The Future of Atmospheric Chemistry Research

The composition of Earth's atmosphere has changed dramatically as a growing global population continues to increase energy use, expand industrial activities, and intensify agricultural activities. Emissions from these and other activities have led to many serious problems, including poor air quality in urban areas ("smog"), acid deposition ("acid rain"), stratospheric ozone depletion (including the Antarctic "ozone hole"), and climate changes resulting from increasing greenhouse gases.

The field of atmospheric chemistry came into its own during the 20th century as researchers responded to those problems. Scientists had to determine what was happening in the atmosphere, identify what was driving it, and develop a sufficient understanding to inform policy choices. Many of those research efforts have been great success stories, leading to both significant improvements in environmental conditions (see Box 1, next page) and to a rapid maturation of the science of atmospheric chemistry.

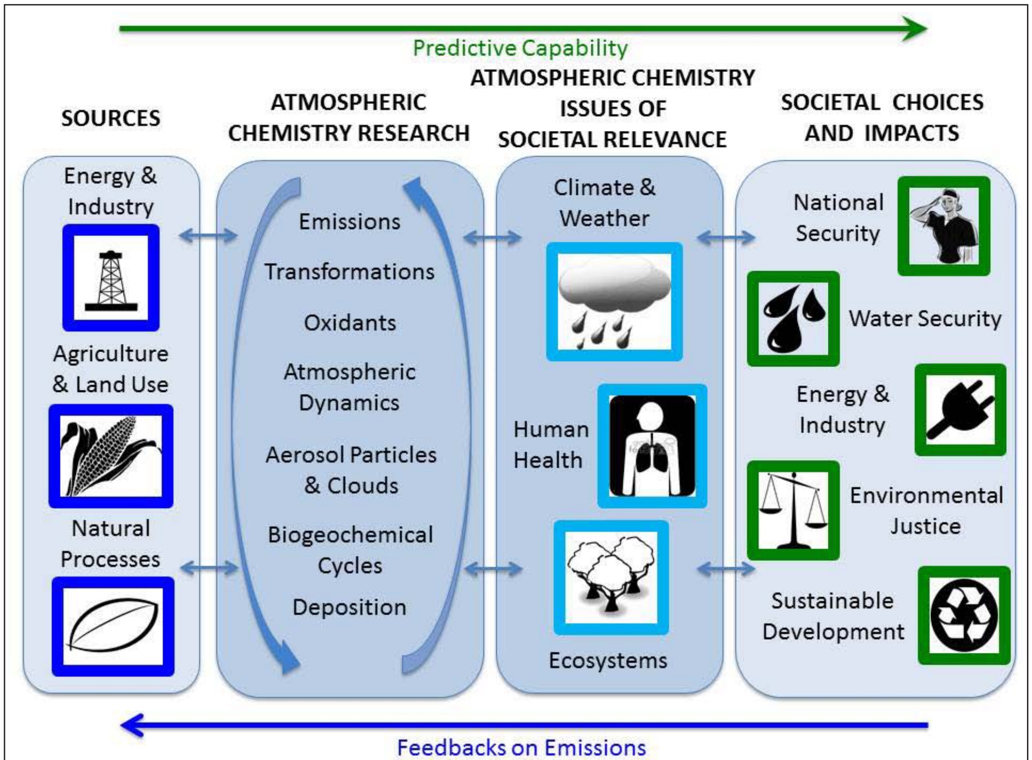

Figure 1. *Schematic showing the connections among major emission sources to the atmosphere, atmospheric chemistry research, scientific issues of societal relevance, and subsequent societal choices and impact areas. Research in atmospheric chemistry helps to build a predictive capability for future environmental conditions that can indicate likely impacts to society of various policy choices.*

Nonetheless, significant challenges related to the evolving atmospheric composition persist. Climate change is one of the greatest environmental challenges facing society today. Air pollution remains a major threat to human health, causing one out of eight deaths globally. In turn, global change and air pollution pose a threat to future food production and global food security, among many other impacts.

A major goal for atmospheric chemistry research is to anticipate and prepare for current and emerging challenges rather than just reacting to them after they occur. With an enhanced predictive capability that foresees environmental changes and societal impacts, society can make better decisions in a number of realms (see Figure 1). This report, which was carried out at the request of the National Science Foundation

(NSF), identifies priorities and strategic steps forward for atmospheric chemistry research for the next decade.

RECOMMENDED SCIENTIFIC PRIORITIES FOR ATMOSPHERIC CHEMISTRY RESEARCH

The Committee sought advice from the U.S. atmospheric chemistry community through a series of Town Hall meetings and online. The Committee identified five Priority Science Areas for atmospheric chemistry research over the next decade; the first two are necessary for building the foundation of atmospheric chemistry, and the other three, which are closely intertwined with the first two, directly address major challenges facing society.

Priority Science Areas

On the basis of input from the scientific community, the Committee identified the five following Priority Science Areas in atmospheric chemistry research.

1. **Advance the fundamental atmospheric chemistry knowledge that enables predictive capability for the distribution, reactions, and lifetimes of gases and particles.** While some predictions can be made with confidence using current understanding, important gaps and inconsistencies remain.
2. **Quantify emissions and removal of gases and particles in a changing Earth system.** Research is needed to reduce uncertainties in emissions for known sources and constrain emissions of poorly understood constituents, as well as to understand deposition processes that remove reactive species.
3. **Advance the integration of atmospheric chemistry within weather and climate models to improve forecasting in a changing Earth system.** Aerosol particles play a critical role through their influence on the growth, formation, and development of clouds and precipitation. In global climate models, the effects of atmospheric aerosol concentrations on radiation and the distribution and radiative properties of clouds are the most uncertain components of overall global radiative forcing.
4. **Understand the sources and atmospheric processes controlling the species most deleterious to human health.** Advanced atmospheric chemistry research techniques (e.g., models, analytical methods, and instrumentation) are necessary to understand the identities, sources, and fates of the air pollutants that negatively affect human health.
5. **Understand the feedbacks between atmospheric chemistry and the biogeochemistry of natural and managed ecosystems.** Biogeochemical cycles control the elements that are necessary to support the functioning and biodiversity of life on Earth (including humans). Goals include understanding the cycling of elements through the various components of the Earth system and the impacts of deposition of atmospheric nutrients and contaminants to natural and managed ecosystems.

Box 1. Success Stories in Atmospheric Chemistry Research

Urban Smog

Air pollution had been recognized as a problem in cities for hundreds of years, but by the mid-19th century it became much more visible and pervasive. In the 1950s, chemists determined the pollutants—many of them from vehicle emissions—and photochemical processes that were major contributors to a new kind of air pollution comprised of particulate matter and ozone (O_3) in the lower atmosphere. This "urban smog" has been demonstrated to have adverse health effects and cause damage to agricultural crops. Understanding the emissions and chemical transformations of precursor gases to urban smog has been instrumental in driving regulations to improve air quality, including the Air Pollution Control Act and the Clean Air Act, which, with subsequent amendments have significantly improved air quality and reduced adverse effects over the past 50 years.

Acid Rain

The combustion of fossil fuels emits nitrogen oxides (NO_x) and sulfur dioxide (SO_2), which are converted in the atmosphere into nitric and sulfuric acids that lead to higher acidity rainfall (known as "acid rain"). In the 1960s, biologists and limnologists conducted large-scale experiments linking acid rain to crop damage, "dead" lakes, damaged forests, and other effects, bringing the problem of acid rain to public attention in the United States. This work resulted in the 1980 Acid Deposition Act. Research on potential pollution control measures resulted in amendments to the Clean Air Act and supporting legislation. These actions led to significant decreases in the acidity of precipitation over the eastern United States. Lessons learned in the United States can be applied to areas in the world where emissions have increased dramatically in recent years, particularly in the developing world where poor air quality remains an issue.

The Ozone Hole

Laboratory studies in the mid-1970s were central in identifying chlorofluorocarbons (CFCs) and oxides of nitrogen as a major cause of depletion of stratospheric O_3, which helps shield Earth from harmful ultraviolet rays. The research predicted the environmental consequences of continuing "business as usual", and formed the basis for the 1978 U.S. ban on the use of CFCs in spray cans. In the mid-1980s, a combination of laboratory studies, theory, models, and field observations determined that CFCs had led unequivocally to the formation of the Antarctic ozone hole, which led to the 1987 international agreement known as the Montreal Protocol. The ozone hole is now healing.

SUPPORTING PROGRAMMATIC AND INFRASTRUCTURE PRIORITIES FOR ADVANCING ATMOSPHERIC CHEMISTRY RESEARCH

The Committee made programmatic and logistical recommendations, which are primarily directed to the NSF Atmospheric Chemistry Program, to help support research for the next decade to enable the Priority Science Areas above.

Development of Tools for Atmospheric Chemistry Research

New analytical techniques, instruments, and instrument platforms are needed to support the Priority Science Areas above. Existing NSF programs have produced valuable breakthrough technologies, but there are generally few opportunities for high-risk, high-reward proposals for instrument development in atmospheric chemistry at NSF. A diversity of modeling approaches is also needed to develop a broad toolbox to understand the complex problems in atmospheric chemistry.

Recommendation 1: NSF should ensure adequate support for the development of the tools necessary to accomplish the scientific goals for the atmospheric chemistry community, including the development of new laboratory and analytical instrumentation, measurement platforms, and modeling capabilities.

Information Collection, Analysis, and Archiving in the Era of "Big Data"

The collection of measurement data over long periods of time allows the discernment of trends that are not apparent in one-time field projects, but research at long-term field sites representing different environments is not adequately supported in the United States.

Recommendation 2: NSF should take the lead in coordinating with other agencies to identify the scientific need for long-term measurements and to establish synergies with existing sites that could provide core support for long-term atmospheric chemistry measurements, including biosphere-atmosphere exchange of trace gases and aerosol particle

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Answers to research questions are often apparent only after intensive data analysis, however funding is often insufficient to mine field data deeply for thorough analysis or to re-analyze existing datasets. Longer grant periods or supplemental installments to afford principal investigators the time and effort to continue analyses may be needed to accomplish these efforts.

Recommendation 3: NSF should encourage mining and integration of measurements and model results that can merge and exploit past datasets to provide insight into atmospheric processes, as well as guide planning for future studies.

Management of large volumes of "big data" is becoming ubiquitous in atmospheric chemistry research as vast and multidimensional datasets are continuously generated, requiring increasingly large resources to manage. Mechanisms are needed for effectively and efficiently archiving, sharing, and mining data, including making them easily available to the broad scientific community and to the public.

Recommendation 4: NSF should establish a data archiving system for NSF-supported atmospheric chemistry research and take the lead in coordinating with other federal and possibly state agencies to create a comprehensive, compatible, and accessible data archive system.

Imperative for Collaborations

Understanding and addressing challenges faced by society will rely on close integration of knowledge from multiple disciplines, including the physical, biological, and social sciences and engineering. While there are examples within NSF of programs that encourage interdisciplinary work, the Committee is concerned that mechanisms to support interdisciplinary work may encounter barriers due to NSF institutional and review structures.

Recommendation 5: NSF should improve opportunities that encourage interdisciplinary work in atmospheric chemistry and facilitate integration of expertise across disciplines and across academia, institutes, government, and industry. This improvement may include support of focused teams and virtual or physical centers of sizes appropriate to the problem at hand.

Although emissions have been reduced and air quality improved in the United States, many individuals are still living with dangerously high pollutant levels that impact their society and health. Working with underrepresented groups within the United States, building capacity (expert human capacity and observational and modeling capability) within the developing world, and collaborating with the international community are important for developing a global understanding of atmospheric chemistry and its impacts on human activities.

Recommendation 6: NSF, in coordination with other agencies, should continue to encourage and support U.S. scientists involved in atmospheric chemistry research to engage with underserved groups, in capacity building activities, and in international collaborations.

Role of a National Center

A national center can be an optimal approach for providing needed observational and computational capabilities for atmospheric chemistry. The National Center for Atmospheric Research (NCAR) was established as a federally funded national center dedicated to achieving excellence in atmospheric science research, and atmospheric chemistry research occurs within many divisions of NCAR. However, many on the Committee have observed that NCAR's atmospheric chemistry capabilities have diminished in the past decade or so. At the same time, NCAR has been pushed to provide instruments, measurements, and models for numerous atmospheric chemistry projects. The Committee believes that it is essential for NCAR to find its unique role in atmospheric chemistry research, complementing and enhancing research by the broader community, and engaging scientists from universities, federal labs, and the private sector.

Recommendation 7: NCAR, in conjunction with NSF, should develop and implement a strategy to make NCAR a vibrant and complementary partner with the atmospheric chemistry community. This strategy should ensure that scientific leadership at NCAR has the latitude to set an energizing vision with appropriate personnel, infrastructure, and allocation of resources; and that the research capabilities and facilities at NCAR serve a unique and essential role to the NSF atmospheric chemistry community.

The Committee sees a deliberate shift in the field of atmospheric chemistry to fully embrace its dual role—observing, learning, and discovering for the sake of fundamentally understanding the Earth system, while also making major contributions to addressing challenges that directly affect society. Although atmospheric chemistry research alone will not solve the challenges of global climate change and air pollution, those challenges cannot be solved without it. After conversations with many members of our community during the course of this study, the Committee is convinced that the community is ready for these challenges.

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