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Air, Climate, and Energy

STRATEGIC RESEARCH ACTION PLAN 2012-2016

SCIENCE

Office of Research and Development
Air, Climate and Energy

EPA 601/R-12/003

Air, Climate, and Energy

Strategic Research Action Plan 2012 - 2016

AIR CLIMATE ENERGY

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Executive Summary

As the U.S. Environmental Protection Agency (EPA) moves forward, it is necessary to more fully understand the interplay between air, climate change, and the changing energy landscape to develop innovative and sustainable solutions to improve air quality and address climate change.

American communities face serious health and environmental challenges from air pollution and the growing effects of climate change, both of which are intricately linked with current and future energy options. Improving air quality, reducing greenhouse gas (GHG) emissions, and developing adaptation strategies to address climate change are central to the Agency's mission to protect public health and the environment. As the U.S. Environmental Protection Agency (EPA) moves forward, it is necessary to more fully understand the interplay between air, climate change, and the changing energy landscape to develop innovative and sustainable solutions to improve air quality and address climate change.

To accomplish this goal, EPA's Office of Research and Development (ORD) has designed a new, integrated research program for Air, Climate, and Energy (ACE) that builds on the highly successful, policy-relevant research that the Agency has conducted in the areas of air pollution and climate change.

During the past several decades, air quality in the United States has improved significantly. During this time period, ORD research, in keeping with its Clean Air Act (CAA) mandate, has played a central role in demonstrating that exposure to air pollution remains a major health concern, as it can lead to damage to the cardiovascular, respiratory, immune, nervous and reproductive systems, as well as cancer and death. These findings have provided the scientific basis of the statutory requirements of the CAA and directly contributed to the Office of Management and Budget's estimates that the benefits of air pollution regulations far exceed their costs.

Despite this progress in improving air quality, millions of people still live in counties that do not meet air quality standards for one or more pollutants.

Global GHG emissions continue to rise and have been shown to lead to a range of major and potentially adverse effects on the environment and public welfare. In response to EPA's finding that greenhouse gases threaten public health and the environment (2009 Endangerment and Cause or Contribute Findings for GHGs), ORD is producing scientific information to support and respond to the Agency's efforts to meet its legal, statutory, and policy requirements in a changing climate, including informing climate mitigation (i.e., reducing concentrations of pollutants that contribute to a changing climate) and adaptation (i.e., coping with the environmental effects due to a changing climate) choices toward sustainable, resilient solutions.

The impacts of air quality and climate change are heavily influenced by the energy choices of the United States and the world. As the demand for energy increases, along with shifts to clean energy alternatives, it is necessary to understand the interaction between air quality and climate change, and the potential impacts on human and environmental health.

With active participation from internal EPA partners, such as EPA program and regional offices, as well as external stakeholders, the major problems faced by EPA decision-makers that span air, climate, and energy were identified. These discussions brought to the forefront the need for research that informs policy choices and subsequently examines:

- The multipollutant nature of air pollution and the development of effective air quality strategies;
- The impacts of climate change and the interactions between adaptation and mitigation;
- The human health and environmental impacts of current and future energy options;
- The populations most susceptible to poor air quality and the populations and ecosystems most vulnerable to climate change;
- The expanding and contracting scales of environmental problems that range from global to local; and
- The social, behavioral, and economic factors that influence the effectiveness of air quality and climate policies.

The policy-relevant research needed by EPA partners will provide the science to:

- **Assess Impacts** — *Assess human and ecosystem exposures and effects associated with air pollutants and climate change at individual, community, regional, and global scales (Research Theme 1);*
- **Prevent and Reduce Emissions** —*Provide data and tools to develop and evaluate approaches to prevent and reduce emissions of pollutants to the atmosphere, particularly environmentally sustainable, cost-effective, and innovative multipollutant and sector-based approaches (Research Theme 2); and,*
- **Respond to Changes in Climate and Air Quality** — *Provide human exposure and environmental modeling, monitoring, metrics and information needed by individuals, communities, and governmental agencies to adapt to the impacts of climate change and make public health decisions regarding air quality (Research Theme 3).*

EPA designed the ACE research program to address the increasingly complex environmental issues that we face in the 21st century. To effectively address these issues, it is necessary to move toward more integrated, transdisciplinary research and away from strategies that focus on a single pollutant and its impact on a single human organ or species in an ecosystem. This requires interaction and active discussions with the other ORD research programs, EPA partners, other federal agencies, and external stakeholders to facilitate a seamless research program that clearly identifies crosscutting issues that can be integrated within and across research areas to support the goals of the Agency.

Introduction

Ambient air pollution can have significant adverse consequences on human health and the environment. Research conducted and supported by ORD has demonstrated that exposure to air pollution can lead to a range of health effects including, but not limited to, respiratory and cardiovascular effects and mortality. Great advances in understanding the human and environmental health impacts of air pollution along with the development of technologies, tools and models to prevent and reduce air pollution have led to greatly improved air quality over the last 40 years. Even so, millions of people in the United States still live in counties that do not meet air quality standards for one or more pollutants.

Global climate change can have a range of major and potentially adverse effects on water resources, agriculture, wildlife, ecosystems, and the built environment (i.e., energy, infrastructure, and settlements).[1] Additionally, changes in climate can lead to higher concentrations of harmful air pollutants, and the presence of some air pollutants in the atmosphere also can accelerate climate change. With global emissions of GHGs increasing and projected to continue to increase unless action is taken to reduce these emissions, there is compelling evidence that the public health and welfare of current and future generations are at risk.[1]

Energy to produce and transport goods, move people, and support the productive and growing economy of the United States is central to the issues of air quality and climate change. Energy production and use has major impacts on both air quality and climate with conventional energy options generally representing a major source of air pollution emissions including GHGs. As demand for goods and services grows in concert with an expanding population, current energy technologies will place further pressure on climate and air quality.[2]

In light of these facts, President Obama has proposed a goal to produce 80 percent of the electricity in the United States from clean energy sources by 2035.[3] Although it remains unclear what future energy options will emerge, it is evident that the United States and the world face a rapidly changing energy landscape with associated changes in impacts on human health and the environment.

Problem Statement

The problems that span the nexus of air, climate, and energy, as well as the major research needs identified by EPA partners and stakeholders, form the basis of the overarching problem statement that will govern the ACE research agenda:

> *Protecting health and the environment from the impacts of climate change and air quality in a sustainable manner are central 21st century challenges. These challenges are complicated by the interplay between air quality, the changing climate, and emerging energy options.*

Integrating the research issues inherent in the problem statement into a seamless research program that addresses air quality, climate

change, and energy presents a substantial challenge to any research organization. From an EPA research perspective, however, it also presents an opportunity. Combining air, climate, and energy research activities enable the development of sustainable, integrated solutions that have synergistic benefits for public health, the environment, and the economy.

Program Vision

To date, EPA's Clean Air, Global Change, and Biofuels research programs have supported and conducted research that has improved the human and environmental health of the United States. These research programs individually have directly supported: the promulgation of the National Ambient Air Quality Standards (NAAQS), the development of the Endangerment and Cause or Contribute Findings for GHGs, and the implementation of the Renewable Fuel Standard. Additionally, each of these programs has produced cutting-edge science leading to significant advances, including a more thorough understanding of the source to health effect continuum of particulate matter (PM),[4] the development of complex multipollutant atmospheric models such as Community Multiscale Air Quality (CMAQ), and a detailed evaluation of the impacts of climate change through a series of Synthesis and Assessment reports.[5]

Problem Statement:

Protecting health and the environment from the impacts of climate change and air quality in a sustainable manner are central 21st century challenges. These challenges are complicated by the interplay between air quality, the changing climate, and emerging energy options.

VISION:

EPA provides the cutting-edge scientific information and tools to support EPA's strategic goals of protecting and improving air quality and taking action on climate change in a sustainable manner.

Research conducted under the Clean Air component of ACE—the longest-running component of the ACE portfolio—has been a fundamental part of EPA's success in improving the Nation's air quality. Although the broad scope of the benefits realized from EPA air research programs is in part unquantifiable, the White House Office of Management and Budget has estimated that the NAAQS has accounted for approximately 94 to 97 percent of estimated benefits from all EPA regulations and approximately 60 to 87

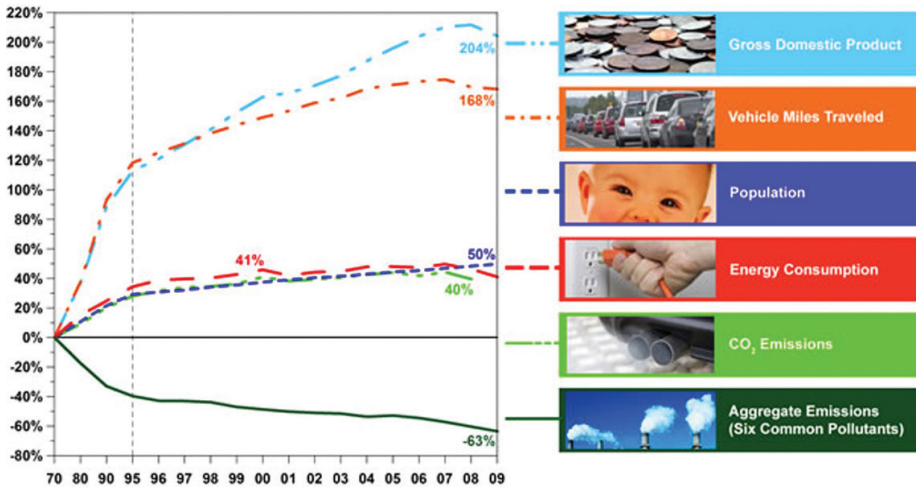

Figure 1. The changing economic, population, and environmental status of the U.S., 1970-2009.[7]

percent of estimated benefits across all federal agencies.[6] These benefits include reductions in the number of hospital admissions and emergency department visits, fewer lost work and school days, and lower numbers of premature deaths. Additional research has indicated that improvements in air quality have led to an increase in life expectancy.

These improvements in air quality and public health resulting from EPA's air programs (i.e., research and regulatory) are illustrated in Figure 1, and highlights the substantial reductions in PM10, nitrogen oxides, volatile organic compounds, carbon monoxide (CO), and sulfur dioxide (SO2) since 1970, even as the gross domestic product and vehicle miles traveled have nearly doubled. The work of ORD was instrumental in providing the scientific and technical foundation for these achievements.

The full benefits of EPA's achievements in clean air, however, have not been shared by all, nor have they been guaranteed for the future. Even with the economic and public and environmental health improvements that have occurred concurrently during the last 40 years:

- Approximately 127 million Americans lived in counties that did not meet the air quality standard for at least one pollutant in 2008;[8]
- GHG emissions continue to increase in parallel with population growth and energy consumption, threatening public and environmental health; and
- The landscape of energy sources and technologies is changing, leading to uncertainty as to the impacts of future energy choices on human and environmental health.

With past accomplishments forming the foundation for meeting future challenges, the vision of the ACE research program is to:

Provide the cutting-edge scientific information and tools to support EPA's strategic goals of protecting and improving air quality and taking action on climate change in a sustainable manner.

The ACE research program builds on its record of highly relevant and exceptionally valuable science, while incorporating sustainability concepts, to continue to inform the Agency's development of policies that create enormous benefits for public health, the environment, and the national economy.

Research Supports EPA Priorities and Mandates

Statutory and Policy Context

The ACE research program will conduct research to support EPA's programs mandated by the Clean Air Act (CAA). In doing so, it will foster innovative approaches to ensure clean air in the context of a changing climate and evolving communities and energy options.

Under the CAA, the Agency is required to set air quality standards to protect the public health and environmental welfare of the Nation. For six common air pollutants (PM, ozone, SO_2, nitrogen dioxide, CO, and lead) that are widely distributed across the country, EPA establishes National Ambient Air Quality Standards (NAAQS). Although regulated individually, collectively particulate matter and ozone account for the majority of adverse health effects resulting from air pollution.[9] In addition to the NAAQS pollutants, the CAA requires EPA to regulate emissions of hazardous air pollutants or air toxics. These pollutants are those that are known or suspected to cause cancer or other serious health or environmental effects.

In 2007, the U.S. Supreme Court determined that GHGs are air pollutants as defined by the CAA. The Court held that the EPA Administrator must therefore determine whether or not emissions of GHGs from new motor vehicles cause or contribute to air pollution that may reasonably be anticipated to endanger public health or welfare or whether the science is too uncertain to make a reasoned decision.

In 2009, after extensively reviewing the full weight of scientific evidence and the thousands of public comments received, the EPA Administrator issued the Endangerment and Cause or Contribute Findings for GHGs under Section 202(a) of the CAA.[1] The finding concludes that GHGs endanger public health and welfare, including but not limited to impacts on air quality, heat events, water resources, ecosystems, sea level rise and coastal areas, energy, infrastructure, and settlements.

Such climate change impacts may also have important implications for programs developed under other statutes such as the Clean Water Act and Safe Drinking Water Act. To provide the scientific foundation for EPA's efforts to meet its legal, statutory, and policy requirements in a changing climate, the ACE research program will inform climate mitigation and adaptation choices towards sustainable, resilient solutions with maximum benefits for the Nation's people and environments.

The American Clean Energy Leadership Act of 2009 requires research to evaluate the impact of energy development and production on water resources, as well as the emissions attributed to alternative transportation fuels.[10] The requirement builds on the mandates of the Energy Independence and Security Act of 2007,[11] which requires EPA to: (1) develop and implement the Renewable Fuel Standard to substantially increase the volume of renewable fuels (primarily biofuels) into the national transportation fuel system and (2) produce a triennial report to Congress summarizing the environmental impacts of the production and use of associated greater volumes of biofuels. The ACE research program must develop the knowledge to enable EPA's responses to the changing energy landscape and the resulting environmental implications.

EPA'S Priorities:

Taking action on climate change

Improving air quality

Assuring the safety of chemicals

Cleaning up our communities

Protecting America's waters

Expanding the conversation on environmentalism and working for environmental justice

Building strong state and tribal partnerships

EPA Priorities

EPA's record of success in protecting public and environmental health over the Agency's 40 year history has relied on building a strong scientific foundation to support policies that reduce the adverse effects of air pollution. Today, protecting the air quality of the Nation is still at the forefront of EPA's mission. Growing concerns about climate change have also become a top priority.

These priorities are reflected in Goal 1 of EPA's FY 2011-2015 Strategic Plan, Achieving our Vision (EPA, 2011): "Taking Action on Climate Change and Improving Air Quality."[8]

The goal recognizes that there are inherent relationships between air quality and the changing climate. Further, the human and environmental health impacts of both air quality and climate change are heavily influenced by the energy choices of the United States and the world.

As a result, achieving the goal of protecting human health and the environment by taking action on climate change and improving air quality is not possible without also understanding the Nation's evolving energy landscape.

It is through the EPA's Air, Climate, and Energy research program that the Agency will conduct research to support the development of sustainable solutions that prevent and reduce all forms of air pollution, protecting the public and environmental health of the United States.

Program Design

Producing an Integrated Program

The impacts of air quality and climate change are heavily influenced by the energy choices of the United States and the world. As the demand for energy increases, along with changes expected to accompany shifts toward clean energy alternatives, it is necessary to understand the interactions between air quality and climate change, and the associated potential impacts on human and environmental health. Furthermore, the ACE research program also must include research that is systems-based to account for interactions across social, economic, and environmental domains (Figure 2).

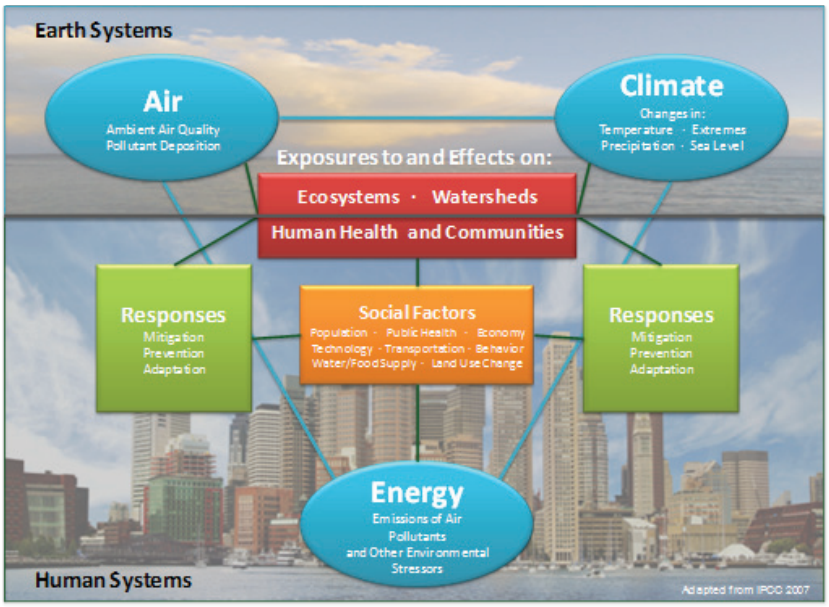

Figure 2. Integration of Air, Climate, and Energy.[i]

The issues of air pollution, climate change, and energy are closely connected and those connections have been recognized by a variety of scientific organizations, including the National Academy of Sciences (NAS) and the U.S. Global Change Research Program.[12,13] These issues cut across a broad range of human, industrial, and natural systems such that narrowly defined approaches to reducing air pollutant and GHG emissions may have unintended consequences, today and into the future.

Therefore, the ACE research program is designed to more closely integrate research in the areas of air, climate change, and energy and to extend this research to better incorporate economic and social factors that may influence anticipated environmental results.

The design of the research program will leverage expertise and capabilities across EPA and from external stakeholders to support the development of effective, sustainable policies. The ACE research program builds on the strong foundation that has been established in predecessor programs in EPA's Office of Research and Development (ORD), including the Clean Air, Global Change, and Biofuels research programs. Through these, ORD has developed significant expertise and capabilities related to science questions that span the source to outcome paradigm, including source emissions characterization and control, atmospheric chemistry, air quality modeling, ambient measurements, human exposure assessment, epidemiology, toxicology, and human clinical research. The specific applications within these areas of expertise will evolve with the ACE research program, but the fundamental scientific capabilities will remain as key components of the program.

[i]Adapted from IPCC, 2007.[14]

Collaborating Across Research Programs

The physical, biological, and human behaviors underlying the environmental impacts related to air, climate, and energy do not have distinct boundaries defined by discipline or organizational structure. The ACE research program, as well as the other ORD research programs, therefore must be designed in a manner that allows them to continuously evolve as the science changes and conduct work across disciplines and boundaries. This will require constant and effective communication and coordination within the ACE research program, with other ORD programs, and with both internal EPA partners, and external collaborators.

An effective ACE research program first requires the proper integration of research activities across air, climate, and energy to form one coherent theme. Areas of commonality will be identified to enhance the transition from three previously separate programs into one research program, including data needs, models, and measurements, as well as stressors that contribute to human and ecosystem responses.

The ACE research program will effectively integrate with the other ORD research programs (see box) to ensure that EPA's science is able to support the development of sustainable solutions to environmental problems. Active communication will facilitate cross-program involvement in research planning and allow for the identification of opportunities to leverage research activities.

EPA's Six Integrated Research Programs:

Air, Climate, and Energy (ACE)

Safe and Sustainable Water Resources (SSWR)

Chemical Safety for Sustainability (CSS)

Sustainable and Healthy Communities (SHC)

Human Health Risk Assessment (HHRA)

Homeland Security (HS) Research

Examples of collaborative ACE work with other ORD research programs include:

- **Chemical Safety for Sustainability (CSS)**—ACE researchers and their partners from the CSS research program are collaborating to reduce exposure to hazardous air pollutants through the development of "green" chemicals and other products that eliminate or reduce the use of toxic substances.

- **Human Health Risk Assessment (HHRA)**—ACE and HHRA researchers are working together to supply research results to inform the development of Integrated Science Assessments for criteria air pollutants.

- **Sustainable and Healthy Communities (SHC)—**ACE and SHC scientists are collaborating to better understand how exposure to air pollutants from roadways can be reduced/prevented by the design of communities and the placement of roadways.

- **Safe and Sustainable Water Resources (SSWR)**—ACE and SSWR researchers are studying how the impacts of climate change can affect water availability and quality, the potential for exposure to different pathogens, and the composition and health of ecosystems.

Developing Partnerships from the Start

Adequately addressing the current and future problems that encompass the nexus of air, climate, and energy requires input from those who will use the research products produced by the ACE research program.

Ongoing interactions with internal EPA partners, primarily program offices (i.e. EPA Office of Air and Radiation, EPA Office of Water, etc.) and the Agency's ten regional offices from around the country, and external stakeholders have been crucial to identifying the major problems that EPA decision-makers face related to air, climate, and energy. These communications brought to the forefront the need for research that supports policy priorities by examining:

- The multipollutant nature of air pollution and the development of more sustainable and innovative multipollutant air quality management strategies that simultaneously improve air quality and reduce GHG emissions;
- The impacts of climate change and the interactions between adaptation and mitigation to support the development of future climate change policies, as well as guidance on the most critical actions to take in the near term;
- The human health and environmental impacts of current and future energy alternatives;
- The expanding and contracting scales of environmental problems that range from global to local; and
- The social, behavioral and economic factors that influence the effectiveness of air quality and climate policies.

The research needs identified above form the underlying basis of the research agenda of the ACE research program, and are consistent with national priority research needs identified by preeminent science advisory groups. For example:

- The National Academy of Science's National Research Council (NRC) recommended that EPA adopt a broader multipollutant research perspective, which was further supported by the EPA's Board of Scientific Counselors; [15,16]
- The NRC called on the federal government to provide "state-of-the-art information on climate change, its impacts, and response options"; [17]
- The Biomass Research and Development Board has identified a growing need for "systematic evaluation of the impact of expanded biofuel production on the environment (including forest land) and on the food supply for humans and animals, including the improvement and development of tools for life cycle analysis of current and potential biofuels"; [18] and
- The National Science and Technology Council Subcommittee on Social, Behavioral, and Economic Sciences stressed the importance and need for understanding the social, behavioral, and economic factors that influence the relationship between energy, the environment, and human dynamics.[19]

Additionally, ACE will work with relevant agencies across the federal government to develop coordinated, government-wide research approaches to support effective responses to air, climate, and energy issues. A coordinated, cross-agency effort is needed to take full advantage of the expertise and research being conducted across the federal government that can be applied to address these complex problems. For example, the ACE research program will build on and leverage existing relationships with the National Oceanic and Atmospheric Administration, the Centers for Disease Control and Prevention, the National Institute of Environmental Health Sciences, the National Aeronautics and Space Administration, and the U.S. Department of Energy. The program also will work to form relationships with other federal agencies.

The coordination with other federal agencies will include interactions with individual agencies, as well as multi-agency interactions through the Air Quality Research Subcommittee and the Global Change Research Subcommittee of the National Science and Technology Council's Committee on the Environment, Natural Resources, and Sustainability.

In addition, the ACE research program will continue its interactions with the global research community to stay abreast of the state of the science and identify the most promising results that can aid in achieving the program's goals.

Research Themes and Priority Science Questions

EPA's extensive capabilities in health and ecological research, exposure and atmospheric sciences, measurement and control technologies, and systems analysis, form a core for developing major research efforts that address the key science problems identified by EPA partners and external stakeholders.

The ACE research program is designed to provide research results that meet EPA needs, fill gaps within the broader efforts across the federal government, and complement the research being conducted by the larger scientific community.

The three ACE research themes described below flow from the problems identified in the previous section and will provide the science to:

Assess Impacts—*Assess human and ecosystem exposures and effects associated with air pollutants and climate change at individual, community, regional, and global scales (Research Theme 1);*

Prevent and Reduce Emissions—*Provide data and tools to develop and evaluate approaches to prevent and reduce emissions of pollutants into the atmosphere, particularly environmentally sustainable, cost-effective, and innovative multipollutant and sector-based approaches (Research Theme 2); and*

Respond to Changes in Climate and Air Quality—*Provide human exposure and environmental modeling, monitoring, metrics and information needed by individuals, communities, and governmental agencies to adapt to the impacts of climate change and make public health decisions regarding air quality (Research Theme 3).*

These research themes are intentionally designed to guide integrated research that considers issues in the context of the interactions among the domains of air, climate, and energy, as opposed to focusing specifically on air, climate, or energy individually. In addition, as depicted in Figure 3, research within the ACE program may cut across multiple themes. Research conducted at the intersections of the themes will present the greatest opportunities for transdisciplinary research.

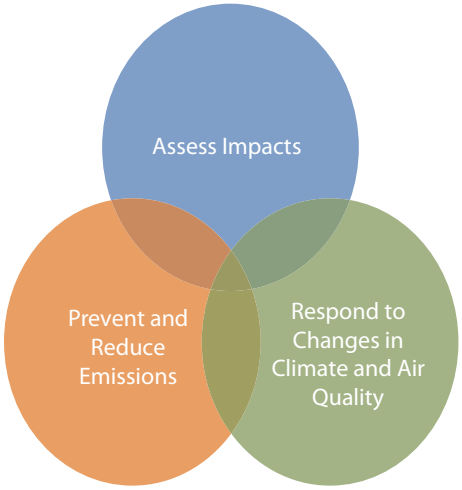

Figure 3. ACE Research Themes

Consistent with the principles and characteristics of ORD's overall research program, the ACE research themes and science questions are unified through a call for sustainable and innovative solutions to environmental problems. Research results to address the sustainability and innovation objectives will draw from activities that cut across the ACE research themes and science, and will require integration at the program level.

The ACE research program has identified the

following five signature projects, which provide a strategic vision for the sustainability and innovative aspects of the entire program.

1. Protecting Human and Ecosystem Health in a Changing Energy Landscape.
2. Developing Sustainable Climate Adaptation and Mitigation Approaches.
3. Changing the Paradigm for Air Pollution Monitoring.
4. Developing a One Environment Modeling System.
5. Developing Green Chemistry Alternative for Toxic Solvents.

The following narratives for each research theme provide a brief overview of the key research drivers for the theme. Each research theme contains broad science questions that are intended to enable staff to apply their expertise and innovation in shaping specific research projects.

Theme 1: Assess Impacts

Research Objective: *Assess human and ecosystem exposures and effects associated with air pollutants and climate change at individual, community, regional, and global scales.*

The human and ecosystem effects of air pollution and climate change occur at multiple scales and result from exposures to a mixture of pollutants in the atmosphere. Exposure and effects also are impacted by complex interactions between climate change and air quality. Social behavior, too, impacts how much human exposure may occur, and the resulting effects. Furthermore, economics and energy choices significantly influence the amount and composition of emissions and the sources of air pollutants.

In addition, the identification of potentially susceptible populations (i.e., individual- and population-level characteristics, as well as exposure differences, that lead to increased risk of air pollutant-related effects, both for human health and ecosystems) must also be factored into these complex interactions to inform the decision-making process.

New and existing methods and models need to be deployed in transdisciplinary studies to assess all of these complex interactions and factors that ultimately impact public health and the environment.

Science Questions

What are the multipollutant exposures and effects, and integrated impacts, of climate change on air and water quality, and on human and ecosystem health?

Related Research: Transdisciplinary, source-to-outcome research will be conducted to assess multipollutant exposures and health effects in field and laboratory settings, such as research related to near-road environments, which include complex mixtures of particles, criteria gases and organic compounds.

Models and methods will be enhanced and applied to assess human and environmental impacts of air pollution and climate change at individual, community, regional, national, and international scales. In addition, models from multiple disciplines will be linked to conduct integrated analyses of the impacts of pollutants in the atmosphere. For example, one approach might include using currently available models (e.g., the CMAQ model) and potentially new models to link economic, air quality, water quality, land use, human and ecosystem exposures to more thoroughly assess the broad impacts of pollutants from alternative energy scenarios.

To achieve the principles of sustainable approaches, integrated assessments would include analyses of both expected and potential unintended impacts of scenarios as they are put into use, such as considering the likely indoor air exposures that individuals will face in tighter, more energy efficient homes and buildings. In essence, the overarching concept is one of systems interactions and intelligent assessment of the positive and negative impacts of human activities.

What innovative approaches are needed to enhance the assessment of human and environmental exposures and effects of pollutants in the atmosphere?

Related Research: Currently available information and indicators will be examined and expanded to include additional components (e.g., multipollutant/multistressor indices to incorporate climate impacts) in order

to advance three areas: (1) develop new indices that would inform the development of new policies by EPA partners, (2) measure progress toward environmental goals, (3) and provide information for communities.

Additionally, currently available technologies would be examined to develop innovative approaches—such as inexpensive personal monitors built into mobile communication devices—to estimate personal exposures quickly and inexpensively and, subsequently, the impacts of air pollution.

What are the characteristics of populations and ecosystems that are susceptible to effects from exposure to air pollutants and climate change impacts?

Related Research: Integrated approaches will be developed to assess the physical, biological, and systemic factors that result in increased susceptibility to air pollutant-related effects. This will include the identification of biological mechanisms that impact susceptibility and key exposure factors. It will also include the examination of the interaction between behavior, and social and economic factors to more thoroughly understand how they may inform research outcomes and impact strategies to protect public health.

Recent scientific findings suggest the possibility that greater numbers of people are susceptible to air pollution-related health effects, such as those with diabetes or certain genetic polymorphisms (genetic variations among individuals), than previously thought.

Research is also needed to identify the factors that result in ecosystems being highly susceptible to changes in climate or to climate-driven changes (e.g., changes in seasonal temperature and precipitation patterns). In addition, climate change can exacerbate the adverse impacts of other stressors already present, such as water and air pollution and changes in surrounding land use, leading to increased susceptibility to climate-related damage.

What are the key uncertainties and data gaps that need to be addressed to inform review of National Ambient Air Quality Standards (NAAQS)?

Related Research: Research on human and ecosystem exposure and effects will be conducted to inform future NAAQS reviews. The Clean Air Act requires a review the NAAQS for each criteria pollutant every five years. The NAAQS review process identifies key uncertainties and knowledge gaps that will help guide ACE priorities on human and ecosystem effects research to inform future decisions.

Illustrative Outputs/ Products/Outcomes

Example 1: Since people actually breathe a mixture of air pollutants and not one pollutant at a time, EPA researchers are investigating new scientific approaches for assessing the health effects resulting from exposures to multiple air pollutants.

Example Output:

A synthesis publication that describes whether cardiopulmonary health effects caused by exposure of healthy and potentially susceptible humans (e.g., older adults, asthmatics) to simple mixtures of air pollutants are worse than the sum of those observed after exposure to single pollutants (i.e. pollutants in a mixture may interact with one another resulting in a more toxic mixture than would be expected based on our current knowledge of the toxicity of individual pollutants).

Research products contributing to this output:

- A peer-reviewed publication comparing the

cardiovascular health effects in humans exposed to: (1) concentrated ambient particles, (2) nitrogen dioxide, and (3) concentrated ambient particles and nitrogen dioxide together.

- A peer-reviewed publication evaluating the combined health effects of ozone and agents of climate change (e.g, temperature) in humans.

Expected outcome of the research: These studies will provide key information needed by the OAR as it transitions from a single pollutant to a multi-pollutant approach to managing air quality. The Agency has new methods and approaches to examine, integrate, and assess the effects of multipollutant exposures in toxicological, epidemiologic and controlled human exposure studies to provide more realistic estimates of air pollution impacts on public health.

Example 2: EPA researchers are enhancing EPA's air quality modeling tools, integrating important advances in atmospheric science.

Example Output

Public releases of the Community Multiscale Air Quality (CMAQ) multipollutant modeling system. This model is pre-eminent in the air quality regulatory community to evaluate alternative approaches to control strategies to reduce air pollutant concentrations and health risks. The model evolves continually with the science incorporating meteorology, pollutant emission data, state-of-the-art atmospheric science to reduce uncertainties and guide air pollution control decisions at the state and local level. The model is used by thousands of government entities in the US and internationally as part of a larger group of interactive air quality regulators.

Research products contributing to this output:

- Improved understanding of how the various layers of the atmosphere, created by weather and thermal properties, mix with one another over time and space, and subsequently how these layers are affected by land use and local micro-meteorology. Collectively, this information will enhance the predictive value of CMAQ and related models.
- An initial assessment of whether computational chemistry can be used to investigate critical reactions that may take place within ambient aerosols.
- Improved understanding of the most sensitive contributing factors involved in particle formation in the atmosphere, such as various gaseous precursors, to enhance the ability of the CMAQ model to predict particulate concentrations.
- Evaluation of the new version of the CMAQ model (5.1) to ensure operational reliability and to minimize remaining uncertainties.

Expected outcome of this research: Air quality management activities conducted by EPA and by Agency stakeholders are enhanced through the application of EPA multipollutant modeling tools and methods.

Example 3: This area of research involves assessing the impacts of climate change on different species and habitats.

Example Output:

A synthesis document assessing the vulnerability of near-coastal species and habitats to individual and multiple climate altering pollutants in specific regions of the United States.

Research products contributing to this output:

- An article synthesizing the 29-year record of near-coastal sea-surface temperatures in the North Pacific, including database of processed sea surface-temperature data in the North Pacific and U.S. Arctic for use in climate modeling.

- A web-based decision-support and outreach tool to predict the vulnerability of near-coastal species and habitats.

Expected outcome of the research: Efforts by EPA and Agency stakeholders to help adapt to the impacts of climate change are targeted effectively toward vulnerable human and ecological populations.

Impact

The Agency possesses the tools and knowledge to identify the impacts of air pollution and climate change on human health and ecosystems to support the development of policies and approaches to fully protect the public and the ecological health of the Nation.

Theme 2: Prevent and Reduce Emissions

Research Objective: *Provide data and tools to develop and evaluate approaches to prevent and reduce emissions of pollutants to the atmosphere; advance sustainable, cost-effective, and innovative multipollutant and sector-based approaches.*

When making environmental decisions, policy-makers are challenged by the complex environmental, economic, and social interactions of various options. More cost-effective and innovative measures are needed to prevent and reduce emissions to meet the standards and regulations that lead to improvements in air quality. It is clear that approaches to reducing GHG emissions will create even greater complexity and challenges.

As a result, there is a growing recognition of the need for multipollutant and sustainable strategies that prevent air pollution of all types without unintended environmental consequences to land or water. Policy-makers are exploring technical and policy approaches that simultaneously address multiple pollutants as an alternative to the one-pollutant-at-a-time approach.

In addition, policy-makers also need to understand how international emissions of air pollutants impact the effectiveness of domestic environmental policies and how domestic emissions impact other countries. Research is also needed to evaluate and assess actions to reduce or eliminate the gases and other compounds that contribute to climate change. With national policies promoting innovation and adoption of clean energy technologies, EPA research plays an important role in analyzing the full life-cycle impacts of technology options to ensure that the clean energy choices of the future are indeed better for the environment as a whole.

Finally, environmental policies are only as effective as the actual emission reductions achieved. Innovative approaches to measure source and ambient pollutant concentrations provide opportunities to improve implementation and enforcement of environmental policies.

Science Questions

What tools are needed to support the management of air pollution problems, at the different scales of time and space, associated with different pollutants and effects?

Related Research: Methods and models will be developed and evaluated to support multiscale management (e.g., from local communities to national and global management efforts) of pollutants in the atmosphere. These tools will be used to understand synergies and tradeoffs associated with various mitigation and prevention options, including air-water-climate interactions.

Research activities that aim to address this science question also will provide the support for the evaluation of near- and long-term benefits and impacts of management strategies.

What methods need to be developed and data obtained to conduct life-cycle analyses of alternative pollution reduction and energy options to inform EPA and other local, regional, national, and international decisions regarding the most sustainable and cost-effective uses of resources?

Related Research: ACE researchers will develop methods, models, and data for life-cycle assessments of traditional and alternative energy systems and their impact on air pollution and climate change. Impacts considered will include costs, performance, and the effects on human health, water quality, and ecosystems.

Additional life-cycle analyses will assess the impacts of anticipated and alternative strategies for achieving national energy and environmental goals. An example is an analysis considering the use of biofuels for transportation, including the evaluation of potential alternative strategies that may improve the sustainable use of limited resources.

What innovative monitoring technologies are needed to support the implementation of management strategies to prevent and reduce air pollution?

Related Research: Innovative technologies for monitoring multiple pollutants at sources and in the ambient air will be developed, evaluated, and adapted for a range of needs including community information, compliance and enforcement, regional and national assessments, and air quality planning.

In particular, portable sensor technologies will be developed that provide real-time, continuous source and ambient data. Such technologies will enable fair, accurate and responsive assessments of reported violations of air pollution emissions and improve overall implementation of clean air regulations.

Analytical and data management tools will also be developed, which will enable local, regional, and national managers to evaluate the effectiveness of air pollution reduction strategies on an ongoing basis.

What are the most efficient integrated, sustainable pollution reduction and prevention solutions?

Related Research: The performance and cost of technologies will be evaluated to enable comprehensive management of sources that co-emit: criteria pollutants, GHGs and other climate-forcing gases and aerosols, and toxic air pollutants. Evaluations will be done in ways that address not only air pollution problems, but also consider implications on water quality, and quantity and disposal of any wastes generated by the air pollution controls.

Additionally, methods, data, and models will be developed to enable the development of atmospheric pollutant management strategies that account for the behaviors of institutions and individuals in response to those strategies.

What methods and tools need to be developed to support implementation of NAAQS?

Related Research: Source and ambient monitoring methods and air quality modeling tools will be developed and evaluated to meet the needs of EPA and state/local agencies in implementing NAAQS.

Illustrative Outputs/Products/Outcomes

Example 1: A new approach for monitoring air pollution in the U.S.

Research studies are investigating multiple approaches for improving and integrating measurements of air pollution to achieve better spatial coverage, real time data and reduced costs

Example output:

Synthesis of findings to describe how satellite data can be used to infer surface air pollution conditions more quantitatively. , This would enhance abilities to predict air pollution levels as well as assess emissions in a changing environment. .

Research products contributing to this output:

- Summary report that evaluates currently available trace gas and aerosol profiles and identifies current/future needs and gaps and potential opportunities, such as ground based LIDAR and spectrometers.

- Journal articles providing a fundamental understanding of how satellite data can be used to infer surface conditions more quantitatively.

- Completed method for the use of inferring surface spatial distributions of key pollutants from satellites.

Expected outcome of this research: New methods are incorporated into monitoring networks and compliance monitoring activities to enhance national coverage at a finer scale of detail, and/or reduce monitoring costs.

Example 2: Science to support analyses of alternative energy options.

EPA researchers are working with EPA policy partners to help assess the full costs of alternative energy options.

Example output:

White paper on the effectiveness of particular alternative energy scenarios for regulatory and technology assessment.

Research product contributing to this output:

- Development of possible future energy technology and policy scenarios for the MARKet ALlocation (MARKAL) energy system model to support regulatory impact analyses (RIAs). Scenarios could include development of algae-based biofuels or policies that support greater use of renewable energy for electricity generation.

- Expected outcome of the research: The Agency has tools and analyses to identify the full cost of alternative energy options, including the systematic evaluation of multimedia impacts and potential tradeoffs between environmental, social, and economic objectives.

Example 3: Emissions from oil and gas production.

EPA scientists are using advanced techniques to examine air pollution emissions from oil and gas production operations.

Example output:

Report on methane and volatile organic compound emissions from oil and gas production operations using advanced source assessment technologies such as geospatial mapping, off-site remote and direct fugitive leak measurement, and infrared camera sensing.

Research products contributing to this output:

- Geospatial database (web report) on volatile organic compound and GHG emissions from select oil and gas production activities.

- Journal article on volatile organic compound and GHG emissions for select oil and gas production activities.

- Journal article on exposure estimates from select oil and gas production operations.

Expected outcome of the research: Decision makers have well-documented, high-quality emissions data from oil and gas production processes to enable development of effective air quality management strategies and approaches to reducing GHG emissions.

Impact

The Agency will have the models and tools needed to develop approaches at various scales (e.g., local, regional, and national) to effectively implement the NAAQS and understand the emissions implications of future policy and technology conditions. Air quality management strategies simultaneously address multiple pollutants to effectively reduce and ultimately prevent air pollution emissions leading to further improvement of the public and ecological health of the Nation.

Theme 3: Respond to Changes in Climate and Air Quality

Research Objective: *Provide human exposure and environmental modeling, monitoring, metrics, and information needed by individuals, communities, and governmental agencies to adapt to the impacts of climate change and make public health decisions regarding air quality.*

The impacts of climate change have the potential to undermine environmental progress and policies, including successful efforts to improve air and water quality, reduce exposures, and improve public and ecosystem health. Although mitigating GHG emissions to minimize future climate changes is crucial, it also is necessary to develop the information to minimize and adapt to the adverse impacts caused by unavoidable changes in the climate.

In addition, tools and information are needed to allow for the development of community- and individual-level strategies to reduce exposures to air pollution. This includes providing the necessary data to guide informed decision-making, as well as a thorough understanding of the public perceptions, behavioral responses, and social and economic factors that influence the decision-making process. Therefore, developing information and tools to allow communities and individuals to adapt to the impacts of climate change and make informed decisions regarding air quality is critical.

In addition, the identification of populations and ecosystems that are the most vulnerable to (i.e., least able to cope with) the adverse effects of climate change will allow for more targeted adaptation approaches.[b] EPA has an important role to play in providing information that will help a wide range of stakeholders implement adaptation strategies both structurally and through policy decisions.

Science Questions

What are the most effective alternative adaptation strategies, focusing on the most vulnerable individuals, communities, and ecosystems?

Releated Research: To most effectively target available resources, policy-makers need to understand which populations and ecosystems face the greatest risks to the adverse effects of climate change.

ACE research efforts will develop methods and tools to improve the understanding of the location, extent, and type of vulnerabilities faced by populations, ecosystems, and the built environment. This information, in combination with an understanding of the potential impacts of adaptation actions, can help inform decisions that are flexible and appropriate.

Research also will develop approaches to support adaptation risk management to enable decision-makers to identify priority adaptation actions and anticipate other related, perhaps less obvious co-benefits or, alternatively, unintended consequences.

It is recognized that approaches taken to adapt to climate change can have environmental and public health consequences that may not be specifically addressed within this

science question. For example, the construction of protective barriers against flooding and sea level rise may damage shoreline ecosystems. Also, in a warming climate individuals may spend more time indoors in air conditioned environments. This, in turn, will spark an, increased demand for electricity, leading to greater air pollution emissions and water demands on the same days that tend to have the most potential for high ground-level ozone concentrations and when water availability for power generation may be at its lowest. Methods and models will be developed and applied to understanding these types of interactions and responses to develop sustainable adaptation strategies.

What innovative methods are needed to inform individual- and community-level adaptation to climate chance and decision making regarding air quality?

Related Research: Information and communication technologies are rapidly evolving, with new and enhanced tools being continually introduced to the market place. These tools have great potential to support climate change adaptation strategies.

EPA already utilizes communication technologies (e.g., Enviroflash, UV Index App) to provide individuals with information that allows them to adapt or make informed public health decisions in response to current environmental conditions.

The effectiveness of these types of tools on behavioral responses will be assessed for human health impacts of air pollution and climate change.

Geographic information systems (GIS) can provide easily understood visualizations of complex, location-based sets of information and data, allowing for informed decision-making aimed at limiting adverse impacts attributed to climate change, and reducing exposures to air pollution, respectively. ACE research will advance the use of GIS to provide information concerning the scope and type of impacts associated with climate change, and the development and delivery of accessible, user-friendly of data, such as information on the climate and air related to different urban planning scenarios.

What are the social, behavioral, and economic factors that may hinder the ability of communities and individuals to implement adaptation strategies for climate change and make informed decisions regarding air quality?

Related Research: Community- and individual-level responses to prevent and reduce climate change impacts and exposures to air pollution are influenced by social, behavioral, economic, and other systems that exhibit nondeterministic behaviors that are not easily modeled or predicted. These consequences can have impacts that cascade well beyond the immediate actions of policies and approaches, often in unexpected ways. For instance, climate change can impact energy systems by affecting crop yields, which subsequently could impact the production of the same alternative fuels intended to address climate change in the first place.

There is a need to develop approaches that integrate across complex systems and explicitly incorporate methods to describe complex system behavior.

Illustrative Outputs/Products/Outcomes

Example 1: Planning for the impacts of climate change.

EPA scientists are studying the central challenges of climate change adaptation planning.

Example output:

Analyses of the impacts, co-benefits, and potential unintended consequences of climate change adaptation strategies.

Research products contributing to this output:

- A synthesis article that addresses the challenge of planning climate change adaptation actions when regional-scale climate impacts are uncertain, the barriers to incorporation of scientific information into planning processes, and the potential value of Robust Decision Making (RDM)-type methods for surmounting these obstacles.
- A report on the use of RDM methods and the applicability of these methods to the key actions identified in the EPA's National Water Program Climate Change Strategy.
- A synthesis of lessons learned from the Office of Water RDM report, with potential application to air quality management, waste siting, and public health.
- Expected outcome of this research: Local and regional entities involved in making decisions regarding mitigation and adaptation measures are better able to effectively incorporate scientific information on climate change into the decision-making process.

Example 2: Responding to Near Road Air Pollution.

Several EPA studies are investigating how communities and susceptible individuals respond to near road traffic emissions.

Example output:

Synthesis of findings from the Near-Road Exposure and Effects from Urban Air Pollutants Study including human exposure, health impacts, and source apportionment results and enhancement of modeling tools for near-road applications.

Research products contributing to this output:

- Journal article describing how much error is caused by the use of community monitoring versus indoor and exposure monitoring and what impact this has on the determination of the size of the resulting health effect in epidemiologic studies.
- Journal articles reporting results of highway air pollutant gradient analysis and spatial and temporal analysis of near-road and industrial source impacts.
- Journal articles describing near-roadway pollution toxicology and how near-roadway exposure to air pollutants impacts asthma aggravation, inflammation and oxidative stress, and respiratory viral infections.

Expected outcome of this research: Individuals and communities have tools and data available to make timely and informed decisions to reduce exposure to air pollution, and track progress toward achieving goals. The Agency and its stakeholders develop and implement effective policies to mitigate exposures and effects of air pollutants near sources.

Impact

EPA develops approaches to enable individuals, communities, businesses, and government agencies to effectively respond to the impacts of climate change and excess air pollution. Information is available to all decision-makers to enable them to develop near- and long-term approaches for adapting to unavoidable impacts of climate change, thereby protecting human health and welfare and ecosystems and the services they provide.

This strategic research plan broadly

Conclusion

The EPA Air, Climate, and Energy research program is designed to address the key science needs to support the Agency in meeting its strategic goals of protecting and improving air quality and taking action on climate change in a sustainable manner.

defines the major research issues related to air pollution, climate change, and the environmental impacts of energy options. These issues were identified through an ongoing dialog between EPA's Office of Research and Development (ORD) and the Agency's program and regional partners. The plan was independently reviewed by the EPA Science Advisory Board and Board of Scientific Counselors to ensure that it focuses on the most pressing issues.

The ACE plan strategically recognizes the growing complexity of environmental problems and the need to address them in a holistic approach. Accordingly, it emphasizes actions that strengthen connections with the other ORD research programs, and with an expanded range of EPA partners and external stakeholders.

In taking these initial steps toward centering research on air, climate, and energy around a need to develop sustainable solutions to the Nation's environmental problems, the ACE research program represents a part of a coordinated ORD and EPA approach to environmental protection based on sustainability.

This plan is the result of many discussions that included a wide range of perspectives regarding research needs for EPA's actions on air pollution and climate change and as such, reflects the needs of decision-makers at federal, regional, state, tribal, and local scales, as well as the need to advance the Agency's understanding of environmental science. These diverse perspectives reflect the ACE research program's commitment to working toward sustainable solutions that address the environmental problems of today while seeking to avoid or minimize environmental problems in the future.

Summary Tables of Outputs and Outcomes

The following tables list the expected outputs from the Air, Climate, and Energy Research Program along with the associated partner outcomes. Although each output is listed under a single theme and science question, many of them serve to answer multiple questions, as indicated in the third column.

Theme 1. Assess Impacts – Assess human and ecosystem exposures and effects associated with air pollutants and climate change at individual, community, regional and global scales.

Science Question 1.1: What are the multipollutant exposures and effects and integrated impacts of climate change on air and water quality and human and ecosystem health?

Outcomes: Agency decisions related to air quality management and climate-change effectively incorporate an understanding of air quality-climate trade-offs and synergies and produce air quality and climate-change co-benefits where possible.

NAAAQS reviews for individual criteria pollutants effectively consider the impacts of co-pollutants and exposure and effects from multipollutant mixtures.

The Agency has new methods and approaches to examine, integrate, and assess multipollutant effects in toxicologic, epidemiologic, and controlled human exposure studies to provide more realistic estimates of air pollution impacts on public health.

The Agency has an integrated modeling system to assess multimedia interactions and impacts.

No.	Outputs	Output Year	Other ACE Science Questions Addressed
1.1.1	Assessment report of the current scientific understanding of the implications of climate change for O3 and PM to address specific policy concerns	FY2014	
1.1.2	Regional climate change scenarios from IPCC AR5 runs from global models using WRF as a regional climate model	FY2014	
1.1.3	A review document synthesizing the additional health risks imposed by increased temperature predicted by climate change associated with air pollutants	FY2015	
1.1.4	Chemical mechanism for inclusion in CMAQ model	FY2014	
1.1.5	Report on the consequences of global change on air quality and the role of black carbon in the coupled climate and air quality systems	FY2016	
1.1.6	Analysis and Decision Support Tools in light of global change impacts and mitigation	FY2014	

No.	Outputs	Output Year	Other ACE Science Questions Addressed
1.1.7	CMAQ with improved air-surface exchange processes and land cover characterization to predict the connection between air concentrations and deposition for development, implementation and review of NAAQS, for critical loads, and for improved linkage to ecosystem models	FY2015	
1.1.8	Coupled meteorology/hydrology system able to down-scale WRF meteorology at 12km to hydrology at 4km for improved linkage to watershed models and capability to promote internally consistent assessments of the implications of climate change on ecosystems	FY2015	
1.1.9	Prototype air-water/terrestrial environmental system, with linkage between coupled air system and watershed/ terrestrial systems, connected to combined health and welfare benefits mapping for multi-media, intra-Agency policy review capability	FY2015	
1.1.10	Synthesis report on the impacts of air pollution on health in Cleveland, OH	FY2014	Theme 1, SQ 4
1.1.11	Synthesis publication summarizing the additive and non-additive health effects associated with exposure to simple mixtures of pollutants and the relative risk of these to susceptible populations	FY2015	Theme 1, SQ 4
1.1.12	Synthesis publication summarizing the evidence that pre-exposure to one pollutant can sensitize a human so that exposure to a second pollutant results in an exaggerated response	FY2015	Theme 1, SQ 4
1.1.13	Synthesis publication demonstrating the utility of using high-throughput tools to screen dozens or hundreds of different air pollution samples	FY2015	Theme 1, SQ 4
1.1.14	Synthesis publication summarizing the association between PM, components and sources and mortality/morbidity in several US cities	FY2015	Theme 1, SQ 4
1.1.15	Synthesis publication the role played by PM, its components and sources, in the incidence and progression of cardiovascular (CV) disease, as well as the genetic factors that control this process	FY2015	Theme 1, SQ 4
1.1.16	Report on results from National Particle Component Toxicity (NPACT) program	FY2012	Theme 1, SQ 4
1.1.17	Report on statistical methods for analyzing the effects of mixtures	FY2013	Theme 1, SQ 4
1.1.18	Report on multipollutant air toxic exposures and health effects in high exposure situations	FY2015	Theme 1, SQ 4
1.1.19	A review of emissions, exposures, and health effects from ultrafine particles	FY2015	Theme 1, SQ 4
1.1.20	Report on findings from health outcomes studies (accountability)	FY2015	Theme 1, SQ 4
1.1.21	Methods and metrics for incorporating multiple policy-relevant endpoints, such as human health effects, ecosystem effects, visibility degradation, long-range transport, and radiative forcing, into a unified analysis framework	FY2019	Theme 1, SQ 4

Science Question 1.2: What innovative approaches are needed to enhance the assessment of human and environmental exposures and effects of pollutants in the atmosphere?			
Outcomes: NAAQS compliance monitoring networks use state of the science measurement methods. Development of more cost-efficient approaches to monitor criteria air pollutants for health and ecosystem studies to support future NAAQS. Air quality management activities conducted by EPA and by EPA stakeholders are enhanced through the application of EPA multipollutant modeling tools and methods.			
No.	**Outputs**	**Output Year**	**Other ACE Science Questions Addressed**
1.2.1	An assessment of the variability in particulate and gaseous emissions from stationary diesels of differing generation capacity both with and without particulate catches	FY2013	Theme 2, SQ 3,5
1.2.2	Methods and technologies for measurement and characterization of emissions from fugitive and area sources to support regulatory actions	FY2015	Theme 2, SQ 3,5
1.2.3	Regulatory method (Aerospace Recommended Practice) for the measurement of black carbon emissions for use in commercial aircraft engine certification	FY2013	Theme 2, SQ 3,5
1.2.4	Improved method for ambient acrolein measurement	FY2013	Theme 2, SQ 3
1.2.5	Ambient air monitoring methods to support implementation and review of NAAQS	FY2016	Theme 1, SQ 4
1.2.6	Development of method for measuring emissions from open and uncontrolled burning	FY2013	Theme 2, SQ 3,5
1.2.7	Provide field and laboratory performance data for source emission test procedures for HCl, CO, and N2O (40 CFR Part 60/63 Performance Specifications and Reference Methods) in support of NESHAP and GHG regulations	FY2012	Theme 2, SQ 3,5
1.2.8	Pollutant-specific source measurement methods development to support regulatory actions	FY2015	Theme 2, SQ 3,5
1.2.9	Assessment of methods and instrumentation for measuring one species as a surrogate to predict the emissions of another related species, with particular interest in organic compounds (HAPs)	FY2013	Theme 2, SQ 3
1.2.10	Assessment of available technologies that provides strategic guidance for future emission measurement method development and demonstration	FY2012	Theme 2, SQ 3
1.2.11	Public releases of CMAQ Modeling System	FY2014	Theme 2, SQ 1,5
1.2.12	Analysis and Decision Support Tools for Sources and Atmospheric Formation of Organic Particulate Matter	FY2012	Theme 2, SQ 1,5
1.2.13	Analysis and Decision Support Tools for improving air pollution emissions information	FY2015	Theme 2, SQ 1,5
1.2.14	A review of ways in which new information can be incorporated into air quality management	FY2017	Theme 2, SQ 1,5
1.2.15	Report on key parameters for modeling organic aerosols	FY2018	Theme 2, SQ 1,5
1.2.16	Modeled cardiopulmonary system for use in analyzing impacts of exposure to air pollutants	FY2014	Theme 1, SQ3

Science Question 1.3: What are the characteristics of populations and ecosystems that are susceptible to effects from exposure to air pollutants and climate change impacts?			
Outcomes: Future NAAQS reviews incorporate enhanced information on exposure and effects on susceptible populations. The Agency has new methods and approaches to examine, integrate, and assess multipollutant effects in toxicologic, epidemiologic, and controlled human exposure studies to provide more realistic estimates of air pollution impacts on public health. Climate adaptation activities conducted by EPA and by EPA stakeholders are effectively targeted toward vulnerable human and ecological populations.			
No.	**Outputs**	**Output Year**	**Other ACE Science Questions Addressed**
1.3.1	Synthesis report on linkages between pollutant sources, with exposures and effects, particularly in the at-risk groups	FY2016	Theme 1, SQ 4
1.3.2	Report on impact of chronic exposures to fine particles in the progression of Atherosclerosis from MESA-Air Study	FY2015	Theme 1, SQ 4
1.3.3	A synthesis report assessing the best approaches and methods to determine toxicity of multipollutant mixtures	FY2016	Theme 1, SQ 1,2,4
1.3.4	Studies on innovative approaches to addressing links between particulate matter exposures, composition, sources, and health effects	FY2012	Theme 1, SQ 1,2,4
1.3.5	Report on cardiovascular health effects of near roadway pollution	FY2015	Theme 1, SQ 1,2,4
1.3.6	Characterization of air pollution mixtures using novel methods and associated health effects	FY2015	Theme 1, SQ 1,2,4
1.3.7	Report on health effects of air pollution mixtures across life stages	FY2015	Theme 1, SQ 1,2,4
1.3.8	Report on air pollution and cardiovascular disease and the convergence with cardiometabolic syndrome	FY2015	Theme 1, SQ 1,2,4
1.3.9	A synthesis report identifying vulnerable people and ecological systems, the key factors that drive that vulnerability, including habitat condition by geographical regions, and which air pollutants and climate factors that are of greatest concern	FY2016	Theme 1, SQ 3
1.3.10	Analysis and Decision Support Tools for nonlinear response to global climate change	FY2012	Theme 1, SQ 3
1.3.11	Analysis and decision support tools for ecological impacts from the interactions of climate change, land use change and invasive species	FY2012	Theme 1, SQ 3

Science Question 1.4: What are the key uncertainties and data gaps that need to be addressed to inform review of the National Ambient Air Quality Standards (NAAQS)?			
Outcomes: NAAQS reviews for individual criteria pollutants effectively consider the impacts of co-pollutants and exposure and effects from multipollutant mixtures. Future reviews of secondary NAAQS will effectively consider the impacts of deposition of NOx and SOx using EPA methods and modeling tools.			
No.	**Outputs**	**Output Year**	**Other ACE Science Questions Addressed**
1.4.1	Refined and evaluated model for use in epidemiological studies to improve the linkages between sources, concentrations, exposures and health effects	FY2015	Theme 1, SQ 1
1.4.2	Development and evaluation of improved multipollutant indicator	FY2014	Theme 1, SQ 1
1.4.3	Synthesis report on effects of variability of air pollutants and human activity patterns on exposure to air pollution	FY2014	Theme 1, SQ 1
1.4.4	Improved methods for quantifying nitrogen and sulfur concentrations and air-surface exchange fluxes with high temporal resolution; improved methods for quantifying the uncertainty in micrometeorological flux measurements	FY2015	Theme 1, SQ 1,2
1.4.5	Datasets of speciated nitrogen, sulfur, and ozone fluxes, concentrations, and ancillary information suitable for transfer to program offices, and improved models for relating ambient concentrations and deposition fluxes for nitrogen and sulfur species	FY2015	Theme 1, SQ 1,2
1.4.6	Synthesis report on improved dry deposition algorithms for CMAQ model	FY2015	Theme 1, SQ 1
1.4.7	Improved estimates of HAPs, nitrogen and sulfur deposition for urban and rural environments using improved source apportionment methods	FY2014	Theme 1, SQ 1,2
1.4.8	Assessment of the impacts of different forms of atmospheric deposition of N (NOx, NH4, NH3, NO3) as well as other sources of nitrogen	FY2014	Theme 1, SQ 1
1.4.9	Analysis and Decision Support Tools for Sources, Composition, and Health Effects of Coarse Particulate Matter	FY2012	Theme 1, SQ 1

Theme 2. Prevent and Reduce Emissions – Provide data and tools to develop and evaluate approaches to prevent and reduce emissions of pollutants to the atmosphere, particularly environmentally sustainable, cost-effective, and innovative multipollutant and sector-based approaches.

Science Question 2.1: What tools are needed to support the management of air pollution problems at the different scales of time and space associated with different pollutants and effects?

Outcomes: The Agency and its stakeholders apply ORD modeling tools to identify air quality management problems and evaluate air quality management options both locally and internationally.

Agency decisions related to air quality management and climate-change effectively incorporate an understanding of air quality-climate trade-offs and synergies and produce air quality and climate-change co-benefits where possible.

No.	Outputs	Output Year	Other ACE Science Questions Addressed
2.1.1	Framework that integrates emissions, dispersion and exposure indicators for potential development into a GIS (or applicable) platform to assess exposure to mobile-source pollution and related sources	FY2014	Theme 1, SQ 2,4
2.1.2	GIS-based air pollution exposure model	FY2014	Theme 1, SQ 2,4
2.1.3	Updated versions of the Consolidated Human Activity Database (CHAD) for input to APEX and SHEDS human exposure models, and model code for modeling longitudinal activity patterns for subpopulations	FY2015	Theme 1, SQ 2,4
2.1.4	A tiered or hierarchical modeling system to accurately and efficiently provide near-field and urban-wide concentration fields	FY2014	Theme 1, SQ 2,4
2.1.6	Advanced fine-resolution modeling techniques for major point and distributed area sources on urban scales to support assessments for NAAQS on a city-wide basis	FY2014	Theme 1, SQ 2,4
2.1.7	Report synthesizing impact of meteorology on air pollution	FY2018	Theme 1, SQ 2,4
2.1.8	Offline and online/fully coupled meteorology-air quality models that can be applied from regional to global scales providing outputs to impacts, adaptation, vulnerability, and economic models to support strategic policy analysis and development	FY2016	Theme 1, SQ 1
2.1.9	Fully integrated climate-air quality modeling system and methodologies for process-based evaluation	FY2015	Theme 1, SQ 1
2.1.10	Methodologies for downscaling NASA/NOAA/NCAR global models using WRF as a regional climate model	FY2013	

No.	Outputs	Output Year	Other ACE Science Questions Addressed
2.1.11	Synthesis document identifying win-win emission strategies for improving air quality, protecting ecoystems, reducing short-lived climate forcers and mitigating greenhouse gases	FY2014	Theme 2, SQ 3
2.1.12	Synthesis document quantifying, using measurements and computational tools, the global warming potential of key climate related compounds	FY2015	Theme 1, SQ 1

Science Question 2.2: What methods need to be developed and data obtained to conduct life-cycle analyses of alternative pollution reduction and energy options to inform EPA and other local, regional, national, and international decisions regarding the most sustainable and cost effective uses of resources?

Outcomes: The Agency has tools and analyses to identify the full cost of alternative energy options, including the systematic evaluation of multimedia impacts and potential tradeoffs between environmental, social, and economic objectives.

The Agency has models and tools to compare and predict the impacts of energy alternatives and efficiency programs.

Development of tools and methods to evaluate current and future energy options to support Agency actions that minimize energy-related impacts on air and water quality.

No.	Outputs	Output Year	Other ACE Science Questions Addressed
2.2.1	Synthesis report describing extended applications of the NYC community- scale MARKAL model	FY2013	Theme 1, SQ 1
2.2.3	Synthesis reports on the results of the sub-sector specific scenario analyses	FY2014	Theme 1, SQ 1
2.2.4	Summary report on scenario analysis to achieve CO2 mitigation goals using the Kaya-based scenarios	FY2013	Theme 1, SQ 1
2.2.5	White paper on the scenario implementations and demonstrating their use in assessing the technology implications and regulatory efficacy	FY2013	Theme 1, SQ 1
2.2.6	Assessments of the impacts of renewable portfolio standard (RPS) and renewable technologies on the U.S. energy system	FY2014	Theme 1, SQ 1
2.2.7	Release of new versions of MARKAL 9-Region and national energy system model databases for use in evaluating the emissions from the production and use of energy	FY2012, FY2014	Theme 1, SQ 1
2.2.8	Synthesis report on the cumulative risk of a transformed energy infrastructure from resource supply/extraction through conversion and end-use	FY2015	Theme 1, SQ 1
2.2.9	Synthesis report on the impacts of building shell changes, energy efficient choices, and human behavior on human health and the environment	FY2015	Theme 1, SQ 1
2.2.10	Future emissions data from scenarios for use in CMAQ and GLIMPSE models	FY2015	Theme 1, SQ 1

No.	Outputs	Output Year	Other ACE Science Questions Addressed
2.2.11	Synthesis report with integrated analyses of cookstove evaluations including health endpoints, technical guidance for regional stove testing centers, and technical support for standard test methods for cookstoves including high throughput toxicity testing	FY2015	Theme 1, SQ 1
2.2.12	Synthesis report analyzing the differences in pollutant behavior and partitioning between air-fuel and oxy-fuel combustion	FY2015	Theme 2, SQ 4
2.2.13	Assessment of air pollution control upgrade requirements for GHG retrofit based on selected model plants from existing coal-fired power plants	FY2012	Theme 2, SQ 4
2.2.14	Synthesis report on the results of the natural gas scenario analysis	FY2014	Theme 1, SQ 1
2.2.15	Synthesis report on the potential for breakthroughs in technologies and fuels/fuel usage to impact the U.S. energy system	FY2016	Theme 1, SQ 1
2.2.16	Synthesis report summarizing analysis of global baseline emissions scenarios on energy technology requirements	FY2015	Theme 1, SQ 1
2.2.17	Synthesis report on reactive gaseous mercury monitoring and delivery of associated database	FY2013	Theme 1, SQ 1
2.2.18	Synthesis reports comparing direct and indirect environmental and human health impacts (including changing exposure pathways) across the energy system resulting from changes in energy resource supplies, technologies, and patterns of end use	FY2016	Theme 1, SQ 1
2.2.19	Research on quantifying, via field measurements and modeling, the improvements in air quality, climate, and public health resulting from an ongoing or planned changeover to cleaner-burning fuels for cooking, heating, or lighting in the developing world	FY2017	Theme 1, SQ 1
2.2.20	Biofuels Report to Congress	FY2015	Theme 1, SQ 1
2.2.21	Inputs for life cycle analyses and modeling of regional human health effects of biofuel feedstock production, storage and processing	FY2013	Theme 1, SQ 1
2.2.22	Synthesis document on dose-response studies of potential human health risks of pollen and molds associated with biofuel feedstock production	FY2015	Theme 1, SQ 1
2.2.23	Synthesis document on use of sustainability metrics to complement life cycle approaches	FY2015	Theme 2, SQ 4
2.2.24	Decision support tool for States and communities to assess water quality impacts from leaking underground storage tanks	FY2013	Theme 1, SQ 1
2.2.25	Synthesis of emissions data to provide PM and VOC speciation profiles for light-duty gasoline vehicles operating on ethanol-blend fuels for inclusion in the SPECIATE database and input into the CMAQ model	FY2013	Theme 1, SQ 1
2.2.26	Profiles of criteria and toxic emissions from ethanol-blend gasoline and biodiesel combustion in on-road motor vehicles for identification and evaluation of potential toxicity differences among biofuel content and operating conditions	FY2014	Theme 1, SQ 1

No.	Outputs	Output Year	Other ACE Science Questions Addressed
2.2.27	Summary of potential impacts of biomass feedstock production on N20, including key uncertainties	FY2015	Theme 1, SQ 1
2.2.28	Synthesis report on emissions from combustion of waste glycerol	FY2015	Theme 1, SQ 1
2.2.29	Synthesis report describing the design, initiation, and methods for field-scale biochar soil amendment demonstration projects	FY2016	Theme 2, SQ 4
2.2.30	Synthesis report on the assessment of the impacts of future climate changes on feedstock production yields, and the resulting energy system and environmental impacts	FY2014	Theme 1, SQ 1
2.2.31	Final report detailing the side-by-side comparison of biogas management technologies	FY2013	Theme 2, SQ 4

Science Question 2.3: What innovative monitoring technologies are needed to support the implementation of management strategies to prevent and reduce air pollution?

Outcomes: New methods are incorporated into monitoring networks and compliance monitoring activities to enhance available information and / or to reduce monitoring costs

No.	Outputs	Output Year	Other ACE Science Questions Addressed
2.3.1	Synthesis report on evaluation of sensor technology to support monitoring applications	FY2014	Theme 1, SQ 2
2.3.2	Demonstration of data fusion modeling approaches to estimate air pollutant concentrations	FY2014	Theme 1, SQ 2
2.3.3	Completion of health and exposure monitoring technology evaluation and preliminary data summarization	FY2016	Theme 1, SQ 2
2.3.4	Feasibility study of the deployment of optical technologies to compliment national air quality monitoring networks	FY2014	Theme 1, SQ 2
2.3.5	Synthesis of Multiscale characterization of ammonia and greenhouse gas emissions using measurement and modeling data	FY2015	Theme 1, SQ 2
2.3.6	Synthesis of findings to provide a fundamental understanding of how satellite data can be used to infer surface conditions more quantitatively, not just for prediction, but also for assessment studies and top□down emissions estimation in a changing environment	FY2015	Theme 1, SQ 2
2.3.7	Develop a community of practice for remote sensing techniques and data collection	FY2017	Theme 1, SQ 2

No.	Outputs	Output Year	Other ACE Science Questions Addressed
2.3.8	Evaluating the value of data from small sensors, developing the technology necessary to combine data from multiple sensors increasing spatial and temporal resolution of air pollutant measurements, and involving communities in activities to understand and decrease their exposure to pollutants	FY2019	Theme 1, SQ 2

Science Question 2.4: What are the most efficient integrated, sustainable pollution reduction and prevention solutions?

Outcomes: New green chemistry options for solvents are incorporated as air toxics regulations

No.	Outputs	Output Year	Other ACE Science Questions Addressed
2.4.1	Synthesis report on proposed green chemical process for reducing emissions of air toxics	FY2014	
2.4.2	Synthesis report detailing the usability and feasibility of the Triple Value model in computationally understanding sustainability in the context of systems	FY2014	
2.4.3	Decision support tool which can quantitatively or qualitatively assess markers towards or away from sustainability according to the Fiksel Triple Value Model	FY2014	

Science Question 2.5: What methods and tools need to be developed to support implementation of National Ambient Air Quality Standards (NAAQS)?

No.	Outputs	Output Year	Other ACE Science Questions Addressed
2.5.1	Data on emissions of interest from key sources for emission inventory improvement	FY2015	Theme 2, SQ 1
2.5.2	Synthesis document on the effects of vehicle technology and operating conditions on performance and pollutant emissions	FY2016	Theme 2, SQ 1
2.5.3	Report on methane and VOC emissions from oil and gas production operations using advanced source assessment technologies such as to geospatial mapping, off site remote and direct fugitive leak measurement, and infrared camera sensing	FY2012	Theme 1, SQ 2
2.5.4	Assessment of exposure from oil and gas production activities	FY2014	Theme 1, SQ 1
2.5.5	Update of SPECIATE database with novel emissions data on selected fugitive and area sources	FY2016	Theme 2, SQ 1
2.5.6	Produce a version of the Industrial Sectors Integrated Solutions Model (ISIS) for the Pulp and Paper Industry to support Rulemaking activities	FY2012	Theme 2, SQ 1

No.	Outputs	Output Year	Other ACE Science Questions Addressed
2.5.7	Web-based techno-economic modeling framework capable of addressing multi-sectors, multi-pollutant, multi-market, and multi-region emission reduction policies, objectives and constraints	FY2015	Theme 2, SQ 1
2.5.8	Technology evaluation roadmap to be used by Regions, States, and local air districts to identify innovative technologies for field demonstration and to address NAAQS non-compliance	FY2014	Theme 2, SQ 1
2.5.9	Final report on Engineered Deployable Rotary Kiln System for Gasification of Solid Wastes	FY2015	Theme 2, SQ 1

Theme 3. Respond to Changes in Climate and Air Quality – Provide human exposure and environmental modeling, monitoring, metrics and information needed by individuals, communities, and governmental agencies to adapt to the impacts of climate change and make public health decisions regarding air quality.

Science Question 3.1: What are the most effective alternative adaptation strategies?

Outcomes: Development of tools and approaches to examine the social responses associated with technologies to mitigate or adapt to climate change to better inform future climate decisions.

Climate adaptation activities conducted by EPA and by EPA stakeholders are effectively targeted toward vulnerable human and ecological populations.

No.	Outputs	Output Year	Other ACE Science Questions Addressed
3.1.1	A framework for adaptation planning based on previous climate impact and adaptation studies at national, regional and local scales, including an application of the framework for adaptation planning for climate-sensitive coral reef ecosystems	FY2016	Theme 1, SQ 1,2
3.1.2	Expansion of decision makers "toolkits" for adaptation through improved understanding of the impacts, co-benefits, and potential unintended consequences of climate change adaptation strategies, with a preliminary focus on water quality rulemaking and subsequent broadening of scope to consider air quality	FY2015	Theme 1, SQ 1,2
3.1.3	Assessments to improve understanding of climate change impacts on the environment and human health and well being	FY2013	Theme 1, SQ 1
3.1.4	Synthesis of forest indicators of climate change, including long term data summaries to assess ecosystem simulation models	FY2015	Theme 1, SQ 1,2

No.	Outputs	Output Year	Other ACE Science Questions Addressed
3.1.5	Frameworks and GIS tools that assist in the development and evaluation of climate change impacts at different spatial (global, regional and local) and temporal scales	FY2016	Theme 1, SQ 1,2
3.1.6	Methods and data to assess climate change impacts at different spatial and temporal scales	FY2014	Theme 1, SQ 1,2 SHC
3.1.7	Characterization of the environmental impacts of climate change and benefits of avoided climate change impacts and GHG reductions strategies through assessments of impacts of climate change on watersheds, water quality, water quantity	FY2016	Theme 1, SQ 1
3.1.8	Synthesis report describing results of research on methods to assess urban resilience	FY2016	Theme 1, SQ 1
3.1.9	Analysis and Decision Support Tools for consequences of global change for air quality	FY2012	Theme 1, SQ 1,2
3.1.10	Analysis and Decision Support Tools for consequences of global change for water quality	FY2014	Theme 1, SQ 1,2
3.1.11	Assessments of the impacts of extreme weather events on the environment and environmental protection systems, including models to evaluate options to adapt to these events	FY2016	Theme 1, SQ 1,2
3.1.12	Direct entomological interventions, changes in land use to create barriers inhospitable to vectors, enhanced monitoring and surveillance techniques, and chemical control	FY2019	

Science Question 3.2: What innovative methods are needed to inform individual- and community-level adaptation to climate change and decision-making regarding air quality?

Outcomes: Individuals and communities have tools and data available to make timely and informed decisions to adapt to climate change and to reduce exposure to air pollution and to track progress toward.

Improvement and expansion of emissions inventories to support future air quality policies.

The Agency and its stakeholders develop and implement effective policies to mitigate exposures and effects of air pollutants near sources.

No.	Outputs	Output Year	Other ACE Science Questions Addressed
3.2.1	N mass balance for selected agricultural systems	FY2015	Theme 1, SQ 2
3.2.2	Synthesis report on meteorologically-dependent, process-based emission estimates	FY2014	Theme 1, SQ 2
3.2.3	Biennial update of Speciate database	FY2013	Theme 2, SQ 1
3.2.4	Recommendations from analysis of a specific NEI sector, such as residential wood combustion (RWC), using existing receptor and source oriented modeling tools and methods with the goal of improving the estimates for the sector	FY2013	Theme 1, SQ 2 Theme 2, SQ 1

No.	Outputs	Output Year	Other ACE Science Questions Addressed
3.2.5	Synthesis report/paper summarizing field and modeling findings for local air quality impact associated with the near-rail yard environment	FY2016	Theme 1, SQ 1, 4
3.2.6	Synthesis report on results from Cleveland Multiple Air Pollutant Study	FY2014	Theme 1, SQ 1, 4
3.2.7	Synthesis of findings from RAMSES near-roadway studies	FY2015	Theme 1, SQ 1, 4
3.2.8	Model framework (e.g. AERLINE) capable of predicting air transport and dispersion of traffic emissions in the presence of varying roadway designs (cut sections, elevated fill sections, etc.) and roadside vegetation	FY2014	Theme 1, SQ 1, 2
3.2.9	Synthesis of findings from the NEXUS study including human exposure, health impacts, and source apportionment results and enhance modeling tools for near road applications	FY2015	Theme 1, SQ 1, 4
3.2.10	Synthesis of actual and perceived impacts of wildfire event on health and economic welfare of the community	FY2016	Theme 1, SQ 1, 2, 4

Science Question 3.3: What are the social, behavioral, and economic factors that may hinder the ability of communities and individuals to implement adaptation strategies for climate change and make informed decisions regarding air quality?

Outcomes: Development of tools and approaches to examine the social responses associated with technologies to mitigate or adapt to climate change to better inform future climate decisions.

No.	Outputs	Output Year	Other ACE Science Questions Addressed
3.3.1	An assessment to provide a better understanding of the current control technologies for mitigating greenhouse gases emitted from industrial and utility sectors	FY2014	Theme 2, SQ 1,4
3.3.2	Synthesis document of key mitigation and adaptation research needs	FY2015	Theme 2, SQ 1,4
3.3.3	Synthesis report on adaptation methods and develop technologies that allow reducing energy consumption, enabling water and energy conservation, and improving system efficiency in water supplies and water management	FY2014	Theme 2, SQ 1,4

References

1. "Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act; Final Rule." Federal Register 74 (15 December 2009): 66496-66546. Print.

2. U.S. Environmental Protection Agency. Global Change Research Program. Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems, Synthesis and Assessment Product 4.6. July 2008.

3. The White House. Remarks by the President in State of Union Address. United States Capitol, Washington, D.C. January 25, 2011.

4. U.S. Environmental Protection Agency. Office of Research and Development. Particulate Matter Research Program: Five Years of Progress. EPA 600/R-04/058. July 2008. Retrieved from http://www.epa.gov/ord/ca/pdf/pm_research_program_five_years_of_progress.pdf.

5. U.S. Environmental Protection Agency. Climate Change Science Program. Synthesis and Assessment Reports. Retrieved from http://www.epa.gov/climatechange/policy/research.html.

6. The White House. Office of Management and Budget. 2010 Report to Congress on the Benefits and Costs of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities. Retreived from http://www.whitehouse.gov/sites/default/files/omb/legislative/reports/2010_Benefit_Cost_Report.pdf

7. U.S. Environmental Protection Agency (2011). Office of Air & Radiation. Air Quality Trends. Retrieved from http://www.epa.gov/airtrends/aqtrends.html#comparison.

8. U.S. Environmental Protection Agency. FY 2011-2015 EPA Strategic Plan: Achieving Our Vision. September 30, 2010.

9. U.S. Environmental Protection Agency. National Center for Environmental Research. Clean Air Research Centers Request for Proposal. Retrieved from http://www.epa.gov/ncer/rfa/2009/2009_star_clean_air.html.

10. United States. Cong. Senate. 111th Congress, 1st Session. S. 1462, American Clean Energy Leadership Act of 2009. Congressional Bills, GPO Access. Retrieved from http://energy.senate.gov/public/_files/s1462pcs1.pdf.

11. United States. Cong. Senate. 110th Congress, 1st Session. H.R. 6, The Energy Independence and Security Act of 2007. Retrieved from http://energy.senate.gov/public/_files/getdoc1.pdf.

12. See the reports under the heading, "America's Climate Choices," National Research Council, http://americasclimatechoices.org/.

13. "Global Climate Change Impacts in the United States," T.R. Karl, J.M. Melillo, T.C. Peterson (eds.), Cambridge University Press (2009).

14. IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A.(eds.)]. IPCC, Geneva, Switzerland, 104 pp.

15. National Academy of Sciences (NAS) National Research Council (NRC) (2004). Research Priorities for Airborne Particulate Matter. The National Academies Press: Washington, DC. Retrieved from http://www.nap.edu/catalog.php?record_id=10957.

16. BOSC Report on the PM-Ozone Program Review (2005). Retrieved from http://www.epa.gov/osp/bosc/pdf/pm0508rpt.pdf.

17. The White House Council on Environmental Quality (2010). Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy. Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf.

18. Biomass Research & Development Board: Initiative: http://www.usbiomassboard.gov/initiative/initiative.html.

19. National Science and Technology Council: Subcommittee on Social, Behavioral and Economic Sciences (2009). Social, Behavioral and Economic Research in the Federal Context. Retrieved from http://www.whitehouse.gov/files/documents/ostp/NSTC%20Reports/SBE%20in%20the%20Federal%20Context%20(for%20NSTC)%204-21-09.pdf

Research Program Partners and Stakeholders

Office of Air and Radiation (OAR)

- Office of Air Quality Planning and Standards (OAQPS)
- Office of Transportation and Air Quality (OTAQ)
- Office of Atmospheric Programs (OAP)
- Office of Radiation and Indoor Air (ORIA)

Office of Policy (OP)

Office of Enforcement and Compliance Assurance (OECA)

Office of Solid Waste and Emergency Response (OSWER)

Office of Water (OW)

Regions

Universities

Non-Governmental Organizations

Acronyms

Acronym	Meaning
ACE	Air, Climate, and Energy
CAA	Clean Air Act
CMAQ	Community Multiscale Air Quality
CO	Carbon monoxide
CSS	Chemical Safety for Sustainability
EPA	U.S. Environmental Protection Agency
GHG	Greenhouse gas
GIS	Geographic information systems
HHRA	Human Health Risk Assessment
MARKAL	MARKet ALlocation energy system model
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NRC	National Academy of Science's National Research Council
OAP	Office of Atmospheric Programs
OAQPS	Office of Air Quality Planning and Standards
OAR	Office of Air and Radiation
OECA	Office of Enforcement and Compliance Assurance
OP	Office of Policy
ORD	Office of Research and Development
ORIA	Office of Radiation and Indoor Air
OSWER	Office of Solid Waste and Emergency Response
OTAQ	Office of Transportation and Air Quality
OW	Office of Water
PM	Particulate Matter
RDM	Robust Decision Making
RIA	Regulatory impact analysis
SHC	Sustainable and Healthy Communities
SO2	Sulfur dioxide
SSWR	Safe and Sustainable Water Resources