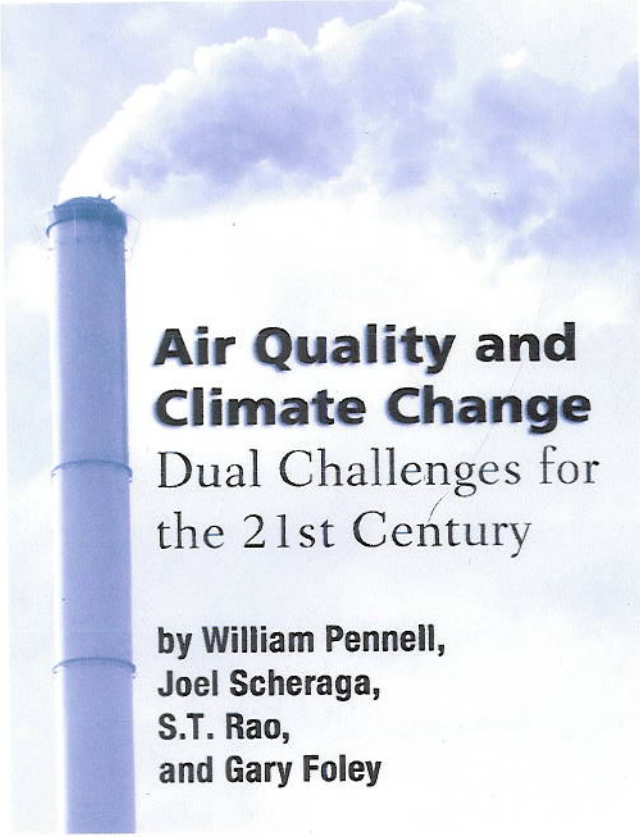

Air Quality and Climate Change
Dual Challenges for the 21st Century

by William Pennell, Joel Scheraga, S.T. Rao, and Gary Foley

For more than 50 years, air quality scientists, engineers, and policy-makers have faced the challenge of understanding the effects of manmade pollutant emissions on air quality. The manifestations of these effects are well known: increases above natural background levels of a variety of pollutants, which, in turn, lead to increased mortality and morbidity in certain exposed populations, adverse impacts on ecosystems, and reduced atmospheric visibility. More recently, a new environmental concern has been receiving increased scientific and political attention: the fact that human activities over the past two centuries have begun to affect the Earth's climate and that these activities have the potential for seriously disrupting the Earth's climate system in the future. These potential changes in climate are of concern because they could have significant consequences for human health, ecosystems, economic activity, and social well-being.

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The possibility that humans could affect climate was recognized more than 100 years ago by Swedish physicist Svante Arrhenius. In the latter part of the 19th Century, Arrhenius considered what effect the burning of fossil fuels might have on regional and global temperatures. He constructed the first climate model of the Earth and, in 1896, predicted that doubling the atmospheric concentrations of carbon dioxide (CO_2) would raise the average global temperature by approximately 5 °C.[1] At the time, this effect was seen as occurring sometime in the distant future. Today, this "distant future" is drawing uncomfortably near.

The Earth's climate has changed over the past 150 years, and this change can be explained only if we account for the effect that human activities have had on the Earth's energy budget. The Earth's climate state is driven by the difference between incoming solar radiation and the fraction of this energy that is reflected or emitted back to space. When these energy fluxes are equal, the Earth is in a state of thermal equilibrium and climate, aside from natural internal variability, will be stable. If this equilibrium is disrupted—as by introducing large quantities of gases or particles that affect the radiative properties of the atmosphere—the Earth will warm or cool until equilibrium is reestablished. CO_2, for example, warms the atmosphere because it is a strong absorber in the infrared. It is also long-lived with an atmospheric residence time on the order of centuries.

Climate will continue to change as the concentrations of greenhouse gases (GHGs) and particles in the atmosphere vary, although the exact magnitude and rate of this change is uncertain. As an example of how human activities have affected the atmosphere, atmospheric concentrations of CO_2, the most significant long-lived GHG, increased from approximately 280 parts per million (ppm) before the Industrial Revolution to 377 ppm in 2004.[2,3] By the end of this century, CO_2 concentrations could range from 450 ppm to greater than 750 ppm, depending upon future emissions.[4] Such increases in CO_2 concentrations could result in additional increases in a global mean surface temperature of 2–5 °C or more.[5]

Given this situation, there is mounting pressure for the implementation of CO_2 reduction strategies. However, there are still gaps in our understanding of the dynamics and thermodynamics of the atmosphere/ocean system and how it responds to anthropogenic pollution. These uncertainties, plus the cost and complexity of effecting significant reductions in GHG emissions, have made it difficult to implement meaningful and cost-effective strategies to address climate change.

SIMILARITIES/DIFFERENCES BETWEEN AIR QUALITY AND CLIMATE CHANGE

At the most basic level, the issues of air quality and human-induced climate change are different manifestations of the same driving force—modification of the chemical composition of the atmosphere due to human activities. As the magnitude of this modification has increased, the spatial scale of its effect has steadily grown from local to regional to global. As discussed in more detail in the articles that follow, there are a number of scientific and technical factors that link the issues of climate change and air quality and argue strongly for a "one atmosphere" approach to address them. Because of these commonalities, actions taken to reduce pollutants that affect air quality may affect emissions of GHGs, and vice versa, and suggest that an integrated policy that addresses air quality and climate change problems in concert may be more cost-effective, as well as more efficient in protecting human health and the environment.

Before we discuss these issues any further, it is important to note that there are at least three fundamental differences between the two issues:

1. Most of the emissions responsible for air quality problems result from process inefficiencies at the source or from fuel contaminants. Such emissions can be reduced or eliminated by implementing process improvements or control devices that treat emissions before they are released to the environment. In the case of climate change, however, the emission of the most important GHG, CO_2, is an inherent consequence of the combustion of fossil fuels. Dealing with CO_2 emissions, such as by capturing and sequestering them before they are released into the atmosphere, is a much more complicated and costly endeavor, and achieving the magnitude of emissions reductions needed to deal with climate change will have fundamental, transforming effects on the global energy system.[6]
2. Emissions responsible for most air quality-related problems have relatively short residence times in the atmosphere. Consequently, atmospheric response to emissions reduction programs should occur relatively rapidly (i.e., within years or, at most, decades). On the other hand, several GHGs have much longer residence times, as much as several centuries in the case of CO_2. These long residence times and the thermal inertia of the coupled ocean–atmosphere system mean a considerable delay between action (i.e., increased or decreased emissions) and response (i.e., more or less climate change). Today's emissions, therefore, are our legacy to future generations. This legacy means that future generations are committed to dealing with the climate consequences of our actions no matter what the resources, values, problems, or priorities of our descendants might be.
3. In the case of air quality management, there are often emissions levels below which there are no statistically significant impacts on human or ecosystem health. However, with respect to long-lived GHGs, any emissions that exceed the natural rates of removal will result in increases in atmospheric concentrations. Thus, stabilizing the atmospheric concentration of a long-lived GHG such as CO_2 requires that the net emissions from fossil-fuel sources must ultimately be reduced to zero. (Note: This is not to say that the use of fossil fuels must be eliminated. Fossil fuels can and will be used for the foreseeable future and can be part of a strategy for stabilizing CO_2 concentrations if there is a compensatory amount of CO_2 capture and permanent sequestration. Transition to zero net emissions can also take place over considerable time. Edmonds and Clarke,[7] for example, discuss various strategies for capping CO_2 concentrations at twice the pre-industrial value that have CO_2 emissions peaking in the late decades of this century and declining to zero over the next 100 years or so.)

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In spite of these differences, there remain strong scientific, economic, and policy reasons to forge a coordinated approach to addressing air quality and climate change. From a science perspective, the more significant intersections occur in the following areas:

- **Emissions**—Many emissions important to climate change have implications for air quality. Projecting long-term trends in these emissions is especially important, but challenging, given uncertainties about future rates of economic growth, energy use, and technological change. In fact, the technological changes that would be required to move to a world of zero net carbon emissions, and the changes in emissions that would result from introducing these technologies, could be the most important effect of a climate-stabilization policy on air quality.
- **Atmospheric Processes**—Many of the chemical and physical processes important for understanding air quality are important in climate change. For example, the formation and transformation of atmospheric particles is key to understanding and managing the problem of atmospheric

particulate matter; similarly, it is important in climate studies to understand how these particles might affect radiative energy transfer in the atmosphere. This commonality becomes even greater as one considers the climate and air quality effects of pollutant emissions on a local and regional scale.

- **Effects**—Since there are numerous process-level similarities in the physics and chemistry of climate change and air quality, it is not surprising that there should be connections in the effects. For example, changes in climate could affect air pollution meteorology, leading to changes in the frequency, duration, and intensity of poor air quality events. Also, increases in the concentrations of GHGs such as methane and water vapor have global implications for atmospheric chemistry, and consequently, air quality. Finally, changes in climate could affect the susceptibility of people and ecosystems to adverse effects from exposure to air pollutants.
- **Modeling and Simulation**—As interest in climate simulation becomes more focused on regional-scale changes and impacts, the interests and concerns of air quality and climate modelers increasingly converge. Although there are differences in the outcomes emphasized by the two modeling communities, there are also substantial opportunities for collaboration in improving the treatment of aerosol processes and effects in regional- to global-scale models.
- **Monitoring**—The issues of air quality management and climate change share a need for high-quality, long-term monitoring of atmospheric composition to document trends in key atmospheric constituents. The air quality and climate research communities have much to gain through cooperation in the design of new—and the continued operation and enhancement of old—networks and systems that can support the observational needs of both communities.
- **Policy Making**—The problems of managing air quality and climate change are coupled, and as mentioned above, actions taken to address one will have consequences for the other. Policy analyses are beginning to focus on the "co-benefits" of GHG mitigation policies and air quality management,[8,9] and research managers are beginning to coordinate research activities in the two fields to leverage limited resources. However, this thinking is not a common consideration in current day-to-day environmental policy or technology management decisions.

OBJECTIVES AND INSIGHTS

The following articles in this issue of *EM* provide an overview of current knowledge about the relationships between air quality and climate change, and they expand in more detail the observations we have highlighted here. Karl et al. (page 11) examine the observational and modeling evidence that the Earth's climate is changing and that human activities have been a significant source of this change. Hogrefe et al. (page 19) describe recent exploratory research into how climate change might affect future air quality. They find that climate change could influence a number of meteorological factors that affect air quality, ranging from the frequency and intensity of mid-latitude cyclones to changes in the frequency and strength of stagnation conditions. Climate change could also affect energy demand, which, in turn, would change emissions. In the third article, Jacob and Gilliland (page 24) provide a primer on how GHGs and aerosols affect climate, and they discuss how air quality management decisions might affect climate change on both the short and long terms. Keating et al. (page 28) discuss the effects of intercontinental transport on air quality. As emissions of both GHGs and pollutants that affect air quality grow in the developing world, and as climate change affects desertification and the frequency of wildfires, the frequency of episodic transport of pollutants and pollutant precursors will increase. Managing air quality will increasingly become an international problem requiring international cooperation. Cooter et al. (page 32) describe the effects of climate change on the Earth's hydrologic cycle and how these changes might affect air quality and air quality-related emissions. As an example of the complexity of these interactions, they describe how changes in temperature and mountain snowpack in the western United States could affect both the demand for energy and the options for meeting this demand. In the final article on this topic, Prinn and Dorling (page 37) discuss the policy implications of managing air quality and climate change, pointing out that managing air quality in a way that supports a climate-stabilization policy could be more difficult than we might think. **em**

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