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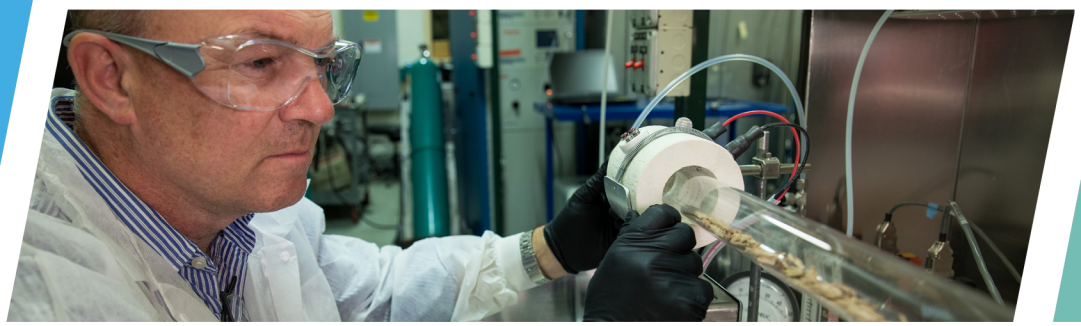
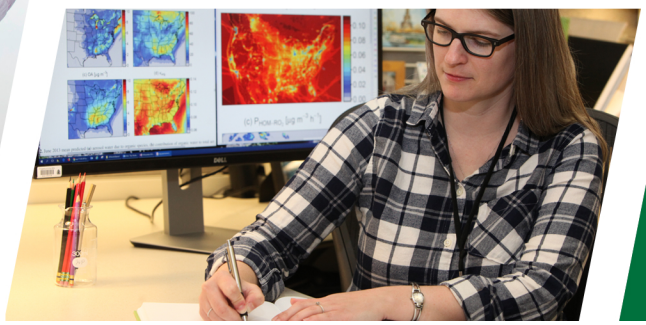


Air and Energy

STRATEGIC RESEARCH ACTION PLAN 2019-2022



Office of Research and Development
Air and Energy

Air and Energy National Research Program

Strategic Research Action Plan, 2019 – 2022

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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
EEM	Emission estimating methodology
EIS	Environmental Impact Statements
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency
ERIS	Environmental Research Institute of the States
EtO	Ethylene oxide
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
HERA	Health and Environmental 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
MJO	Multijurisdictional Organization
NAAQS	National ambient air quality standards
NADP	National Atmospheric Deposition Program
NASA	National Aeronautics and Space Administration
NEHA	National Environmental Health Association
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NGM	Next-Generation Methods
NGO	Non-governmental organization
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

PO	Program Office
PSD	Prevention of Significant Deterioration
R2P2	Regional Research Partnership Program
RARE	Regional Applied Research Effort
RCRA	Resource Conservation and Recovery Act
RO	Regional Office
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 aerosols
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 and protect public health and the environment.

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 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, increasing diversity in the nation's energy portfolio, and broader changes in land use, transportation, and climate, 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. EPA's Office of Research and Development (ORD) plans and implements the A-E Research Program to provide partners in EPA program 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 potential benefits and consequences of those decisions.

The objectives of the A-E Research Program are:

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.

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.

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

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.

To achieve these objectives, the A-E research activities will be structured under three inter-related topic areas: (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 and will be an integrated science focus of the program.

This A-E StRAP describes the overall structure and purpose of the A-E Research Program and outlines a strategic research framework. The A-E Research Program will continue to engage with EPA and external partners as ORD works to identify specific deliverables and implement the research program. Through this collaborative approach, the A-E Program will 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 areas across the United States that do not meet the national standards, improve public health and the environment, and meet broader EPA legal and statutory mandates.

Introduction

Ambient air pollution has significant adverse consequences on human health and the environment, including asthma and other respiratory and cardiovascular effects that can lead to disease and death in humans, as well as visibility impairment and deposition of air pollutants that can harm surface waters. 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 of the six criteria air pollutants[1], even as precursor emissions for these pollutants 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 public health, as well as 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)
- Health and Environmental Risk Assessment (HERA)
- Safe and Sustainable Water Resources (SSWR)
- Sustainable and Healthy Communities (SHC)

Research to Support the EPA and ORD Strategic Plans

EPA's six StRAPs 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, 2018, 2019). 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, by cultivating an efficient, innovative, and responsive research enterprise.

As part of its mission to protect human health and the environment, EPA is dedicated to improving air quality in the United States, and therefore several goals in EPA's Strategic Plan are directly relevant to the A-E program as summarized in Table 1 and discussed below.

[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).

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

EPA Goal	EPA Objective
Goal 1 — A Cleaner, Healthier Environment: Deliver a cleaner, safer, and healthier environment for all Americans and future generations by carrying out the Agency's core mission	**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 — More Effective Partnerships: Provide certainty to states, localities, tribal nations, and the regulated community in carrying out shared responsibilities and communicating results to all Americans	**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 — Greater Certainty, Compliance, and Effectiveness: Increase certainty, compliance, and effectiveness by applying the rule of law to achieve more efficient and effective agency operations, service delivery, and regulatory relief	**Objective 3.3 — Prioritize Robust Science:** Refocus the EPA's robust research and scientific analysis to inform policy making
	Objective 3.5 – Improve Efficiency and Effectiveness: Provide proper leadership and internal operations management to ensure that the Agency is fulfilling its mission

EPA 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, "More Effective Partnerships," focuses on close communication with Agency regional and program office partners, state and local agencies, and external stakeholders. ORD is strengthening its direct relationship with states and engaging decision makers 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) other tribal organizations such as the National Tribal Air Association (NTAA), and with several public health organizations such as the National Environmental Health Association (NEHA) and the Association of State and Territorial Health Officials (ASTHO).

[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.

EPA Goal 3, Objective 3.3, "Prioritize Robust Science," emphasizes research and scientific analyses to inform policymaking. This objective helped shape the research priorities articulated throughout the A-E StRAP. For air quality, the EPA Strategic Plan 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*.

EPA Goal 3, Objective 3.5, "Improve Efficiency and Effectiveness," strives to streamline and modernize business processes including financial, facility, human resource, contract, grant, and information technology management – all of which are necessary elements for a successful scientific enterprise to effectively address 21st century environmental problems. EPA is identifying specific processes where efficiencies are needed and applying Lean Management principles to achieve these improvements.

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).

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." It specifies inclusion of "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 requirements specified in the CAA include 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

[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.

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 these statutes. 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).

Engagement with Partners and Stakeholders

ORD, including the A-E Research Program, 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 informed by scientific evidence. A-E will measure its progress over the next four years by increasing the percentage of research products that meet customer needs. The research portfolio outlined in this draft StRAP has been developed with considerable input from EPA partners and other outside stakeholder groups. This has been done through a variety of mechanisms including:

- Recurring meetings (monthly or quarterly) with individual Regional and Program Office (RO/PO) managers and staff
- Biweekly/monthly calls with participation by ORD and RO/PO staff (A-E Connections and Climate calls)
- Participation in Region and State-related organization meetings (e.g., EPA Air Division Directors and Air Program Managers, National Association of Clean Air Agencies, Association of Air Pollution Control Agencies)
- A-E Research News (web-based quarterly newsletter)
- Meetings with state (e.g., Environmental Council of the States, Environmental Research Institute of the States) and tribal organizations (e.g., Tribal Science Council, National Tribal Air Association)

Additionally, we also held a series of meetings to engage and solicit input from EPA RO/PO partners and ORD to develop the StRAP (see Table 2).

Table 2. Partner Engagement Meetings

Early conversation	Individual meetings with Deputy Regional Administrators, Office Directors, and Science Leads; ORD participants invited to listen (February 20, 2018)
Informational webinar for A-E community (all interested EPA staff)	Shared 2-page draft proposed A-E program structure (March 28, 2018)
Partner Engagement Workshop	Identified key draft program outputs and deliverables (April 11, 2018)
Updates on proposed A-E program structure	Proposed Topics/Research Areas (July 2, 2018) Early draft list of proposed strategic Outputs (July 11; August 20, 2018)
Intra-Agency review of draft StRAP	Shared broadly with RO/PO partners and ORD (August 22 – September 21, 2018)
Regular Communication with RO/PO Science Leads	Ongoing

The A-E Research Program will continue to engage with our EPA partners and state, tribal, and local organizations, including multijurisdictional organizations (MJOs), as we implement the research program, support our research products after they are delivered, and in doing this, evaluate the usefulness and effectiveness of our research in helping solve environmental and public health problems.

The A-E Research Program strategically integrates intramural and extramural research efforts to create a robust portfolio. Scientists and EPA partners representing a wide range of disciplines work together to improve our understanding of complex environmental problems using a variety of research approaches that include collaborations across government agencies and with the private sector, grants and contracts, such as EPA's Science to Achieve Results (STAR) grants, and the Small Business Innovation Research (SBIR) program, public/private partnerships, and open-source challenges and prizes.

Environmental Problems and Research Program Objectives

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. 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 the environment and harms the economy. 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.

Research Program Objectives

The A-E research 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:

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.

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.

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.

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.

Research Topics

The four research objectives identified above serve as the framework for developing research topics to focus the scope and nature of the A-E Research Program over the next four years. The organization of the A-E Research Program is being updated to:

- Improve integration across multiple scientific disciplines;
- Better leverage resources to more efficiently and effectively address critical research needs; and
- Enhance translation and accessibility of science to inform the decisions of Agency partners and stakeholders.

The A-E Research Program will be centered around three inter-related research topic areas: (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 these three topics. Figure 1 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.

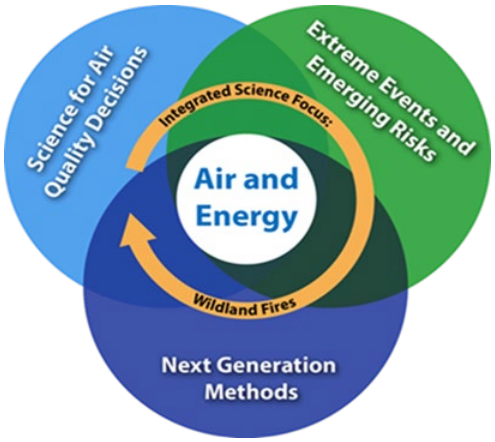

Figure 1. Air and Energy Research Topics.

The research topics are further divided into research areas as summarized in Table 3 and described in more detail below. The research areas and specific deliverables ("Outputs")[4] 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 the Appendix. Research Area plans will be developed subsequent to the StRAP that describe the specific research undertaken to achieve the goals of the Research Area and Topic. These plans will include a more detailed description of deliverables (outputs and products), timeline and mechanism for delivery, and partner engagement plan that describes how partners will access data, reports, etc.

Table 3. Overview of Air and Energy Research Program Structure

Topic	Research Areas	
1. 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	
2. Extreme Events and Emerging Risks	#4: Public health and environmental exposures and responses to emerging air pollutants and sources	
	#5: Methods to evaluate environmental benefits and consequences of a changing energy system	
	#6: Methods to enable resilience to future environmental stressors	
3. 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	

[4] Outputs are deliverables with the research results synthesized and/or translated into the format needed by the end user(s).

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. Work conducted under this research topic is related to achieving all four of the A-E Research Program objectives identified above.

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.

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. The establishment and review of the NAAQS is a complex undertaking, involving synthesis of the extensive science on the impacts of air pollution on humans and ecosystems. 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. The A-E Research Program works closely with the Health and Environmental Risk Assessment (HERA) Research Program in carrying out the research needed to inform the NAAQS reviews.

The Science for AQD topic includes three Research Areas that will include research to:

- *Address key uncertainties and data gaps to inform future reviews of the NAAQS*
- *Expand our understanding of 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*
- *Improve characterization of the multipollutant exposures, effects, and integrated impacts of dynamic environmental conditions on health, air and water quality, and ecosystems*
- *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*
- *Evaluate control technologies and identify best practices for more efficient integrated and sustainable pollution reduction and prevention solutions, while considering relevant social, behavioral, and economic factors*
- *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 Area 1: Approaches to Support Air Quality Management Programs for Multiple Pollutants at Multiple Scales

Research Area 1 Priority: Development, evaluation, and application of air quality and multimedia models for regulatory and research applications including deposition of nutrients to sensitive ecosystems

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. 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.[5]

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.

The Community Multiscale Air Quality (CMAQ) modeling system[6], a core component of the A-E Research Program, combines meteorological, emissions, and air chemistry transport and deposition models 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. For two decades, 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.

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 ongoing research include the following: improving the quantification of the contributions of local and regional sources versus background source contributions (such as trans-Pacific

[5] Multipollutant air quality assessments may include consideration of simple and complex mixtures of particles, criteria pollutant gases, and selected HAPs.

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

transport of air pollution) to non-attainment areas, which will inform efficient and effective NAAQS attainment strategies; improving representation of secondary organic aerosols (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). Furthermore, through the National Atmospheric Deposition Program (NADP) Total Deposition (TDEP) Science Committee[7], 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.[8]

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 regional-scale air quality modeling efforts between North America and Europe 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.

EPA regions, as well as state and local agencies and tribes, often use models in the permit review process to estimate air pollutant concentrations at ground-level receptors surrounding particular sources. A-E researchers will continue to work closely with EPA's OAR to develop and refine air dispersion models to assess local-scale impacts from a variety of sources. For example, ORD collaborates with OAR on the AERMOD modeling system[9] 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) as 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

[7] Learn more about the NADP and the TDEP Science Committee at: http://nadp.slh.wisc.edu/NADP/.
[8] 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.
[9] 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.

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[10] 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 mobile source emissions (both tailpipe and brake/tire wear) as well as 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.

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.

[10] 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).

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

Research Area 2 Priority: Federal Reference and Equivalent Methods research for criteria pollutants, methods development for hazardous air pollutants, and methods to measure area source emissions

Expanding our knowledge of the sources of air pollutants, how pollutants 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. To better inform decision makers, A-E researchers are developing, evaluating, and applying methods to improve characterization of source emissions, air quality, and human and environmental exposures for individual and mixtures of air pollutants. Research and data collection efforts will be directed at improving our understanding of factors that influence the magnitude and duration of air pollutant exposures and expanding the knowledge base of factors that contribute to regional differences.

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, where accuracy, durability, ease of use, and cost-drivers are major factors.[11] 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 consideration of updates to methods for toxic organic pollutants in ambient air.

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 2016-2019 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 current StRAP. Overall, the cookstove research will look to evaluate best practices and alternative technologies for cleaner energy systems that reduce emissions and impacts to public health and the environment.

A-E researchers are continuing to advance methods and air measurement technologies to better characterize source emissions. EPA partners, state and local agencies, and tribes have expressed interest in this research, 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 for both tailpipe and brake/tire wear emissions; wildland fires; agricultural sources; residential wood combustion) and pollutants (e.g., condensable PM, 1,3-butadiene, acrolein, ethylene oxide,

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

chloroprene). Improved source emissions data are critical for reducing uncertainties in national emissions inventories and informing the development, implementation, and enforcement of regulations. For example, the A-E Research Program is furthering the development of fenceline and mobile technologies to improve characterization of previously undetected leaks from industrial and oil and gas facilities.

A-E researchers will continue improving the characterization of emissions from animal and crop agricultural operations. This work includes improving our understanding of ammonia (NH_3), PM, and volatile organic compound (VOC) emissions from AFOs related to manure application, as well as NH_3 and oxides of nitrogen (NO_x) soil emissions from fertilizer applications. A-E 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.

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.

EPA partners 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. 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. This work supports critical Agency programs, including applications for implementation and compliance with relevant air pollution standards.

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

Research Area 3 Priority: Factors affecting vulnerability of people and ecosystems including biological, exposure/deposition characteristics, and environmental justice

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 work will inform future NAAQS reviews and advance assessments of multi-pollutant exposures. The results of A-E research will contribute directly to the Integrated Science Assessments (ISAs)[12] developed in the HERA program to inform the NAAQS reviews conducted by EPA's OAR.

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

A-E researchers will 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, and genetics/epigenetics; environmental justice factors such as social, economic, cultural, and race; behavioral, and other factors that may 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.

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.[13] 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 standard levels, 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 in enhancing our understanding of exposure durations of concern; 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.

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.[14] 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

[13] See *Our Nation's Air*, summarizing the United States air quality status and trends through 2017.
[14] 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.

our understanding of the relationships between climate change, air quality, and human and ecological impacts. This work will include advancing the understanding of: (1) the impact of 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. Scientific information produced by A-E researchers in this area will inform improved strategies through 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 environmental effects.

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 evaluate whether such interventions have benefits as measured by indicators of health, well-being, or economics.

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.

Determining the effectiveness of these decisions over the long term 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 frequent and extreme high-temperature events. These events 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.

The E3R topic includes three Research Areas that will include research to:

- *Advance understanding of the potential impacts of emerging and future risks to human health, air quality, water quality, ecosystems, and built infrastructure*
- *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*
- *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 preparedness and adaptation strategies to mitigate air pollutant and climate impacts to protect at-risk populations, communities, and ecosystems*

Research Area 4: Public Health and Ecosystem Exposures and Responses to Emerging Air Pollutants and Sources

Research Area 4 Priority: Development and laboratory and field evaluation of methods to measure pollutants of emerging interest including per- and polyfluoroalkyl substances (PFAS) and ethylene oxide

To maintain and improve air quality, EPA's 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.

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 the 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, HERA, SSWR, and SHC Research Programs that collectively is aimed at developing effective risk assessment, management, and mitigation strategies.

OAR and EPA regional offices have also requested information about, and methods to measure, emissions and ambient concentrations of ethylene oxide (EtO) at very low concentrations. Recent evaluations of EtO toxicity have led to concerns regarding public exposure to EtO, and possible public health risks, at levels below the capability of current measurement methods. A-E researchers will work with OAR and other partners to advance techniques to accurately measure emissions and ambient concentrations of EtO to inform development of EPA and state management strategies to protect public health.

Research Area 5: Methods to Evaluate Environmental Benefits and Consequences of a Changing Energy System

Research Area 5 Priority: Development of scenarios of energy-system evolution of power generation, transportation, industry, and building sectors

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 EISA, A-E researchers will develop the triennial Report to Congress on the environmental impacts of biofuel production and use.[15] 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

[15] *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).

researchers work with experts from other ORD research programs and EPA partner offices, as well as local, state, and tribal stakeholders to develop life-cycle evaluations of energy system scenarios.

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

Research Area 6 Priority: Resilience and adaptation to extreme events and climate change

Included in EPA's FY19 Performance Measures[16] 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 (NOAA), 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, the effect of heat and other extremes on 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 potential users to co-develop methods and tools. Workshops, webinars, and other means of engagement with community representatives have generated ideas about how information can be most effectively developed and communicated and increased the understanding of the science at the community level.

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, an understanding of potential future changes in air temperature and precipitation patterns is 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.

[16] https://www.epa.gov/sites/production/files/2018-03/documents/fy19-cj-13-performance-measures.pdf

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

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 the A-E objective of advancing measurement and modeling. This work will also address the remaining A-E objectives to improve assessment of impacts, develop approaches to prevent and reduce emissions, and inform decisions at national, state, tribal, and local levels.

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 assessing 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 to ensure that the information and technologies are of sufficient quality for the uses and decisions of interest.

Similarly, in the era of "big data," the issues of data management and interpretation are 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 PM 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 air quality modeling system will also advance the science of air quality modeling and understanding of critical processes across local to global 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 creates opportunities to merge research on air sensor technologies 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 will be used to make progress in improving air quality and public health. The A-E Research Program has had success and will continue to explore opportunities to use open-source challenges and prizes, 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, followed by a SBIR solicitation to further advance this technology. A-E research scientists have also worked extensively with community groups and other non-governmental organizations (NGOs) on the use of sensors involving citizen scientists and exposure/health effects studies involving volunteer participants. These efforts have enabled research studies to be much more successful than they would have been otherwise. The A-E Research Program, together with its partners, will continue to capitalize on open-source challenges and prizes, the SBIR program, and establishing working relationships with NGOs and community groups, whenever appropriate, to advance next-generation methods.

The NGM topic includes two Research Areas that will include research to:

- *Develop innovative approaches for assessing human and environmental exposures and effects of pollutants in the atmosphere*
- *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.

Research Area 7: Emerging Approaches to Improve Air Quality and Exposure Characterization

Research Area 7 Priority: Development of innovative and advanced approaches to measure and model air pollutants

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.

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.

Many new air sensor technologies are entering the market, but the quality and reliability of the data they produce are 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, local, 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.

Advanced methods are needed to better measure source or near-source emissions in challenging situations. This research will include expanding knowledge of near-source impacts and control strategies, including near-road environments, complex multi-source environments, rail yards, ports, and other transportation facilities. The development and evaluation of advanced next-generation fenceline monitoring methods combined with facility-specific, real-time, and lower-cost sensors networks will improve measurements and reduce the costs of compliance monitoring.

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 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, and satellite data, and (3) modeling results to reduce uncertainties in exposure assessments.

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 as to whether 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

Research Area 8 Priority: Development of advanced capabilities to characterize public health and ecosystem risks

New and innovative methods and models are needed to assess the multiple chemical and non-chemical interactions that ultimately impact public health and welfare. Quantitative assessments of exposures and potential human and ecosystem effects associated with air pollutants should also describe the impacts of changing environmental conditions on human health, air quality, and water quality.

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 HERA 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 $PM_{2.5}$.[17] 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

[17] 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.

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.

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.

Integrated Science Focus: 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 Area 9 Priority: Approaches to reduce exposures and risks from wildland fires to people and ecosystems

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 human populations and the biological, geological, and

environmental justice characteristics that confer vulnerability; 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 and how ecosystems and human populations 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.

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 characterizing source emissions; (4) improving the 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.

Program Design

To plan and implement work in each of the Research Areas, the A-E program includes a complementary set of research components and emphasizes “solutions-driven” research. Communication and collaboration across ORD’s six research programs promote integration of research efforts, where appropriate, to meet program objectives.

Program Components

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 (Figure 2). By its nature, the A-E Research Program comprises a breadth of research activities across a wide array of scientific and programmatic issues. As the science progresses, we must periodically evaluate the research to capitalize on opportunities to more effectively address environmental problems and science questions using new and innovative approaches. The A-E Research Program will review its nine Research Areas each year to identify and adopt revisions to the science ensuring that an appropriate balance is struck between addressing short-term needs of EPA partners and longer-term, exploratory research objectives. In this

regard, A-E will remain relevant and responsive to EPA's needs and at the forefront of environmental science.

The intramural component of the A-E Research Program involves EPA scientists representing a wide range of disciplines who work together to improve our understanding of complex environmental problems. Internally, the A-E Research Program engages with scientists across multiple ORD research 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.

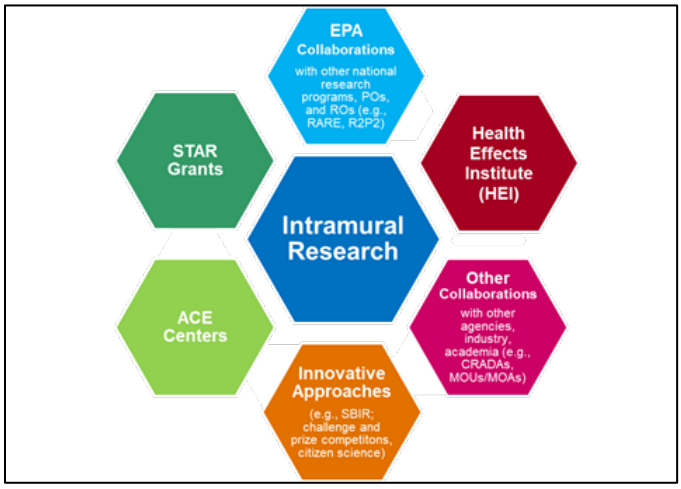

Figure 2. Integration of Intramural and Extramural Research Efforts.

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 and will continue to be relied upon to investigate new lines of research related to emerging environmental problems. The A-E Research Program will build on the success and long history with the STAR program that spans more than two decades to address emerging air-, climate-, and energy-related issues. Previous awards engaged academic researchers on a broad range of issues, advancing our understanding of atmospheric chemistry, air quality modeling and measurements, epidemiology, toxicology, climate- and energy-related impacts. In addition, since 1999 the A-E Research Program has funded a total of 17 multi-university collaborative research centers through larger, multi-year grants, each of approximately five-year duration. These research centers have contributed to a greater understanding of the health impacts of 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 A-E extramural research is public-private partnerships, which can provide additional 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 non-profit entities that receive balanced funding from the government and a regulated industry. For example, the Health Effects Institute (HEI) chartered in 1980 is a well-regarded partnership that receives balanced funding from EPA (ORD/A-E and OAR) and the worldwide motor vehicle industry. HEI 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 SBIR Program. The A-E Research Program will continue to capitalize on the SBIR program and, wherever possible, expand the use of SBIR to develop next-generation answers to emerging environmental problems, such as those related to PFAS and ethylene oxide.

A-E researchers are also exploring opportunities to use 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.

Solutions-Driven Research

ORD, including the A-E Research Program, 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 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:

- Planned partner and stakeholder engagement throughout the research process, starting with problem formulation and informing all elements of research planning, implementation, dissemination, and evaluation
- A focus on solutions-oriented research outputs identified in collaboration with partners and stakeholders
- Coordination, communication, and collaboration both among ORD researchers and between researchers and partners to develop integrated research that multiplies value to partners and stakeholders
- Application of research outputs in cooperation with partners and stakeholders to solve complex environmental problems, and 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[18] 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.

Integration Among Research Programs

EPA's six research programs (A-E, CSS, HERA, HSRP, SHC, SSWR) 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. A few examples of cross-program coordination are briefly described below:

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.

[18] Learn more at: https://ncats.nih.gov/.

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 Safe Drinking Water Act (SDWA), Clean Water Act (CWA), 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 the 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 SDWA, 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 (A-E); address resilience and preparedness with respect to immediate emergency response (HSRP); and provide long-term planning for resilient communities (SHC), contaminated site remedies (SHC), and watersheds and

water infrastructure (SSWR).

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 NAAQS and the science upon which they are based. EPA completed its most recent review of the Pb NAAQS in 2016.[19] Priority areas of lead research for our partners OAR include new information related to assessments and biomodelling research. This work is carried out by our colleagues in the HERA Research Program. In addition, our colleagues in the 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 HERA and SHC to ensure impacts from lead in the air are addressed by ORD.

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 present new challenges in meeting air quality objectives.

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, 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 overarching 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.

[19] 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.

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Appendix

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	1.1 FY19- Release of CMAQ v5.3 and instrumented versions supporting source apportionment 1.2 FY22 – Release updates to CMAQ 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	1.3 FY22- 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)	1.4 FY22- Enhanced monitoring and modeling approaches to characterize mesoscale pollution episodes

Research Area	Program, Regional, State and/or Tribal Need	Output Title
	Improved understanding of near-source air pollution impacts and exposures including expanded knowledge of how roadside solid and vegetative barriers affect near-road impacts and how freight movement activities influence community air quality	1.5 FY22 - Fine-scale assessment and mitigation methods for near-source impacts
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	2.1 FY20 - Summary of research advancements to characterize emissions, exposures, and related health and environmental impacts associated with solid-fuel combustion for household energy needs (cooking, heating, and lighting)
	Support of regulatory compliance efforts relevant to: (i) NAAQS attainment, (ii) the National Greenhouse Gas Inventory, (iii) National Emission Standards for Hazardous Air Pollutants [Air Toxics] (NESHAPs), (iv) New Source Performance Standards (NSPS), and (v) State Implementation Plans (SIPs).	2.2 FY22- Progress update on the characterization and mitigation of key combustion sources
	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	2.3 FY22- Development, evaluation, and implementation of updated ambient air measurement methods
	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	2.4 FY22 – Progress update on fugitive, area source, fenceline, and roadway emissions research
	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	2.5 FY22- Methods for estimating methane emissions from surface

Research Area	Program, Regional, State and/or Tribal Need	Output Title
	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	water reservoirs for the U.S. GHG Inventory Report
	Improved characterization of air emissions from animal and crop agricultural operations	2.6 FY22- Emission estimating methodologies (EEMs) and future research needs for emissions from agricultural sources
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	3.1 FY19- Report synthesizing 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
	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	3.2 FY22- 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	3.3 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	3.4 FY22- Summary of the effect of changing environmental conditions on the chemistry and health impacts of air pollution mixtures and subsequent responsiveness
	Improved measurements and modeling capabilities to address currently identified knowledge gaps and uncertainties in total deposition estimates	3.5 FY22- Synthesis of the scientific advances on deposition and critical load-related research
Topic 2: Extreme Events and Emerging Risks		
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	4.1 FY22- Measurement methods development of PFAS in air
	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	4.2 FY22- State-of-the Science: synthesis of research on airborne PFAS emissions, sources, control, dispersion, environmental fate, and impacts and identification of remaining critical knowledge gaps
	Enhanced understanding of the role of various organic species (e.g., monoterpenes, volatile consumer products, SVOCs, IVOCs) to form criteria air pollutants and modeling, experimental, and computational chemistry methods to assess these impacts	4.3 FY22- Evaluation of organic species impacting criteria pollutant formation
	Methods to measure ethylene oxide emissions at the source, near-source, and ambient levels	4.4 FY22- Ethylene oxide – state of the science and methods development

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	5.1 FY22- Report on air quality under future energy scenarios
	Required assessment under the Energy Independence and Security Act for environmental impacts of biofuels	5.2 FY21- Biofuels and the Environment: The Third Triennial Report to Congress (RtC3)
	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	5.3 FY22- Progress update on environmental consequences of emerging transportation technologies, policies 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	6.1 FY22- Updated and expanded scenario data for population, land use, and extreme events as input to risk communication and management
	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	6.2 FY22 - Summary of advances in interactions of future environmental changes on PM, ozone, wildfires and associated human health impacts
	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	6.3 FY22- Analysis of environmental impacts and vulnerabilities due to effects of changing conditions and extreme events on water quality and aquatic resources

Research Area	Program, Regional, State and/or Tribal Need	Output Title
	Improved understanding of environmental responses to extreme events and identification and evaluation of mitigation options	6.4 FY22- Methods for adaptation planning and decision analysis to improve environmental resilience to changing conditions and extreme events
Topic 3: Next-Generation Methods to Improve Public Health and the Environment		
7. Emerging approaches to improve air quality and exposure characterization	Improved understanding of the spatial and temporal characterization of human and environmental exposures	7.1 FY22- Advancement of methods in combining different types of observational and model data for air pollution characterization
	Enhanced understanding of how use, manage, and communicate measurement data from air sensors	7.2 FY22- Improved capability to manage, process, analyze, and visualize next-generation air pollution data
	Improved understanding of air sensor performance and quality of technologies on the market	7.3 FY21- Air quality sensors – performance evaluation, targets development, testing protocols, and best practices guidance
	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	7.4 FY22- Development of advanced air quality modeling approaches for global to urban scales

Research Area	Program, Regional, State and/or Tribal Need	Output Title
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	8.1 FY22- Development of new health research approaches that take advantage of newly available electronic health databases, molecular data cohorts, and advanced cellular models
	Increased understanding of wildland fire impacts on water bodies and ecosystems, including: erosion, use of fire suppressants, surface and groundwater, and drinking water	8.2 FY22- Integration of atmospheric, fire, ecosystem, and watershed models and approaches to assess the impacts of wildfires on multiple health, ecosystem, and environmental management endpoints, jointly where possible to account for adverse and beneficial impacts.
Integrated Science Focus		
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	9.1 FY20- Interim progress update on wildland fire research summarizing multidisciplinary research being conducted across A-E research topics
		9.2 FY22- Public Health Actions to Reduce Risks from Exposure to Wildland Fire Smoke
		9.3 FY22- State of the Science: Synthesis of wildland fire research findings related to improved modeling and measurement methodologies, public health impacts and interventions, and ecosystem impacts