Framework for EPA's

Air, Climate, and Energy

Research Program

June 14, 2011

Submission for Review by the EPA's Science Advisory Board (SAB) and Board of Scientific Counselors (BOSC)

Air, Climate, and Energy (ACE) Research Program

I. Executive Summary

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 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 improving air quality and addressing climate change. To accomplish this goal, EPA's Office of Research and Development (ORD) is designing a new, integrated research program for **Air, Climate and Energy (ACE)** that will build upon the highly successful, policy relevant research the Agency has conducted in the areas of air pollution and climate change.

> ***ACE Problem Statement.*** Protecting human health and the environment from the effects of air pollution and climate change, while sustainably meeting the demands of a growing population and economy is critical to the well-being of the Nation and the world. As we explore solutions to prevent and reduce emissions, we are challenged by uncertainties surrounding the complex interplay between air quality, a changing climate, and a changing energy landscape, and the subsequent human health and ecological effects attributed to exposure to an evolving array of pollutants in the atmosphere.
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> ***ACE Vision.*** To provide cutting-edge scientific information and tools to support EPA's strategic goals to take action on climate change and improve air quality.

Over the past decades, air quality in the U.S. has improved significantly. During this time period ORD research 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 Clean Air Act (CAA) and directly contributed to the Office of Management and Budget's (OMB) 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 the 2009 Endangerment and Cause or Contribute Findings for GHGs, ORD has the responsibility to produce the scientific information needed to respond to the Agency's efforts to meet its legal, statutory, and policy requirements in a changing climate, including informing climate mitigation and adaptation choices towards sustainable, resilient solutions.

The impacts of air quality and climate change are heavily influenced by the energy choices of the U.S. 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 in this changing energy landscape, and the potential impacts on human and environmental health.

With active participation from EPA partners and 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 supports policy priorities and subsequently examines:

- The multipollutant nature of air pollution in order to develop 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 is designing the ACE research program to address the increasingly complex environmental issues we face in the 21st century. To effectively address these issues, it is necessary to move towards 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.

This framework will be used during this process to evaluate the relevance and alignment of current and future research activities within the context of the ACE research program. Ultimately these activities will lead to the development of the Research Action Plan (RAP) in October 2011, which will provide the rationale, approach, and product delivery timelines for research activities within the ACE research program.

II. Introduction

a. What is the environmental problem?

i. What are the health and environmental risks?

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 U.S. 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, as well as the built environment (i.e., energy, infrastructure, and settlements).[1] Additionally, changes in the climate can lead to higher concentrations of harmful air pollutants, and the presence of some air pollutants in the atmosphere can also accelerate climate change. With global emissions of greenhouse gases (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 U.S. 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, the President has proposed a goal to produce 80 percent of the electricity in the U.S. from clean energy sources by 2035.[3] Although it remains unclear what future energy options will emerge, it is evident that the U.S. and the world face a rapidly changing energy landscape with associated changes in impacts on human health and the environment.

Air pollution defined:

"Any air pollution agent or combination of such agents, including any physical, chemical, biological, radioactive (including source material, special nuclear material, and byproduct material) substance or matter which is emitted into or otherwise enters the ambient air."

- CAA Section 302[g]

ii. 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 which will govern the ACE research agenda:

> *Protecting human health and the environment from the effects of air pollution and climate change, while sustainably meeting the demands of a growing population and economy is critical to the well-being of the Nation and the world. As we explore solutions to prevent and reduce emissions, we are challenged by uncertainties surrounding the complex interplay between air quality, a changing climate, and a changing energy landscape, and the subsequent human health and ecological effects attributed to exposure to an evolving array of pollutants in the atmosphere.*

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. However, from an EPA research perspective, combining air, climate, and energy enables the development of sustainable, integrated solutions that have synergistic benefits for public health, the environment, and the economy.

b. Why is EPA investing in this research?

i. What is the regulatory/statutory and policy context for the research?

Under the Clean Air Act (CAA), EPA is required to set air quality standards to protect the public health and environmental welfare of the Nation. For six common air pollutants (i.e., PM, O_3, SO_2, NO_2, CO, and Pb) that are widely distributed across the country, EPA establishes National Ambient Air Quality Standards (NAAQS). Although regulated individually, collectively PM and O_3 account for the majority of adverse health effects due to air pollution.[4] In addition to the NAAQS pollutants, the CAA requires EPA to regulate emissions of hazardous air pollutants (HAPs), or air toxics. These pollutants are those that are known or suspected to cause cancer or other serious health or environmental effects. The ACE research program will conduct research to support EPA's programs mandated by the CAA, and will foster innovative approaches to ensure clean air in the context of a changing climate and evolving communities and technologies.

In 2007, the 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 which 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 months of reviewing the full weight of scientific evidence and the thousands of public comments received, the Administrator issued the Endangerment and Cause or Contribute Findings for GHGs under Section 202(a) of the CAA.[1]

This 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 (ACELA) 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.[5] This requirement builds upon the mandates of the Energy Independence and Security Act (EISA) of 2007,[6] 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 these greater volumes of biofuels. The ACE program must develop the knowledge to enable EPA's responses to the changing energy landscape and the resulting environmental implications.

The issues of air pollution, climate change, and energy are closely connected, and have been recognized by a variety of scientists including the National Academy of Sciences (NAS) and the U.S. Global Change Research Program (USGCRP).[7,8] 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.

ii. How will the research program address the priorities identified in EPA's strategic plan?

Since its inception, EPA's success in protecting public and environmental health has relied strongly upon understanding and providing the scientific basis 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, but growing concerns over climate change have also become a top priority. These priorities are reflected in Goal 1 of EPA's Strategic Plan, which is "Taking Action on Climate Change and Improving Air Quality."[9] This 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 U.S. 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 ACE research program that the Office of Research and Development (ORD) will conduct research to support the development of sustainable solutions that prevent and reduce all forms of air pollution to protect the public and environmental health of the U.S.

c. How is this research program designed?

i. Why is an integrated approach necessary for this research program?

The impacts of air quality and climate change are heavily influenced by the energy choices of the U.S. and the world. As the demand for energy increases, along with shifts to clean energy alternatives, it is necessary to understand the interactions between air quality and climate change in this changing energy landscape, and the potential impacts on human and environmental health. Furthermore, the ACE research program must also include research that is systems based to account for interactions across social, economic, and environmental domains. Therefore, the ACE research program is designed to more closely integrate ORD's 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. This design will leverage expertise and capabilities across ORD and from partners and stakeholders to support the development of effective, sustainable policies. Figure 1 shows a simplified illustration of the relationships between air, climate, and energy, identifies the major earth and human systems impacted by air pollution and climate change, and portrays the responses and social factors that have major influences on the relationships between each area.

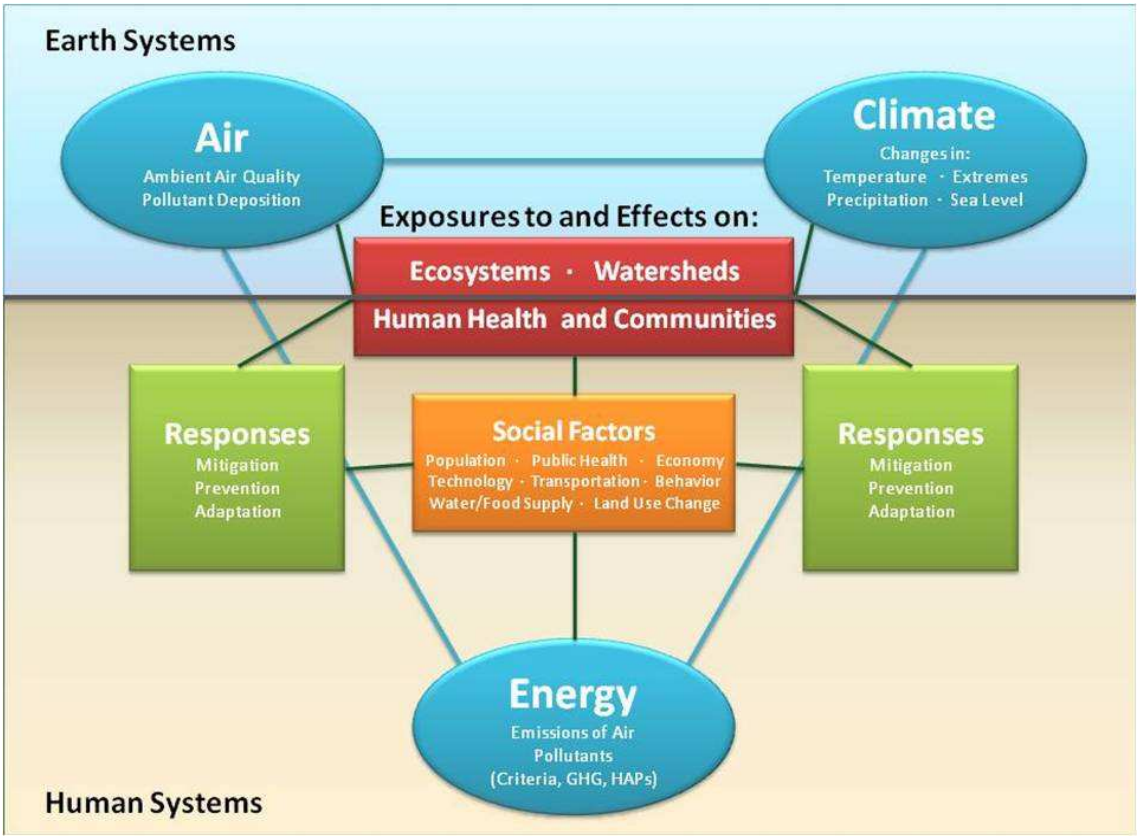

Figure 1. Integration of Air, Climate, and Energy.[a]

[a] Adapted from IPCC, 2007.[10]

ii. How will this program build on /evolve from ORD's existing research program?

The ACE research program will build upon the strong foundation of research that has been established in predecessor ORD research programs, including the Clean Air, Global Change, and Biofuels research programs. Through these programs, 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 program, but the fundamental scientific capabilities will remain as key components of the program.

iii. What are some recent ORD research accomplishments in this area and what will research in the realm of air, climate, and energy aim to address?

To date, the Clean Air, Global Change, and Biofuels research programs have supported and conducted research that has improved the human and environmental health of the U.S. These research programs individually have directly supported: the promulgation of the NAAQS; the development of the Endangerment Finding; and the implementation of the Renewable Fuel Standard. Additionally, each of these programs have produced cutting edge science leading to significant advances, including a more thorough understanding of the source to health effect continuum of PM,[11] 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.[12]

Research conducted under the Clean Air component of ACE – the longest-running part 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 these research programs is in part unquantifiable, the White House Office of Management and Budget (OMB) has estimated that the NAAQS has accounted for approximately 94-97% of estimated benefits from all EPA regulations and approximately 60-87% of estimated benefits across all federal agencies.[13] 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.

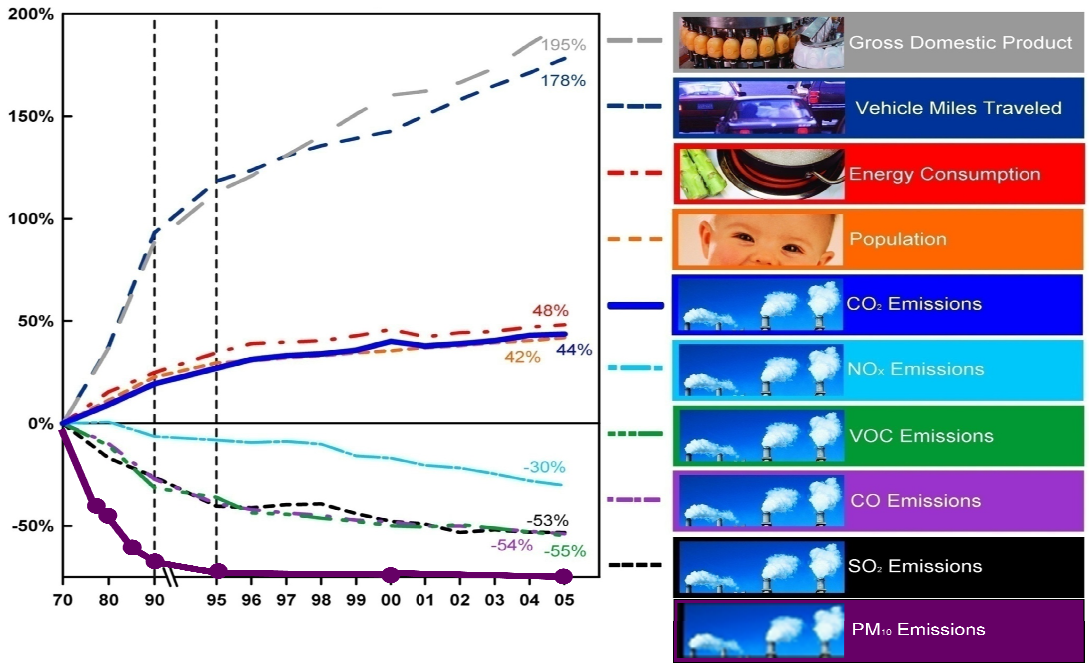

Figure 2. The changing economic, population, and environmental status of the U.S., 1970-2005.[13]

These improvements in air quality and public health resulting from EPA's Clean Air programs are illustrated in Figure 2, which demonstrates the substantial reductions in PM_{10}, NOx, VOC, CO, and SO_2 since 1970, even as the gross domestic product (GDP) and vehicle miles traveled have nearly doubled. The work of ORD was instrumental in providing the scientific and technical foundation for these achievements. Yet the full benefits of EPA's achievements 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 over 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;[9]
- 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 needed to support EPA's strategic goals to take action on climate change and improve air quality.*

The ACE research program will build upon its record of highly relevant and exceptionally valuable science to continue to support the Agency's development of policies that create enormous benefits for public health, our environment, and the national economy.

iv. Explain rationale for combining programs. How will the new program be better than what we were able to do before?

EPA research has provided effective solutions to high-priority environmental problems for the past 40 years. These solutions were necessarily achieved using 20th century approaches. For example, assessing risk or developing controls to emissions has usually focused on a single pollutant and its impact on a single target organ or species. However, such single-pollutant, source-specific, and end-of-pipe approaches are limited in their ability to address the increasing complexity of 21st century environmental challenges with solutions that are effective, efficient, and sustainable – solutions that meet current needs without compromising the future. EPA is transforming its research capability to more fully understand these complex interactions and the implications of policy choices to develop more sustainable solutions.

To accomplish this shift in philosophy, EPA is strengthening its planning and delivery of science by implementing an integrated transdisciplinary research (ITR) approach. By looking at problems systematically and holistically instead of in isolation, an ITR approach will take advantage of synergies that yield benefits beyond those possible from narrowly targeted approaches that focus on single chemicals, disciplines, or environmental media. A focus on developing sustainable solutions means that ORD will work with its partners within the Agency and other stakeholders to plan, develop, and conduct research that accounts for the immediate as well as longer-term impacts to environmental, economic, and social systems. This approach requires that ORD's research plans incorporate input from external stakeholders such as federal, state and local government agencies, non-governmental organizations, industry, and communities affected by environmental problems.

> *"Twenty-first century environmental problems require 21st century solutions; we cannot effectively address such challenges with 20th century approaches."*
>
> - Paul Anastas, ORD Assistant Administrator

To that end, ORD is realigning its current 12 research areas into four better integrated research programs:

- Air, Climate, and Energy (ACE)
- Safe and Sustainable Water Resources (SSWR)
- Sustainable and Healthy Communities (SHC)
- Chemical Safety for Sustainability (CSS)

The ORD research portfolio will be rounded out by the existing programs of Human Health Risk Assessment (HHRA) and Homeland Security (HS), which integrate findings from the four new transdisciplinary programs in response to specific legislative or policy mandates.

Figure 3 represents the four realigned ORD research programs and how they are interrelated and fit within larger EPA and stakeholder contexts. To provide scientific information and tools that sustainably advance environmental protection, the four national program areas must contribute to and reinforce one another, and work jointly with decision makers both inside and outside EPA. To fully address all of the issues that fall within the ACE research program, ORD recognizes that, where appropriate, research related to air, climate, and energy must be integrated with other ORD research programs.

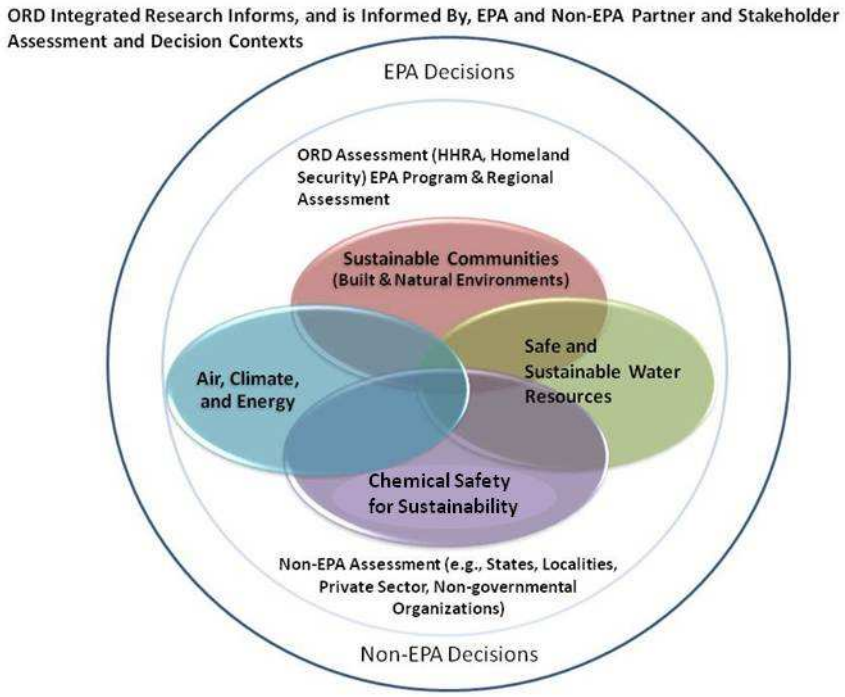

Figure 3. Integrated ORD Research Programs Within EPA and Non-EPA Partner and Stakeholder Contexts

The ACE research program is focused on the EPA priority, *Taking Action on Climate Change and Improving Air Quality*.[9] Applying transdisciplinary research within the ACE research program ensures that the realigned research program provides innovative science, engages end users of its research from problem formulation through product application, and most importantly, yields results that enable EPA to accomplish its goal.

v. How will this program interact and integrate with other research programs?

a. With ORD/EPA

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, must therefore be designed in a manner that allows them to continuously evolve as the science changes and to conduct work across discipline and boundary. This will require constant and effective communication and coordination within the ACE program, with other ORD programs, 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, whether this consists of data needs, models, and measurements or stressors that contribute to human and ecosystem responses, to enhance the transition from three previously separate to one research program. The ACE research program will effectively integrate with the other ORD research programs (e.g., SSWR, SHC, and CSS) to ensure that EPA's science is able to support the development of sustainable solutions to environmental problems. Active communication within ORD will facilitate cross-program involvement in research planning and allow for the identification of opportunities to leverage research activities. Examples include:

- Chemical Safety for Sustainability (CSS)
  - Exposure to HAPs can be reduced by the development of chemicals and other products that eliminate or reduce the use of toxic substances (e.g., feedstocks, solvents);
- Human Health Risk Assessment (HHRA)
  - Research results to inform the development of Integrated Science Assessments (ISA) for criteria air pollutants.
- Sustainable and Healthy Communities (SHC)
  - Exposure to air pollutants from roadways can be reduced/prevented by the design of communities and the placement of roadways; and
- Safe and Sustainable Water Resources (SSWR)
  - 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.

b. With other Federal agencies

ACE will need to integrate with relevant federal agencies to develop coordinated, government-wide responses to air, climate, and energy issues to take full advantage of the expertise and research that is being done across the federal government can be applied to address these complex problems. For example, the ACE program will build upon and leverage existing

relationships with NOAA, CDC, NIEHS, NASA, and DOE and we will work to extend 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 (AQRS) and the Global Change Research Subcommittee (GCRS) of the National Science and Technology Council's Committee on the Environment, Natural Resources, and Sustainability (CENRS). In addition, the ACE research team must continue its interactions with the global research community to stay abreast of the state of the science and to identify the most promising results that can aid in achieving the program's goals. All of these integration activities require on-going input from EPA partners and stakeholders to clearly identify areas in which integration within and across research areas can be achieved to supporting the goals of the Agency.

vi. Briefly describe partner and stakeholder involvement in the Problem Formulation process.

To adequately address 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 program. Ongoing interactions with internal EPA partners (i.e., program and regional offices) and external stakeholders have been crucial to the identification and development of the major problems faced by EPA decision makers that span air, climate, and energy. These discussions brought to the forefront the need for research that supports policy priorities and subsequently examines:

- the multipollutant nature of air pollution, to create more sustainable 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 actions that are most critical 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.

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

- The NAS'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 (BOSC); [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 (BRDB) 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 (NSTC) subcommittee Social, Behavioral and Economic Sciences of the National Science and Technology Council 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]

III. ACE Research Themes

The organization of the ACE research program is based upon gathering the key research needs into major themes that balance integration across research topics with the need to apply a critical mass of expertise and capability. ORD'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. This structure describes how 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 fit into the work of the scientific community. The three ACE program themes described below flow from the problems identified in the previous section and will provide the science to:

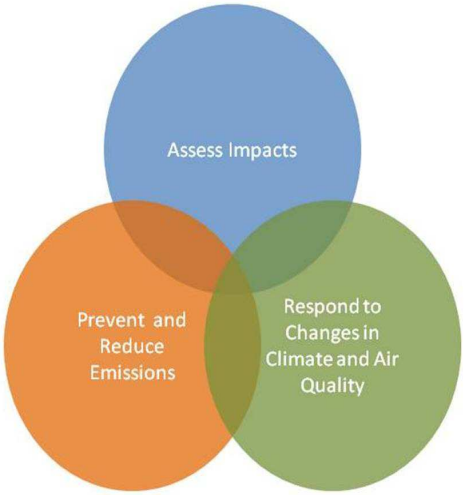

Figure 4. ACE Research Themes

- ***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)

These research themes are intentionally designed not to be specific to air, climate, or energy individually; rather, they are designed to guide research that considers the air- or climate-specific efforts in the context of the interactions among the domains of air, climate, and energy. In addition, as depicted in Figure 4, 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.

The following narratives for each Research Theme provide a brief overview of and 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.

Research 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.

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 are also impacted by complex interactions between climate change and air quality. Social behavior also impacts level of exposure and the resulting effects. Furthermore, the amount and composition of emissions from sources of air pollutants are impacted by economics and energy choices. In addition, susceptibility (i.e., individual- and population-level characteristics, as well as exposure differences, that lead to increased risk of air pollutant-related effects, both human health and ecosystem) must also be factored into these complex interactions to inform the decision making process.[b] 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.

[b] This definition of susceptibility is derived from EPA's Integrated Science Assessments for the criteria air pollutants, specifically particulate matter [EPA (2009). *Integrated Science Assessment for Particulate Matter*. (Report No. EPA/600/R-08/139F). Research Triangle Park, NC.] , and is further discussed in Sacks JD, Stanek LW, Luben TJ, et al. (2011). *Particulate Matter Induced Health Effects: Who's Susceptible?* Environ Health Perspect 119:446-454.

Science Questions:

- *What are the multipollutant exposures and effects and integrated impacts of climate change on air and water quality and human and ecosystem health?* Transdisciplinary source to outcome research will be conducted to assess multipollutant exposure 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 Community Multiscale Air Quality (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, these integrated assessments would include analyses of both expected and potential unintended impacts of these options as they are integrated into use, such as indoor exposures of individuals 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?* Currently available information and indicators will be examined and expanded to include additional components (e.g., multipollutant/multistressor indices to incorporate climate impacts) to develop new indices that would support the development of new policies by EPA partners, measure progress toward environmental goals, 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?* 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, key exposure factors, and the examination of the interaction between social and economic factors and behavior to more thoroughly understand how they may inform research outcomes and impact strategies to protect public health. Recent scientific findings suggest the possibility of even greater numbers of people susceptible to air pollution effects such as those with diabetes or certain genetic

polymorphisms. 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). The presence of other stressors such as water and air pollution, and changes in surrounding land use can be exacerbated by, and lead to greater susceptibility to damage from climate change.

- *What are the key uncertainties and data gaps that need to be addressed to inform review of National Ambient Air Quality Standards (NAAQS)?* 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. Research of human and ecosystem exposure and effects will be conducted to inform future NAAQS reviews.

Research 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 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. As air quality continues to improve, more cost effective and innovative measures are needed to prevent and reduce emissions to implement 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 address multiple pollutants simultaneously 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.

<u>Science Questions:</u>

- *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?* Methods and

models will be developed and evaluated to support multi-scale management (e.g., community to national to global) 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 will also 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?* Methods, models, and data will be developed that will enable the assessment of life-cycle impacts of energy systems (traditional and alternative) on air pollution and climate change, including 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, such as biofuels for transportation, including 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?* 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, technologies that provide real-time, continuous source and ambient data with portable designs will improve implementation and enable fair, accurate and responsive assessments of reported violations of air pollution emissions. Analytical and data management tools will also be developed, which will enable the effectiveness of air pollution reduction strategies to be evaluated at the local, regional, and national levels on an on-going basis.

- *What are the most efficient integrated, sustainable pollution reduction and prevention solutions?* 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 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 National Ambient Air Quality Standards (NAAQS)?* 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.

Research 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.

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 is also 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, but also 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 most vulnerable to (i.e., least able to cope with) the adverse effects of climate change will allow for more targeted adaptation approaches.[c] 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.

<u>Science Questions:</u>

- *What are the most effective alternative adaptation strategies, focusing on the most vulnerable individuals, communities, and ecosystems?* Policy makers need to understand what populations and ecosystems face the greatest risks in order to most effectively target available resources. Research efforts will develop methods and tools to improve 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 will also develop approaches to support adaptation risk management to enable decision makers to identify priority adaptation actions and anticipate

[c] The National Research Council has defined vulnerability as, "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." [National Research Council (2010). *Advancing the Science of Climate Change*. Washington, DC, National Academies Press.]

other related, perhaps less obvious co- or disbenefits. 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, increasing the demand for electricity and leading to greater emissions on days that tend to have the greatest potential for high ground-level ozone concentrations and at times 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 in order 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?* 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 adaptation strategies. EPA already utilizes communication technology (e.g., Enviroflash and the UV Index App) to provide individuals with information to allow 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 and subsequently human health impacts of air pollution and climate change will be assessed. Geographic information systems (GIS) can provide easily understood visualizations of the scope and type of impacts and the potential for adaptation strategies or the development of data, such as information on urban planning, to allow for informed decision making to limit adverse impacts attributed to climate change and reduce exposures to air pollution, respectively. As technology continues to evolve, other innovative approaches for adaptation will be developed and evaluated.

- *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?* 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 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.

IV. ACE Research Projects, Outputs, and Outcomes

This framework for ORD's ACE research program provides the rationale for developing this new research program and broadly defines major research issues related to air pollution, climate change, and the environmental impacts of energy options. This document has been informed by the policy-relevant science needs of EPA partners and stakeholders and will guide the development of a Research Action Plan (RAP), which will define in more detail the research that ORD will conduct over the next five years in the ACE research program. The ACE RAP will include the research projects and associated outputs and outcomes of the research program.

This framework provided the foundation for the identification of specific outputs by the ACE partners. To facilitate discussions among ORD scientists, the identified partner outputs were categorized into the following research topic areas: Energy, Climate Mitigation/Adaptation, Climate-Air Quality Interactions, Emissions/Measurements, Modeling/Decision Support Tools, Multipollutant, NAAQS, and Sustainable Solutions. Appendix A of this framework contains tables for each ACE theme that contain the partner identified outputs and the associated science questions. In addition, these tables also include anticipated outcomes from the delivery of the outputs and the associated research topic(s) for each output. This framework and the tables in appendix A will be used to develop the projects that will form the ACE RAP.

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Appendix A

ACE Outputs and Outcomes by Theme and Science Question (see attached)

Appendix A - ACE Theme 1: Assess Impacts

Science Question	Topic Area	Output	Outcome	Areas of Integration (within ACE and across ORD)
What are the multipollutant exposures and effects and integrated impacts of climate change on air and water quality and human and ecosystem health?	Climate Adaptation and Mitigation and Climate Air Quality Interactions	Characterize and communicate the environmental and public health impacts of climate change and benefits of avoided climate change impacts and GHG reductions strategies	Future Agency decisions and products that directly or indirectly related to climate-change incorporate knowledge of multimedia impacts and the associated effects on humans and ecosystems.	Theme 2, SSW, SHC
	Climate Adaptation and Mitigation	Characterize impacts across media from adaptation approaches, such as measures to ensure adequate water supply and the cross-media effects on energy demands and air pollutant emissions		Theme 3, SSW, SHC
	Climate Air Quality Interactions	Characterize relationships between air quality, climate, and adverse health effects		
	Multipollutant	Increased understanding of the linkages between sources of air pollution (outdoors and indoors), ambient concentrations, exposures, and effects, particularly for 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.	Susceptibility, HHRA
	Multipollutant	"True" multipollutant effects/impacts (single pollutants acting in combination).		HHRA
	Multipollutant	Improved understanding of multipollutant exposure (especially to highly exposed subgroups, e.g. near roads and facilities).		Susceptibility, HHRA
	Multipollutant	Source composition effects and impacts (source to outcome, urban/rural).		HHRA
	Energy	Health and environmental impacts of the evolving mobile source/transport sector		HHRA
What innovative approaches are needed to enhance the assessment of human and environmental exposures and effects of pollutants in the atmosphere?	Climate Adaptation and Mitigation	Methods and data to assess climate change impacts at different spatial (global, regional and local) and temporal scales.	Data is available for the Agency to adequately assess climate impacts and inform future climate decisions.	Theme 3, SHC
	Emissions/ Measurements	Monitoring methods to support NAAQS Development	Development of more cost-efficient approaches to monitor criteria air pollutants for health and ecosystem studies to support future NAAQS.	
	Modeling-Decision Support Tools	Improve the interoperability/linkages of multimedia/multistressor models.	The Agency has an integrated modeling system to assess multimedia interactions and impacts.	Theme 2, SSW, SHC
	Modeling-Decision Support Tools	National scale comprehensive One-Environment modeling system		Theme 2, SSW, SHC
	Modeling-Decision Support Tools	Tools to evaluate exceptional events, especially fires		
What are the characteristics of populations and ecosystems that are susceptible to effects from exposure to air pollutants and climate change impacts?	NAAQS	Exposures/Effects on Susceptible Populations	Future NAAQS reviews incorporate enhanced information on exposure and effects on susceptible populations.	HHRA

Appendix A - ACE Theme 1: Assess Impacts

Science Question	Topic Area	Output	Outcome	Areas of Integration (within ACE and across ORD)
What are the key uncertainties and data gaps that need to be addressed to inform review of National Ambient Air Quality Standards (NAAQS)?	NAAQS	Disentangling single pollutant effects/impacts from multipollutant exposures.	Multidiscipline exposure and health data are continually updated in a manner amenable to ready review and incorporation into more refined exposure-health assessment activities which clarifiy uncertainties associated with human and ecosystem exposures and subsequent effects attributed to criteria air pollutants.	Multipollutant, HHRA
	NAAQS	Human and ecological impacts of Nitrogen/Ammonia.		HHRA
	NAAQS	Identify the exposure uncertainty associated with the NAAQS as it applies to "true" human exposures.		HHRA
	NAAQS	PM composition and relationship to toxicity across size spectrum (ultrafine to coarse).		HHRA
	NAAQS	Deposition modeling to understand impacts of PM.		HHRA

Appendix A - ACE Theme 2: Prevent and Reduce Emissions

Science Question	Topic Area	Output	Outcome	Areas of Integration (within ACE and across ORD)
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?	Climate Adaptation and Mitigation and Climate Air Quality Interactions	Analyze net impacts (climate and air quality) of potential policy decisions including those to control both climate-forcing pollutants and traditional air pollutants	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.	Theme 1, SHC
	Climate Air Quality Interactions	Characterize the impacts of short-lived climate forcers (e.g., black carbon) to inform effective air quality and climate policies		Theme 1
	Emissions/ Measurements	Address important gaps in emissions inventories for major sectors (e.g., transportation)	Improvement and expansion of emissions inventories to support future air quality policies.	Theme 1
	Emissions/ Measurements	Emissions projection methods and models (economic, technology, and spatial projections).		Theme 1
	Emissions/ Measurements	Systematic process for identifying, prioritizing, and filling emission inventory gaps.		Theme 1
	Energy	Continued development of emissions profiles for biofuels/biomass		Theme 1
	Energy	Develop or improve existing models to assess GHG and criteria air pollutant benefits of State Energy Programs.	Agency has models and tools to compare and predict the impacts of energy alternatives and effeciency programs.	Theme 1
	Multipollutant	Tools to assess multipollutant impacts of energy sources and technologies (existing and emerging).		Theme 1, SSW, SHC
	Climate Adaptation and Mitigation	Strengthen the evaluation of climate impacts of ozone-depleting substitutes to support the development of effective policies for both climate change and ozone depletion	Agency decisions relating to climate-change and/or ozone depletion incorporate an understanding of trade-offs and synergies.	Theme 1
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?	Energy	Lifecycle/systems analyses of multimedia impacts of energy and mineral extraction and injection processes	The Agency has tools and analyses to identify the full cost of alternative energy options, including the systematic evalutaion of multimedia impacts and potential trade-offs between environmental, social, and economic objectives.	Theme 1, SSW, SHC
	Energy	Life cycle environmental and health impacts from increased use of biomass/biofuels.		Theme 1, SSW, SHC
	Energy	Peer reviewed assessments of multi-media impacts of emerging technologies.		Theme 1, SSW, SHC
	Emissions/ Measurements	Ambient monitoring methods for key pollutants (e.g., ammonia, acrolein)	New methods are incorporated into	Theme 1

Appendix A - ACE Theme 2: Prevent and Reduce Emissions

Science Question	Topic Area	Output	Outcome	Areas of Integration (within ACE and across ORD)
What innovative technologies are needed to support the implementation of management strategies to prevent and reduce air pollution?	Emissions/ Measurements	Remote Sensing for ambient, fugitive, and fence line (solar occulation, DIAL, differential absorption LIDAR).	New methods are incorporated into monitoring networks and compliance monitoring activities to enhance available information and / or to reduce monitoring costs.	Theme 1
	Modeling-Decision Support Tools	Improved air quality modeling tools		Theme 1
What are the most efficient integrated, sustainable pollution reduction and prevention solutions?	Energy	Development of tools for state and local governments to deal with a changing climate and energy options and their impacts on air and water quality.	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 .	Theme 3, SSW, SHC
	Energy	Identify clean energy technologies and changes to traditional energy production technologies that may affect adaptation.		Theme 3
	Energy	Evaluation of emerging technologies to meet water regulations using less energy.		SSW
	Energy and Climate Adaptation and Mitigation	Tools and data to assess and characterize the effectiveness and costs and benefits of emerging technologies that mitigate climate change impacts (e.g., energy efficiency measures, carbon capture and sequestration [CCS] technologies)		Theme 1
	Sustainable Solutions	Evaluation of Sustainable Materials Management Practices	The benefits of sustainable materials management practices are clearly understood and communicated.	SHC, SSW
	Multipollutant	Develop/evaluate emerging control techniques, particularly those with cross-pollutant control effects (e.g., criteria pollutants, hazardous air pollutants, and greenhouse gases).	Development of cost-effective approaches to prevent and reduce multipollutant exposures to support future air quality management strategies.	
	Multipollutant	Innovative and cost effective multipollutant measures and approaches.		
What methods and tools need to be developed to support implementation of National Ambient Air Quality Standards (NAAQS)?	Emissions/ Measurements	Monitoring methods to support NAAQS Implementation	NAAQS compliance monitoring networks use state of the science measurement methods.	Innovative Technologies

Appendix A - ACE Theme 3: Respond to Changes

Science Question	Topic Area	Output	Outcome	Areas of Integration (within ACE and across ORD)
What are the most effective alternative adaptation strategies, focusing on the most vulnerable individuals, communities, and ecosystems?	Climate Adaptation and Mitigation	Approaches to characterize and manage uncertainty, variability, knowledge gaps, and societal responses to or associated with technologies and approaches that address mitigation of emissions associated with climatic changes (including biofuels and CCS)	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.	Theme 2, SHC
	Climate Adaptation and Mitigation	Tools to identify and evaluate options/technologies to mitigate and adapt to climate change, including their environmental and socioeconomic interactions and impacts (to avoid unintended consequences and to design better policy options)		Theme 1 , Theme 2, SHC
What innovative methods are needed to inform individual- and community- level adaptation to climate chance and decision making regarding air quality?	Sustainable Solutions	Indicators: o New indicators that may be more directly linked to health and welfare effects of PM. o Standardized measures/metrics of climate impacts o Measures and metrics to measure the effectiveness of adaptation policies o Expansion of the AQI to include other pollutants besides O3 and PM	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 .	Theme 1, SHC
	Climate Adaptation and Mitigation	Development of methods, metrics and tools to measure the impacts and effectiveness of adaptation policies		Theme 1, SHC
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?	Sustainable Solutions	Behavioral/Social aspects to support implementation/adoption of sustainable solutions.	The Agency is more effective in communicating and implementing programs to promote sustainable solutions.	SHC
	Sustainable Solutions	Evaluation, Education, and Communication of Sustainable Technologies		SHC
	Climate Adaptation and Mitigation	Understanding decision making processes and behavioral/cultural changes and responses to adaptation policy initiatives		SHC