential impacts of emerging and future environmental risks to human health, air quality, water quality, ecosystems, and built infrastructure to evaluate the long-term effectiveness of air quality management strategies, including NAAQS attainment strategies	18. FY21- Updated and expanded scenario data for population, land use, and extreme events as input to risk evaluation and management
	Development and application of risk-based models to inform decisions that result in improved environmental protection and natural resource management while addressing climate adaptation goals	19. FY22- State of the Science: analysis of environmental impacts due to effects of extreme weather conditions and events on forested watersheds
	Improved understanding of environmental responses to extreme events and identification and evaluation of mitigation options	20. FY22- Methods for decision analysis to improve environmental resilience to extreme events

Research Area	Program, Regional, State and/or Tribal Need	Output Title
Topic 3: Next-Generation Methods to Improve Public Health and Environment		
7. Emerging approaches to improve air quality and exposure characterization	Improved understanding of the spatial and temporal characterization of human and environmental exposures	21. FY21- Advancement of methods and evaluation of uncertainty in combining reference level monitor data, sensor data, satellite data, and/or model output to improve air pollution exposure estimation
	Enhanced understanding of how to use measurement data from air sensors to support partners in managing and communicating the data	22. FY21- Improved capability to manage, visualize, and process sensor data
	Improved understanding of air sensor performance and quality of technologies on the market in support of partners' monitoring programs	23. FY22- Evaluation of performance of sensor technologies, including development of performance targets and test methods
	Expanded air quality modeling capabilities to better characterize finer scales (for example, neighborhoods); enhanced ability to model at different scales include regional and global scales for use in future air quality management decisions	24. FY22- Release and demonstrate Advanced Air Quality Modeling Platform supporting multiscale air quality assessment over a global domain
8. Novel approaches to assess human health and ecosystem impacts and risks	Improved approaches and systems to better assess health and ecosystem impacts and risks associated with environmental stressors to inform the periodic review of the science underlying the NAAQS	25. FY21- Development of new health research approaches that take advantage of newly available electronic data systems and advanced cellular models
	Increased understanding of wildland fire impacts on water bodies and ecosystems, including: erosion, use of fire suppressants, surface and ground water, and drinking water	26. FY22- Integration of ecosystem and forest service models to assess public health and ecosystem impacts of fires

Research Area	Program, Regional, State and/or Tribal Need	Output Title
Cross-Topic Research		
9. Wildland fires	Enhanced understanding of wildland fire impacts on public health and the environment and improved approaches to reduce associated risks; includes improving characterization of exceptional events to inform NAAQS compliance decisions	27. FY20- Interim progress update on wildland fire research summarizing multidisciplinary research being conducted across the three A-E research topics summarized above
		28. FY21- Translational pilot project on wildland fires
		29. FY22- Capstone wildfire research synthesizing multidisciplinary research conducted across the three A-E research topics summarized above

Appendix 2: State Needs Reflected within ORD/A-E Research Planning

The table below lists the state research needs identified in the 2016 Environmental Council of States (ECOS) survey and in discussions between state representatives and ORD in the spring of 2018 related to air quality. These needs are aligned to specific A-E ORD Research Areas (RAs) and, where noted, other ORD national research program StRAPs.

Source	State Need	Research Area
2016 Survey	Achieve compliance with the newly lowered ozone standard, ozone modeling and monitoring issues	Approaches to support air quality management programs at multiple scales Approaches for source emissions, air quality, and exposure characterization
	Interstate and cross-border transport	
	Emissions from grassland burning, wildfires and forest fires (atmospheric and AQ models)	Wildland fires, HSRP is assessing the potential for radiological contaminants to be spread as a result of forest fires
	Advanced monitoring and sensors	Innovative approaches to improve characterization of air quality and exposure
Media Meeting	High altitude ozone research (WY)	Approaches to support air quality management programs at multiple scales
	Prescribed burns/wildfires and emission factor work with KS and EPA Region 7 (NE)	Wildland fires
	Tying improvements in air quality to public health (TN)	Public health and environmental responses to air pollution
	Look at how air deposition of toxics (PCBs and others) contributes to water loadings (WA)	N/A
	$PM_{2.5}$ indicators-- wood smoke and public health	Public health and environmental responses to air pollution
	Expanding the national mesoscale meteorological and photochemical modeling domains to include the state of Hawaii could provide significant positive impact (reference to Hawaii letter) with respect to (HI): 1. Accuracy of the National Air Toxics Assessment 2. Efficiency of state efforts regarding Regional Haze, Exceptional Events 3. Understanding of health risks of extreme events associated with volcanic sulfate from the Kilauea volcano on the Island of Hawaii	1. Programmatic lead, OAR-OAQPS 2. Programmatic lead, OAR-OAQPS 3. Innovative approaches to improve characterization of air quality and exposure (including STAR community monitoring grant focused on Hawaii volcanic smog, see https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/10741/report/0)

Source	State Need	Research Area
	4. Expanding EPA research efforts to better include the state of Hawaii could help avoid similar delays in submission deadlines for future federal rules	4. Innovative approaches to improve characterization of air quality and exposure

Appendix 3: Cross-cutting Research Issues

The following table lists research issues and briefly summarizes activities coordinated across the ORD national research programs.

Research Issue	National Research Program					
	A-E	CSS	HHRA	HSRP	SHC	SSWR
Ecosystem services	• Secondary NAAQS • Near road & urban air quality • Wildland fires • Extreme heat	• Ecotoxicity	• Ecological risk assessment	• Regulating services (mitigation of flooding, other extreme events)	• Site recovery • Health promotion • Community revitalization • Ecosystem services	• Secondary NAAQS
Lead			• Regulatory models • Risk Assessment	• Sensors and water infrastructure modeling, including contaminant fate and transport	• Locations • Exposure data & evaluated models • Innovative solutions	• Water treatment systems • Drinking water quality sampling • Risk Assessment • Sensors & Water Infrastructure
Nutrients	• Atmospheric deposition of airborne nitrogen and phosphorus to ecosystems	• Toxicity testing				• Sensors and Water Infrastructure(w/SHC) • Nitrogen & Co-pollutants • Toxicity Testing (w/CSS)
PFAS	• Air and emissions sampling and control potential	• Analytical standards • Adverse outcome pathways • Rapid toxicity testing	• Risk characterization	• Treatment of contaminated water from emergency response activities, including use of PFAS containing firefighting foam	• Tech Support • Fate and transport at contaminated sites and landfills • Estimating human exposure	• Analytical methods • Remediation • Waste-water treatment • Toxicity Testing

Research Issue	National Research Program					
	A-E	**CSS**	**HHRA**	**HSRP**	**SHC**	**SSWR**
Resilience	• Sector-based approaches to resilience • Assessment of trends and development of scenario to support adaptation and resilience for extreme events			• Emergency preparedness and response for all hazards	• Indicators of long term resilience • Preparation and response to natural disasters	• Coastal Resilience • Stormwater
Wildland fires	• Models and measurement methodologies • Vulnerable ecosystems and human populations • Approaches to mitigate risks			• Fate and transport of contaminants during wildland fires, e.g., fire in asbestos contaminated area	• Models and measurement methodologies	