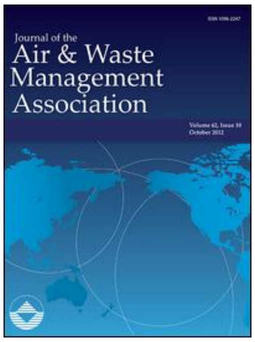

Journal of the Air & Waste Management Association

ISSN: 1096-2247 (Print) 2162-2906 (Online) Journal homepage: https://www.tandfonline.com/loi/uawm20

Multipollutant Air Quality Management

Judith C. Chow , John D. Bachmann , John D. Kinsman , Allan H. Legge , John G. Watson , George M. Hidy & William T. Pennell

To cite this article: Judith C. Chow , John D. Bachmann , John D. Kinsman , Allan H. Legge , John G. Watson , George M. Hidy & William T. Pennell (2010) Multipollutant Air Quality Management, Journal of the Air & Waste Management Association, 60:10, 1154-1164, DOI: 10.3155/1047-3289.60.10.1154

To link to this article: https://doi.org/10.3155/1047-3289.60.10.1154

2010 CRITICAL REVIEW DISCUSSION

ISSN:1047-3289 *J. Air & Waste Manage. Assoc.* **60**:1154–1164
DOI:10.3155/1047-3289.60.10.1154

Multipollutant Air Quality Management

Judith C. Chow
Desert Research Institute, Reno, NV

John D. Bachmann
Vision Air Consulting, Chapel Hill, NC

John D. Kinsman
Edison Electric Institute, Washington, DC

Allan H. Legge
Biosphere Solutions, Calgary, Alberta, Canada

John G. Watson
Desert Research Institute, Reno, NV

George M. Hidy
Envair/Aerochem, Placitas, NM

William T. Pennell
Columbia Research and Education Associates, Pasco, WA

INTRODUCTION

The 40th annual A&WMA critical review[1,2] by Hidy and Pennell provided a conceptual framework for multipollutant air quality management (AQM) and the assessment of accountability.[3] The critical review[1] summarized and elaborated on the NARSTO[4] integrated assessment[5] dealing with the same topics, proposing that a multipollutant risk analysis methodology be developed that would relate multiple concentrations to multiple effects, with a primary emphasis on adverse health effects. Although straightforward in theory, the critical review[1] identified substantial deficiencies in current knowledge to fully implement such an approach. It noted the emphasis on criteria pollutants, at the expense of other hazardous air pollutants (HAPs),[6] in current AQM. It also recognized the limitations of current monitoring networks, which focus on compliance with criteria pollutant standards,[7,8] for determining exposures and relationships of these exposures with adverse effects.

This discussion was compiled from written submissions and presentation transcripts that were revised for conciseness and to minimize redundancy. Substantial deviations from the intent of a discussant are unintentional and can be addressed in a follow-up letter to the journal. Invited discussants are as follows:

- John D. Bachmann, Primary for Vision Air Consulting, where he advises on environmental policy issues. He was formerly Associate Director for Science/Policy and New Program Initiatives at the U.S. Environmental Protection Agency (EPA)'s Office of Air Quality Planning and Standards (OAQPS), where he worked since 1974 developing and applying the U.S. National Ambient Air Quality Standards (NAAQS) review process. He authored the 2007 critical review on AQM.[9]
- Mr. John D. Kinsman, Senior Director of Environment at the Edison Electric Institute, where he has been employed for more than 20 years. His work focuses on air quality regulation and legislation relevant to U.S. shareholder-owned electric companies.
- Dr. Allan H. Legge, President of Biosphere Solutions, where he provides leadership and consulting on air pollution effects on ecosystems. Before forming Biosphere Solutions in 1993, he was a Senior Research Scientist at the Kananaskis Center for Environmental Research at the University of Calgary and a Senior Research Officer in the Environmental Research and Engineering Department for the Alberta Research Council.
- Dr. John G. Watson, Research Professor at the Desert Research Institute (DRI), critical review committee member since 1982, and chair of the committee from 1993 to 1997. He authored the 2002 critical review on visibility[10] and served on peer review panels for the National Research Council (NRC)[11] and NARSTO assessments[5] that motivated the 2010 critical review.[1]

INVITED COMMENTS BY JOHN BACHMANN

The NARSTO assessment,[5] summarized by Hidy and Pennell,[1] was inspired by the landmark NRC[11] evaluation of AQM. This critical review[1] provides useful "one-stop shopping" for readers interested in key findings on this important subject, as well as those who want to access the full text and references in the 13-chapter NARSTO assessment.[5] Because the NARSTO assessment[5] was constrained to certain scientific and technical aspects by its sponsors, however, it and the critical review[1] provide insufficient discussion or evaluation of efforts by policy-makers to recognize and address multipollutant challenges in implementing AQM policies.

Hidy and Pennell's[1] idealized goal is a system that would provide enough information to optimize air pollution control strategies, maximize risk reductions, and minimize costs, with the addition of effects-tracking that would show benefits and costs as they are realized. Such effectiveness and efficiency are conceptually desirable. In practice, however, costs in terms of equity, flexibility, simplicity, needed resources, legislation, and timing to deliver such a system may outweigh its benefits.

Hidy and Pennell's[1] concept is a logical extension of the current "risk-based" U.S. system,[9] which is driven by the NAAQS. As NRC[11] suggests, adopting a multipollutant perspective with greater emphasis on accountability could provide a useful paradigm for air-quality-related policy, regulation, legislation, and science. Based on the critical review's[1] assessment of current human exposure monitoring, atmospheric modeling, and risk assessment tools, however, full implementation of the recommended approaches is probably impossible in the foreseeable future. The critical review[1] would have been more helpful if it had proposed and examined more limited multipollutant and accountability approaches that provide some advantages in the near term. NRC[11] also noted that much of the current AQM system has been productive, some newer transitional policies could build on that success, and that the "ideal" approach is not possible in the near future.

In focusing on a more comprehensive *risk-based* regulatory paradigm, the critical review[1] could have examined the benefits of multipollutant *technology-based* programs. A clear example is the national tailpipe and fuel standards for mobile sources, which are based on multipollutant technologies that collectively reduce volatile organic compounds (VOCs), carbon monoxide (CO), oxides of nitrogen (NO_x), sulfur oxides (SO_x), lead (Pb), and particulate matter (PM; specifically PM ≤ 10 [PM_{10}] and ≤ 2.5 [$PM_{2.5}$] μm in aerodynamic diameter) from various classes of motor vehicles. Several of the important HAPs are included in the VOC and PM emissions. These rules are responsible for large emission reductions since 1970.[9] Other examples include New Source Performance Standards (NSPS) for large stationary sources, and the multipollutant legislative/regulatory initiatives to address multimedia effects of NO_x, SO_x, mercury (Hg), and PM from power generation.[12,13] NRC[11] recommended an expansion of these kinds of national, multistate, and multipollutant performance-oriented programs.

A subcommittee of the multistakeholder Clean Air Act Advisory Committee (CAAAC) produced reports[14,15] with a range of detailed to broad specific technical, procedural, and policy recommendations. Examples of the more policy-oriented recommendations include the following:

- Coordinate implementation of ozone (O_3) and PM standards.[14] NRC[11] and others agree that from a risk and implementation perspective, attainment of the O_3 and PM NAAQS represents one of the major long-term AQM challenges during the next 20 yr. The current $PM_{2.5}$ program is already stimulating multipollutant State Implementation Plans (SIPs). Combining strategies for O_3 precursors and PM creates opportunities for more efficient and effective multipollutant source programs. Unfortunately, EPA has not been able to implement this recommendation.
- Streamline the SIP process.[14] EPA has considered the opportunity for changing the relative importance of advanced modeling and air quality/emissions tracking in SIP development and implementation. Progress has not yet gone beyond developing some pilot projects.[16]
- Replace SIPs with a "Comprehensive AQM Plan" that includes multipollutant NAAQS and toxic air pollutant programs.[15] EPA is sponsoring three ongoing pilot programs (New York,[17] North Carolina,[18] and St. Louis MO/IL[19]) to examine the issues and challenges inherent in such an approach. The critical review[1] identifies a pilot project for optimizing O_3, PM, and some HAPs improvements using risk-based modeling for Detroit.[20]

This discussant has long agreed with increased emphasis on accountability or, as Hidy[21] once put it, "closing the circle" of AQM. However desirable an objective, the NARSTO assessment[5] and other work[22] indicate how difficult it is to measure health and environmental effects that result from modest year-to-year changes in air quality. Accordingly, "full" accountability measures are probably an unrealistic goal for individual AQM programs. The critical review,[1] however, notes a growing number of "intervention" studies with sufficient population and air quality changes to observe improvements in health and other environmental effects. Quick-response interim indicators are also needed that could signal the need for midcourse corrections to AQM programs.[14,15]

Some final thoughts and recommendations stimulated by the critical review[1] are:

- Multipollutant perspectives and accountability already have informed U.S. AQM technology-based programs on national, regional, and local scales. The critical review[1] could have elaborated more on how this can be done now.
- There is substantial information on the health risks of O_3 and PM from multipollutant mixture studies.[23–26] Improvements in risk management would require a priority to be placed on research concerning the relative contribution to risk from VOC and PM components.
- Some consideration should be given to how to

address environmental equity in a risk-based multipollutant paradigm. This is one of the key AQM challenges raised by the NRC.[11] The critical review[1] appears to equate maximizing risk reduction with the "body count" (population risk) and essentially ignores equity.

- EPA should expand consideration of climate effects of air pollutants that are short-lived climate forcers in implementing the O_3 and PM NAAQS.
- EPA should continue and expand multipollutant AQM pilot projects to promote innovative ways of specifying and coordinating NAAQS. EPA should evaluate and publish results of these programs.
- The Clean Air Act (CAA) of 1970 and its major amendments of 1990 pass 40- and 20-yr milestones in 2010. Within the next few years, pending multipollutant and/or climate legislation likely will prompt some reconsideration of the CAA. This would provide an opportunity for modest changes to authorize or facilitate improved multipollutant AQM approaches.

INVITED COMMENTS BY JOHN KINSMAN

Congress and EPA already are moving toward the critical review's[1] so-called Level 2 of multipollutant AQM (increased attention to co-benefits attainable with single pollutant attainment) via: (1) the linked Clean Air Interstate Rule (CAIR)–Clean Air Mercury Rule final rules of 2005,[27–41] (2) Senator Carper's proposed CAA Amendments of 2010, (3) EPA's just-proposed replacement Transport Rule for the overruled[41] CAIR plus its upcoming March 2011 HAP and NSPS proposals; and (4) EPA's upcoming 2012 joint NO_x-SO_x secondary NAAQS review.

There are many obstacles to fully implementing multipollutant AQM, however. EPA Assistant Administrator for Air and Radiation, Gina McCarthy,[42] stated that there are major gaps in research data—including how to better assess different mixtures of pollutants—that the EPA must fill before it can achieve a multipollutant approach to regulation. Among the major research gaps are: (1) lack of data on cumulative and synergistic interactions between pollutants, (2) toxicity of different pollutant mixtures, (3) the impact of pollutant mixtures on children, and (4) limitation of the national air pollutant monitoring network for human exposure.

The critical review[1] recognizes the many challenges for multipollutant AQM, including the following:

- Risk analysis is largely meaningless without advance knowledge about health and ecological risks and relative severity of response. This type of information is incomplete for listed single pollutants and virtually nonexistent for exposure to multipollutant mixtures. Accounting for antagonisms or synergisms in multipollutant responses is rare.
- Epidemiology challenges include access to health data; monitoring data for one or few sites representing the community as a whole; and distinguishing between indoor, outdoor, and personal exposure.
- Measurement advances are needed for VOCs, PM organic compounds, and HAPs such as trace metals, Hg, aromatic compounds, and aldehydes. Even then, it is difficult to impossible in practice to measure multipollutant mixtures with the spatial and temporal density required for detailed exposure characterization. Exposures are not well measured at the local or neighborhood level.
- Air quality model performance needs to be improved. Current models only can estimate concentration fields within a factor of two or more, depending on averaging times and species modeled.
- Remedying the most critical technical deficiency, understanding of human health and ecosystem effects arising from exposure to mixtures, would require an aggressive research program well beyond current research plans and funding levels.

Several additional comments are important to consider. First, the critical review[1] states that "The regulated community is principally concerned with simplifying the bureaucratic hierarchy of pollutant management and to create efficiencies in addressing current regulation." Regulated entities are equally or more concerned with the justification for some EPA decisions, such as those related to NAAQS setting and implementation, attainability, and costs. Industry groups are concerned with some EPA interpretations of health studies such as those related to the expected tightening of the O_3 and PM NAAQS scheduled for August 2010 and October 2011, respectively. More stringent standards will increase the number of nonattainment areas. Permitting of new sources given the new 1-hr nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) standards will become more difficult, especially considering air quality model uncertainties. Costs of compliance will increase; EPA estimates the year 2020 cost of compliance with a 60-parts per billion (ppb) O_3 standard at $90 billion (U.S.).[43]

Second, industry groups also would be concerned with the critical review's[1] suggestion that accountability analysis be used to correct or modify AQM actions. Once a facility puts controls on or modifies a process, it does not expect to make additional investments for the same purpose for some length of time. Adding controls and again modifying processes is inefficient, expensive, and disruptive.

Third, the critical review's[1] suggestion for grouping pollutant mixtures within common source types would be difficult for power plants and probably for other source types. Fossil-fuel power plants use different fuels, boilers, and pollution control technologies. The combination of these and other factors leads to a wide range of emission characteristics. The universe of these factors is constantly changing in the fleet as the long list of regulatory requirements is addressed.

Fourth, the critical review's[1] scope was constrained. A March 2010 resolution[44] by the Environmental Council of the States (ECOS),[45] a nonprofit, nonpartisan association of state and territorial environmental agency leaders, more properly defines the full scope of multipollutant AQM:

> . . . in pursuing a multipollutant strategy, the U.S. Congress, U.S. EPA, and the States should proceed in a manner that protects the public

> health and environment, promotes efficient expenditures of resources, provides adequate and reliable energy, is scientifically sound and technically feasible and minimizes government impediments to the achievement of these goals and cost savings while significantly reducing environmental impacts and providing industry with the ability to plan for the future.

Finally, the CAA has not been amended since 1990, and those amendments entailed a several-year battle. Unfortunately, there remain few lawmakers who went through that process, and there is concern about opening the floodgates. As stated in this and prior critical reviews and discussions,[9,10,21,46,47] the CAA's regulatory framework, administered by EPA and the federal land managers, is the result of more than 40 yr of statutory and case law and is embodied in the U.S. Code of Federal Regulations, supplemented by numerous state and local regulations.

There are many reasons to consider amending the CAA, including requiring multipollutant and risk-based AQM. Congress could advance research on pollutant mixtures, monitoring, modeling, etc. Health effect advances could include updated reviews of health impacts for individual HAPs. Implementation challenges related to the NAAQS, HAPs, and New Source Review (NSR)[48–51] could be addressed, as well as current and upcoming EPA regulations. Congress could create a more coordinated and efficient transition to the future—addressing the environment, energy and the economy—as ECOS[44] recommends.

The air quality regulatory burden, at least for the electric power sector, includes several new rules that generally will be dealt with separately: (1) the 1-hr NO_2 NAAQS (finalized February 2010): (2) the 1-hr SO_2 NAAQS (finalized June 2010): (3) the reconsidered 8-hr O_3 NAAQS (to be finalized August 2010): (4) the Transport Rule replacing CAIR (proposed August 2010 and to be finalized in late spring 2011): (5) the remanded PM NAAQS (to be finalized October 2011): (6) HAP regulations (to be finalized November 2011); and (7) NO_x, SO_2, and PM NSPS (to be finalized November 2011). These are in addition to water quality, greenhouse gas, coal combustion product (coal ash) disposal, and other regulations. It is unfortunate that multipollutant AQM will not play a major role in 2010–2012 EPA decision-making. Congressional action could be required to move forward in a sensible manner.

INVITED COMMENTS BY DR. ALLAN LEGGE

Hidy and Pennell[1] recognize that the current AQM frameworks in North America have become well established during the past 4 decades. Application of these frameworks, as they have evolved through time, has generally resulted in reduced emissions and air pollution plus a reduction in the effects of air pollution on people and some components of the environment.[1] Although the point is made that AQM using the single "criteria pollutant" approach has achieved results despite the inherent limitations,[9] the current North American NAAQS are primarily formulated for human health, with other effects relegated to the less binding status of "secondary standards."

The underlying premise of the critical review[1] is that multipollutant AQM can be achieved within the established AQM, subject to slight modifications made progressively through time with increased accountability and an enhanced risk analysis methodology. This premise is probably not valid. After 4 decades, current AQM, with its associated legislation and regulations, has become complex, convoluted, and cumbersome and has become operationalized and institutionalized. The net result is that the process of managing and regulating the legislation has become more important than the original reasons for the CAA.

An additional weakness is that multipollutant optimization is described in the critical review[1] only in the limited terms of effects on human health; token reference is given to the associated effects of elevated concentrations on other air-quality-related values such as climate,[52,53] visibility,[10,47] nuisances,[54] material damage,[55–58] and ecosystem degradation.[59–64] The net result is that much of the environment has been ignored. Although there is some mention of "co-benefits" in the critical review,[1] there is insufficient elaboration on how these can and should be assessed, although there is a growing literature on this topic.[65–68] As is suspected for human health,[69] it has been documented that the effects of multiple pollutant ecosystem exposures also can be "antagonistic" (less than additive) or "synergistic" (more than additive).[70] It may be that an antagonistic effect for one outcome (e.g., human health) may be synergistic for another outcome (e.g., climate or ecosystems).

AQM needs to be simplified rather than made more complicated. The underlying AQM paradigm is not "clean air," but "cleaner air." One simple concept is to define and characterize what is meant by clean air and then use that definition as the goal to be reached to protect all receptors. Clean air is represented by air that is essentially odorless, tasteless, looks clear, and has no measureable short- or long-term adverse effects on people, animals, and the environment.[71] The key is to simplify our thinking and our approach to AQM.

INVITED COMMENTS BY DR. JOHN WATSON

As noted by the previous discussants, the critical review[1] is a useful condensation of the NARSTO assessment[5] and a logical extension of the NRC[11] AQM evaluation. Important takeaway messages include: (1) the effects of different pollutants may not add linearly; (2) O_3 and PM strategies are implicitly multipollutant in terms of the precursors and common sources; (3) investments in emission reductions should manifest themselves as exposure and adverse health effects improvements, in addition to downward trends in measured emissions and ambient concentrations; (4) the current AQM approach has improved pollution levels, as indicated by long-term downward trends; and (5) greater benefits would accrue with more attention to multipollutant planning.

Despite making important points, none of these documents[1,5,11] has critically evaluated the feasibility and uncertainties of the risk assessment models upon which the risk-based strategy is based. These assessments do not sufficiently recognize the iterative process of current AQM that ensures eventual accountability by periodically reevaluating and revising pollutant standards and determining attainment or nonattainment through long-term ambient monitoring.[9,21,46] They neither elicit nor propose small, incremental steps that can be taken to move the AQM process more rapidly in the direction of multipollutants. Finally, these assessments seem to cherry-pick isolated examples, mostly from the experiences of the authors, rather than examine the weight of evidence that has accrued on this topic during the past 4 decades of systematic AQM. In particular, a large body of relevant knowledge has been published in the *Journal of the Air & Waste Management Association* and *EM* that will be cited in the comments below.

The confidence in risk assessment models is misplaced. As currently applied, risk models[72–87] estimate human exposure to a single pollutant through multiple pathways, including inhalation and ingestion. These exposures are multiplied by an excess risk factor (see Appendix A of the South Coast Air Quality Management District [SCAQMD][88] for a summary of these) that usually is expressed in incremental cancer onsets per $\mu g/m^3$ of inhalation exposure to the single pollutant. The Multiple Air Toxics Exposure Studies (MATES)[88,89] are the most carefully executed examples of such risk assessment modeling. MATES[88,89] has a multipollutant character in that diesel particulate matter (DPM), as indicated by elemental carbon (EC) measurements[90,91] applied to ambient $PM_{2.5}$ samples to estimate exposures, constitutes more than 80% of the excess risk. This probably represents many potential health-averse chemical compounds in carbonaceous aerosols.[92] Yet even these well-executed and costly studies recognize the limitations, uncertainties, and difficulties in estimating risks with current assessment technologies. In a companion review based on the NARSTO assessment,[5] Mauderly et al.[93] detail, again conceptually, the long-term research effort that would be needed to evaluate whether or not uncertainties might be reduced in future risk models. One might also ask, “What additional value is added by this risk analysis?” It is well known that diesels emit soot (as indicated by EC measurements), which contributes to PM, which is regulated by NAAQS and the Regional Haze Rule,[94] and that rules are in place to reduce these emissions from on-road and nonroad engines.[95,96] The critical review[1] could have examined the value of current risk assessments in other source sectors to evaluate what might be gained over current practice by using a risk-based strategy.

Past AQM shows many examples of multipollutant emission reduction strategies. Even for controls on single pollutants such as CO and Pb, the AQM strategy has been a multipollutant one. CO and Pb are primary emittants from known sources. They have directly detectable effects that are not affected by other pollutants, such as increased blood levels of carboxyhemoglobin[97,98] for CO and increased Pb serum levels for Pb.[99–101] CO is derived mostly from inefficient combustion of fossil fuels and biomass, whereas Pb contamination derives from mining, smelting, lead paint, and gasoline additives. Yet, the gasoline-engine catalytic converter[102–104] (the most effective measure for reducing emissions, concentrations, and biomarkers for these pollutants) was originally intended to reduce CO and VOC emissions, then eventually NO_x emissions. Gasoline-engine Pb reductions were a beneficial (and recognized) byproduct, eventually resulting in the phase-out of Pb additives that contaminated the catalyst and that some claim did not belong there in the first place.[105] There were substantial unintended benefits for PM, as evidenced by higher emission rates before the catalyst achieves its operating temperature.[106–114] Because CO and black carbon (BC) are often highly correlated in incomplete combustion exhaust,[115] there are probably some additional benefits that accrue to visibility and climate improvements.[10,116] Accountability was instituted in terms of engine emission certification standards as well as inspection and maintenance (I/M) testing. Flaws in the accountability measures were revealed by real-world emission testing (e.g., source-dominated studies using in-plume and cross-plume measurements in source-dominated environments such as roadsides, parking garages, tunnels, etc.).[117–127]

An example of AQM for multipollutants and multiple effects is the long-term regional strategy for health, visibility, and ecological benefits in the U.S. Midwest, U.S. Northeast, and Canadian southeast regions. The O_3 Transport Assessment Group (OTAG),[128] NO_x SIP call,[129–133] NSR[50,51,134,135] and its failure to reduce emissions from grandfathered power generators, the Regional Haze Rule,[10,47,94,136] and the CAIR and Clean Air Mercury Rules[12,134,137–142] all address multipollutants and in some cases required continuous emission monitors (CEMs) for accountability. A century ago there was recognition of the adverse effects of air pollution (e.g., deplorable daytime visibility in Pittsburgh and other cities, dense plumes belching from industrial smokestacks, people keeling over in Donora) that were directly attributable to inefficient coal combustion.[9,21,143–151] Use of cleaner coal, improved combustion conditions, switching to natural gas, and eventually effluent controls made a big difference on local concentrations, exposures, and very evident improvements in effects. After the implementation of local pollution controls, the effects of long-range transport on O_3 and secondary $PM_{2.5}$ sulfate were realized for ambient concentrations and deposition.[152–165] The series of region-wide emission reduction measures cited above resulted from periodic examinations of the source-receptor relationships during several decades and is still in progress. As noted in Hidy et al.,[5] there is a large body of evidence that further NO_x and SO_2 reductions will reduce O_3, $PM_{2.5}$, and acid deposition in the region.

There are many small, but meaningful, steps that can be taken in the direction of multipollutant AQM, some of which are scattered throughout, but not emphasized by, the assessments.[1,5,11] The following are three more:

- Develop and apply multipollutant source characterization methods that are more compatible with real-world emissions and ambient measurements. It makes no sense to climb the smokestack with 1950s-era glass impingers to separately measure NO_x, SO_2, PM_{10}, etc., as required by EPA's certification source testing methods.[166] It is time to replace these antiquated practices with a dilution system, similar to that used for mobile sources,[109,167–172] to which ambient sampling and analysis methods can be coupled.[173–177]

- Reformulate Federal Reference Method (FRM) and Federal Equivalent Method (FEM)[178] procedures to encourage development and deployment of multipollutant ambient measurement systems. The high cost of locating, permitting, and operating permanent monitoring shelters needed for current FRMs and FEMs mitigates against the need for measurements to assess exposures in microenvironments. Recent advances in miniature detectors[179–181] indicate the potential to obtain a wider range of chemical components with much lower cost than those currently involved in compliance monitoring.
- Require O_3 and $PM_{2.5}$ SIPs to evaluate the effects of emission reductions for one pollutant (e.g., NO_x reductions for O_3) on another related pollutant (e.g., NO_x reductions for $PM_{2.5}$ nitrate). A good example of this is the CAIR modeling[141] that demonstrated the benefits of extending summer NO_x controls to winter months to address the midwestern nitrate bulge.[182]

RESPONSE FROM DRS. GEORGE HIDY AND WILLIAM PENNELL

The critical review authors thank the discussants for their thoughtful comments on the critical review.[1,2] The authors generally agree with the points made by the discussants, although they reflect implicit definitions or concepts that differ from those used as the basis for the critical review.[1,2,5] These derive especially from the concepts of relative risk and accountability—seemingly there is no dispute about what multipollutant means, except perhaps the inability to integrate criteria pollutants with the extensive list of HAPs.

Neither the authors nor the NARSTO members are advocating a risk-based multipollutant approach to AQM. The purpose of the assessment[5] was to examine the technical feasibility of this approach. There are some definite advantages and improvements in regulatory efficiency that would result from coordinating AQM actions involving pollutants having common sources and air chemistry within the current framework of the CAA. Although such coordination is improving, there are inconsistencies within the standard setting and implementation framework for individual pollutants that show ambivalence toward multipollutant AQM, as recognized by Bachmann and Kinsman in their comments. There could be greater regulatory effort to address pollutant-coordinated management practice, but this goal may have to await future review of the CAA by Congress.

At this time, the authors agree that there is insufficient information and understanding to evaluate alternative AQM proposals involving multipollutants on the basis of relative risk reduction. Addressing relative risk will depend on substantial improvements in knowledge of human and ecosystem response to pollutant exposure. Conceptually, air quality risk-based decision-making could be a key element in priority setting for individual pollutants and mixtures. With respect to the capabilities and limitations of contemporary risk assessment models, their application will remain controversial as decision-making tools, especially if there is significant uncertainty in input data. However, this observation does not preclude their use in resource priority setting when based on best available knowledge of health or ecosystem stress and when differences in ambient concentrations and potency are considered as indices of relative risk among regulated pollutants. To some extent, this is done now with O_3 (as an indicator for oxidants) and PM mass (as an indicator of a combination of different chemicals).

The authors did not consider environmental equity in the analysis because "equity" is a socioeconomic and political issue that is beyond the scope of the assessment.[5] This issue is complex in terms of economic and other factors, but it is noted that epidemiologists have begun to examine this degree of freedom in the response of subpopulations to exposure gradients.[88]

With regard to a pathway toward multipollutant AQM, the authors again note the four-level transition from current practice to full implementation. This was intended as an intellectual construct for thinking about the problem, not as a prescriptive road map for implementation. Development of a practical road map was beyond the scope of the critical review[1] and NARSTO assessment.[5] In this respect, the comments from Bachmann and Kinsman have added important practical perspective, which provides some optimism for future multipollutant considerations, yet they indicate that the existing CAA "bureaucracy" and sociopolitical driving forces will be difficult to overturn in favor of advanced approaches. Perhaps these changes will be motivated by future technical innovations in measurement and assessment tools. An interesting example of a new tool for source-oriented PM toxicology has been proposed by Bein et al.[183] Rapid progress in complex spatial and multipollutant epidemiology and laboratory toxicology also holds promise.[5,88]

Legge notes in his comments the long-time concern that inadequate priority is given to the measurement and consideration of environmental stress and damage relative to human health effects. Although material damage and loss of ecological services are potentially important economic factors that are relegated as secondary drivers of risk, it is difficult to place a largely esthetic issue such as visibility impairment as more than a secondary factor, although the CAA directly addresses it. As a practical matter, the authors chose to limit their comments to human health issues in the critical review,[1] although considerable attention is given to ecological issues in the NARSTO assessment.[5] The NARSTO ecological review focused on the issues of response of natural systems to O_3, acid deposition, persistent organic pollutants, and metal interactions, particularly Hg. Canada has taken the lead in the regulatory protection of ecosystems through such measures as critical and target loads, whereas the United States has adopted emission reductions as the means for reducing ecosystem exposure. In Mexico, considerations of ecosystem stress are just emerging as part of their AQM.

As for managed ecosystems, including agriculture, the NARSTO co-chairs[5] were unable to find a coauthor to write about this important area. In the end, the critical review authors relied on the "old saw" that, in agriculture at least, one can manage stress or crop loss from pollutant exposure by plant hybridization to increase crop tolerance, or at worst by moving production of sensitive crops away from areas of elevated pollutant exposure. These measures of adaptation are an element often neglected in the portfolio of management options.

The critical review authors are surprised that the discussants chose not to comment on climate air quality interactions in any detail, although Bachmann makes this a point for future progress. Quite apart from the air quality issues, climate forcing in its own right is multipollutant in character. This is discussed briefly in the NARSTO assessment.[5] As an international problem linked with world energy strategies, the issue appears to be sidelined politically in the United States as of mid-2010. Alternatively, innovative multipollutant approaches to reducing climate forcing may come from looking at source-based risk reduction, as proposed by Unger et al.[184]

Finally, the critical review authors thank the discussants for their additional comments on the problem of accountability, recognizing the diversity of definitions imbedded in this issue, which are especially noted in Watson's comments. Achieving the definition[1,5] of complete accountability in the sense of tying specific AQM actions to specific improvements in public health indicators is probably unrealistic in most cases. However, the authors believe that it is possible to move farther down the accountability chain than is done today.

Foley et al.[185] examined accountability related to achievement of a then new O_3 standard. They considered completion of the accountability paradigm through changes in health effects but abandoned this part stating that it was impractical. Thus their accountability sequence terminated with some form of exposure estimate. Foley et al.[185] appeared a year before the NRC report,[11] but followed (without reference) the introduction of this paradigm earlier by Demerjian et al.[186] and NARSTO.[187]

ACKNOWLEDGMENTS

The authors thank Ms. Jo Gerrard and Mr. Roger Kreidberg of DRI, Reno, NV, for their assistance in assembling and editing the manuscript.

REFERENCES

1. Hidy, G.M.; Pennell, W.R. Multipollutant Air Quality Management: a Critical Review; *J. Air & Waste Manage. Assoc.* **2010**, *60*, 645-674; doi: 10.3155/1047-3289.60.6.645.
2. Pennell, W.R.; Hidy, G.M.; Multipollutant Air Quality Management: a Critical Review Summary; *EM* **2010**, *June*, 52-55.
3. Walton, J.; Alabaster, T.; Jones, K. Environmental Accountability: Who's Kidding Whom? *Environ. Manage.* **2000**, *26*, 515-526.
4. *NARSTO: Better Air Quality for North America*; NARSTO: Pasco, WA, 2010; available at *http://www.narsto.org* (accessed July 2010).
5. Hidy, G.M.; Brook, J.; Demerjian, K.; Molina, L.; Pennell, W.R.; Scheffe, R. *Technical Challenges of Multipollutant Air Quality Management*; Springer: New York, 2010.
6. McIver, A.; Mathai, C.V. The U.S. Clean Air Act and Hazardous Air Pollutants: An Introduction; *EM* **2009**, *September*, 3-5.
7. Scheffe, R.D.; Solomon, P.A.; Husar, R.B.; Hanley, T.; Schmidt, M.; Koerber, M.; Gilroy, M.; Hemby, J.; Watkins, N.; Papp, M.; Rice, J.; Tikvart, J.; Valentinetti, R. The National Ambient Air Monitoring Strategy: Rethinking the Role of National Networks; *J. Air & Waste Manage. Assoc.* **2009**, *59*, 579-590; doi: 10.3155/1047-3289.59.5.579.
8. Chow, J.C.; Watson, J.G. New Directions: Beyond Compliance Air Quality Measurements; *Atmos. Environ.* **2008**, *42*, 5166-5168; doi: 10.1016/j.atmosenv.2008.05.004.
9. Bachmann, J.D. Will the Circle Be Unbroken: A History of the U.S. National Ambient Air Quality Standards—2007 Critical Review; *J. Air & Waste Manage. Assoc.* **2007**, *57*, 652-697; doi: 10.3155/1047-3289.57.6.652.
10. Watson, J.G. Visibility: Science and Regulation—2002 Critical Review; *J. Air & Waste Manage. Assoc.* **2002**, *52*, 628-713.
11. *Air Quality Management in the United States*; National Research Council; National Academies: Washington, DC, 2004.
12. Rule to Reduce Interstate Transport of Fine Particulate Matter and Ozone (Clean Air Interstate Rule); Revisions to Acid Rain Program; Revisions to the NO_x SIP Call; Final Rule. *Fed. Regist.* **2005**, *70* (91), 25162-25405.
13. Mathai, C.V. Multipollutant Legislation for the Electric Power Generation Industry: an Update; *EM* **2003**, *April*, 18.
14. *AQM Work Group Recommendations: Phase I and Next Steps*; Prepared by Air Quality Management Work Group, Research Triangle Park, NC, for the U.S. Environmental Protection Agency; Clean Air Act Advisory Committee: Research Triangle Park, NC, 2005; available at *http://www.epa.gov/air/caaac/aqm/report1-17-05.pdf* (accessed July 2010).
15. *AQM Subcommittee Phase II Recommendations*; Prepared by Air Quality Management Subcommittee, Research Triangle Park, NC, for the U.S. Environmental Protection Agency; Clean Air Act Advisory Committee: Research Triangle Park, NC, 2007; available at *http://www.epa.gov/air/caaac/aqm/phase2finalrept2007.pdf* (accessed July 2010).
16. Page, S.; McLerran, D.J.; Sturdevant, T.; Nolan, J.L.; Dillon, H. Memorandum of Understanding between the U.S. Environmental Protection Agency Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency Region 10, State of Washington Department of Ecology, Puget Sound Clean Air Agency, and the Puyallup Tribe 2010; available at *http://www.pscleanair.org/announce/hearings/documents/100420MOUfinal_000.pdf* (accessed July 2010).
17. *A Conceptual Model for the Development of an Air Quality Management Plan for the State of New York*; Prepared by the Division of Air Resources, New York State Department of Environmental Conservation for the U.S. Environmental Protection Agency: Research Triangle Park, NC, 2009; available at *http://www.epa.gov/air/aqmp/pdfs/may2009/CMNewYork.pdf* (accessed July 2010).
18. *North Carolina's Air Quality Management Process (AQMP): Conceptual Model*; Prepared by the North Carolina Department of Environment and Natural Resources Division of Air Quality, Raleigh, NC, for the U.S. Environmental Protection Agency: Research Triangle Park, NC, 2009; available at *http://www.epa.gov/air/aqmp/pdfs/may2009/CMNorthCarolina.pdf* (accessed July 2010).
19. *St. Louis, Missouri, and Illinois Air Quality Management Process (AQMP) Conceptual Model*; U.S. Environmental Protection Agency: Research Triangle Park, NC, 2010; available at *http://www.epa.gov/air/aqmp/pdfs/may2009/CMStLouis.pdf* (accessed July 2010).
20. Wesson, K.; Fann, N.; Morris, M.; Fox, T.; Hibbell, B. Risk-Based Approach to Air Quality Management: Case Study for Detroit; *Atmos. Pollut. Res.*, submitted for publication.
21. Chow, J.C.; Watson, J.G.; Feldman, H.J.; Nolan, J.; Wallerstein, B.R.; Hidy, G.M.; Lioy, P.J.; McKee, H.C.; Mobley, J.D.; Bauges, K.; Bachmann, J.D. 2007 Critical Review Discussion—Will the Circle Be Unbroken: A History of the U.S. National Ambient Air Quality Standards (NAAQS); *J. Air & Waste Manage. Assoc.* **2007**, *57*, 1151-1163; doi: 10.3155/1047-3289.57.10.1151.
22. Assessing Health Impact of Air Quality Regulations: Concepts and Methods for Accountability Research; Health Effects Institute (HEI) Communication 11; HEI: Boston, MA, 2003.
23. *Air Quality Criteria for Ozone and Related Photochemical Oxidants: Volume I*; EPA 600/R-05/004aF; U.S. Environmental Protection Agency; Office of Research and Development: Research Triangle Park, NC, 2006.
24. *Air Quality Criteria for Ozone and Related Photochemical Oxidants: Volume II*; EPA 600/R-05/004bF; U.S. Environmental Protection Agency; Office of Research and Development: Research Triangle Park, NC, 2006.
25. Air Quality Criteria for Ozone and Related Photochemical Oxidants: Volume III; EPA 600/R-05/004cF; U.S. Environmental Protection Agency; Office of Research and Development: Research Triangle Park, NC, 2006.

26. *Integrated Science Assessment for Particulate Matter (Final Report)*; EPA/600/R-08/139F; U.S. Environmental Protection Agency: Washington, DC, 2009; available at *http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546* (accessed July 2010).
27. Weiss, D.; Kinsman, J. The CAIR Vacatur Raises Uncertainty in the Power Generation Industry; *EM* **2008**, *December*, 11-13.
28. Patton, V. The Important Quest to Protect Health and the Environment from Interstate Air Pollution; *EM* **2008**, *December*, 14-17.
29. Royden-Bloom, A. The CAIR Vacatur: A Dilemma for States; *EM* **2008**, *December*, 18.
30. Becker, W. State and Local Air Quality Regulators: STAPPA/ALAPCO's Perspectives on CAMR and CAIR; *EM* **2005**, *August*, 18-19.
31. Foerter, D. The Air Pollution Control Industry: EPA's Mercury Rule: With Technology Today, We Can Do Better; *EM* **2005**, *August*, 16-17.
32. Mathai, C.V. Introduction to Stakeholder Perspectives on the Clean Air Interstate and Clean Air Mercury Rules; *EM* **2005**, *August*, 6.
33. Jezouit, D.; Rambo, F. The Clean Air Interstate Rule; *EM* **2005**, *July*, 10-15.
34. Mathai, C.V. Introduction to the Topic: EPA's Mercury and Pollution Transport Rules; *EM* **2005**, *July*, 8.
35. Holmstead, J. U.S. Environmental Protection Agency: A Multipollutant Approach to Emissions Reductions; *EM* **2005**, *August*, 7-8.
36. McManus, J.; Boyd, S.; Sullivan, V.; Weiss, D.; Kinsman, J.D.; Lomax, S.; Rossler, M. The Utility Industry: Reactions to EPA's Clean Air Interstate and Clean Air Mercury Rules; *EM* **2005**, *August*, 10-12.
37. Steele, D.; Schaefer, G. Western Fuels: The Case for Coal Rank Subcategorization to Regulate Mercury Emissions; *EM* **2005**, *August*, 13-14.
38. Stadler, F. National Wildlife Federation: EPA's Mercury Rule: the Latest Delay Tactic; *EM* **2005**, *August*, 14-15.
39. Rossler, M. The Clean Air Mercury Rule; *EM* **2005**, *July*, 16-20.
40. Shore, M. Environmental Defense: Clean Air Lessons from the Myth of Sisyphus; *EM* **2005**, *August*, 9-10.
41. Bachmann, J.D.; Wierman, S. Urgent CAIR Needed; *EM* **2008**, *December*, 6-10.
42. McCarthy, G. U.S. Environmental Protection Agency and the Multipollutant Challenge: So Much to Do and So Little Knowledge! In *Proceedings of the Health Effects Institute 2010 Annual Conference*; Health Effects Institute: Boston, MA, 2010.
43. *Supplement to the Regulatory Impact Analysis for Ozone*; U.S. Environmental Protection Agency: Research Triangle Park, NC, 2010. *http://www.epa.gov/air/ozonepollution/pdfs/fs20100106ria.pdf* (accessed July 2010).
44. *Resolution on Multi-Pollutant Strategies for the Control of Air Pollution*; Environmental Council of the States: Washington, DC, 2010; available at *http://www.ecos.org/section/policy/resolution/?committee=1* (accessed July 2010).
45. *The Environmental Council of the States*; Environmental Council of the States: Washington, DC, 2010; available at *http://www.ecos.org* (accessed July 2010).
46. Bachmann, J.D. 2007 Critical Review Summary—Will the Circle Be Unbroken: A History of the U.S. NAAQS; *EM* **2007**, *June*, 27-34.
47. Chow, J.C.; Bachmann, J.D.; Wierman, S.S.G.; Mathai, C.V.; Malm, W.C.; White, W.H.; Mueller, P.K.; Kumar, N.K.; Watson, J.G. 2002 Critical Review Discussion—Visibility: Science and Regulation; *J. Air & Waste Manage. Assoc.* **2002**, *52*, 973-999.
48. Mathai, C.V. NSR Litigation and Reform: An Introduction to the Topic; *EM* **2004**, *January*, 14.
49. Meade, K.R. Back to the Future? Enforcement in the Post-NSR Reform Era; *EM* **2004**, *September*, 27-32.
50. Schneider, C.G. Up in Smoke: Regulatory Immortality for "Grandfathered" Power Plants under the NSR Rule Changes; *EM* **2004**, *January*, 30-32.
51. *New Source Review for Stationary Sources of Air Pollution*; National Research Council; National Academies: Washington, DC, 2006.
52. Edgerton, S.A.; MacCracken, M.C.; Jacobson, M.Z.; Ayala, A.; Whitman, C.E.; Trexler, M.C. Prospects for Future Climate Change and the Reasons for Early Action: Critical Review Discussion; *J. Air & Waste Manage. Assoc.* **2008**, *58*, 1386-1400; doi: 10.3155/1047-3289.58.11.1386.
53. MacCracken, M.C. Critical Review: Prospects for Future Climate Change and the Reasons for Early Action; *J. Air & Waste Manage. Assoc.* **2008**, *58*, 735-786; doi: 10.3155/1047-3289.58.6.735.
54. Powell, F.M. Trespass, Nuisance, and the Evolution of Common Law in Modern Pollution Cases; *Real Estate Law* **1992**, *21*, 182-215.
55. Brysson, R.J.; Trask, B.J.; Upham, J.B.; Booras, S.G. The Effects of Air Pollution on Exposed Cotton Fabrics; *J. Air Pollut. Control Assoc.* **1967**, *17*, 294-298.
56. Gillette, D.G. Sulfur Dioxide and Material Damage; *J. Air Pollut. Control Assoc.* **1975**, *25*, 1238-1243.
57. Haynie, F.H.; Spence, J.W. Air Pollution Damage to Exterior Household Paints; *J. Air Pollut. Control Assoc.* **1984**, *34*, 941-944.
58. Lipfert, F.W. Dry Deposition Velocity as an Indicator for SO_2 Damage to Materials; *J. Air Pollut. Control Assoc.* **1989**, *39*, 446-452.
59. Adams, R.M.; Hamilton, S.A.; McCarl, B.A. An Assessment of the Economic Effects of Ozone on U.S. Agriculture; *J. Air Pollut. Control Assoc.* **1985**, *35*, 938-943.
60. Legge, A.H.; Bogner, J.C.; Krupa, S.V. Foliar Sulfur Species in Pine—A New Indicator of a Forest Ecosystem under Air Pollution Stress; *Environ. Pollut.* **1988**, *55*, 15-27.
61. Legge, A.H.; Nosal, M.; McVehil, G.E.; Krupa, S.V. Ozone and the Clean Troposphere—Ecological Implications; *Environ. Pollut.* **1991**, *70*, 157-175.
62. Leung, S.K.; Reed, W.; Geng, S. Estimations of Ozone Damage to Selected Crops Grown in Southern California; *J. Air Pollut. Control Assoc.* **1982**, *32*, 160-164.
63. Percy, K.E.; Ferretti, M. Air Pollution and Forest Health: Toward New Monitoring Concepts; *Environ. Pollut.* **2004**, *130*, 113-126.
64. Williams, W.T.; Brady, M.; Willison, S.C. Air Pollution Damage to the Forests of the Sierra Nevada Mountains of California; *J. Air Pollut. Control Assoc.* **1977**, *27*, 230-234.
65. Rive, N. Climate Policy in Western Europe and Avoided Costs of Air Pollution Control; *Econ. Model.* **2010**, *27*, 103-115.
66. Rive, N.; Aunan, K. Quantifying the Air Quality Cobenefits of the Clean Development Mechanism in China; *Environ. Sci. Technol.* **2010**, *44*, 4368-4375.
67. Rypdal, K.; Rive, N.; Berntsen, T.; Fagerli, H.; Klimont, Z.; Mideksa, T.K.; Fuglestvedt, J.S. Climate and Air Quality-Driven Scenarios of Ozone and Aerosol Precursor Abatement; *Environ. Sci. Policy* **2009**, *12*, 855-869.
68. Markandya, A.; Armstrong, B.G.; Hales, S.; Chiabai, A.; Criqui, P.; Mima, S.; Tonne, C.; Wilkinson, P. Health and Climate Change, Three Public Health Benefits of Strategies to Reduce Greenhouse-Gas Emissions: Low-Carbon Electricity Generation; *Lancet* **2009**, *374*, 2006-2015.
69. Mauderly, J.L.; Samet, J.M. Is There Evidence for Synergy among Air Pollutants in Causing Health Effects? *Environ. Health Perspect.* **2009**, *117*, 1-6.
70. Fangmeier, A.; Bender, J.; Weigel, H.J.; Jager, H.J. Effects of Pollutant Mixtures. In *Air Pollution and Plant Life*, 2nd ed.; Bell, J.N.B., Treshow, M., Eds.; John Wiley & Sons: Chichester, United Kingdom, 2002; pp 251-272.
71. Legge, A.H.; Guidotti, T.; English, M.; Sandhu, H.S. A Vision of Clean Air; *J. Air & Waste Manage. Assoc.* **1992**, *42*, 888-891.
72. Thomson, V.E.; Jones, A.; Haemisegger, E.; Steigerwald, B. The Air Toxics Problem in the United States: An Analysis of Cancer Risks Posed by Selected Air Pollutants; *J. Air Pollut. Control Assoc.* **1985**, *35*, 535-540.
73. Finkel, A.M.; Evans, J.S. Evaluating the Benefits of Uncertainty Reduction in Environmental Health Risk Management; *J. Air Pollut. Control Assoc.* **1987**, *37*, 1164-1171.
74. Kowalczyk, G.S.; Gratt, L.B.; Ricci, R.F. An Air Emission Risk Assessment for Benzo(*a*)pyrene and Arsenic from the Mt. Tom Power Plant; *J. Air Pollut. Control Assoc.* **1987**, *37*, 361-369.
75. Amaral, D. Including Uncertainty in Assessments of Sulfur Oxide Health Risks; *J. Air Pollut. Control Assoc.* **1988**, *38*, 399-405.
76. Paustenbach, D.J.; Jernigan, J.D.; Finley, B.L.; Ripple, S.R.; Keenan, E. The Current Practice of Health Risk Assessment: Potential Impact on Standards for Toxic Air Contaminants; *J. Air & Waste Manage. Assoc.* **1990**, *40*, 1620-1630.
77. Summerhays, J. Evaluation of Risks from Urban Air Pollutants in the Southeast Chicago Area; *J. Air & Waste Manage. Assoc.* **1991**, *41*, 844-850.
78. Naugle, D.F.; Pierson, T.K. A Framework for Risk Characterization of Environmental Pollutants; *J. Air & Waste Manage. Assoc.* **1991**, *41*, 1298-1307.
79. Grisinger, J.E.; Marlia, J.C. Development and Application of Risk Analysis Methods to Stationary Sources of Carcinogenic Emissions for Regulatory Purposes by the South Coast Air Quality Management District (SCAQMD); *J. Air & Waste Manage. Assoc.* **1994**, *44*, 145-152.
80. Saltzman, B.E. Health Risk Assessment of Fluctuating Concentrations Using Lognormal Models; *J. Air & Waste Manage. Assoc.* **1997**, *47*, 1152-1160.
81. Mukerjee, D. 1998 Critical Review—Assessment of Risk from Multimedia Exposures of Children to Environmental Chemicals; *J. Air & Waste Manage. Assoc.* **1998**, *48*, 483-501.
82. Biswas, P. Critical Review Discussion: Children's Risk from Multimedia Exposure to Environmental Chemicals; *J. Air & Waste Manage. Assoc.* **1998**, *48*, 1116-1123.
83. Lai, A.C.K.; Thatcher, T.L.; Nazaroff, W.W. Inhalation Transfer Factors for Air Pollution Health Risk Assessment; *J. Air & Waste Manage. Assoc.* **2000**, *50*, 1688-1699.
84. Parkin, R.T.; Balbus, J.M. Can Varying Concepts of Susceptibility in Risk Assessment Affect Particulate Matter Standards? *J. Air & Waste Manage. Assoc.* **2000**, *50*, 1417-1425.
85. Pearson, R.L.; Wachtel, H.; Ebi, K.L. Distance-Weighted Traffic Density in Proximity to a Home Is a Risk Factor for Leukemia and Other Childhood Cancers; *J. Air & Waste Manage. Assoc.* **2000**, *50*, 175-180.

86. Stieb, D.M.; Burnett, R.T.; Smith-Doiron, M.; Brion, O.; Shin, H.H.; Economou, V. A New Multipollutant, No-Threshold Air Quality Health Index Based on Short-Term Associations Observed in Daily Time Series Analyses; *J. Air & Waste Manage. Assoc.* **2008**, *58*, 435-450; doi: 10.3155/1047-3289.58.3.435.
87. Pratt, G.C.; Dymond, M. Multipathway Screening Factors for Assessing Risks from Ingestion Exposures to Air Pollutants; *J. Air & Waste Manage. Assoc.* **2009**, *59*, 419-429; doi: 10.3155/1047-3289.59.4.419.
88. *Multiple Air Toxics Exposure Study in the South Coast Air Basin (SCAB) MATES III*; South Coast Air Quality Management District: Diamond Bar, CA, 2010; available at *http://www.aqmd.gov/prdas/matesIII/MATESIIDraftFinalReportJuly2008.html* (accessed July 2010).
89. Burke, W.A.; Glover, N.J. *Multiple Air Toxics Exposure Study in the SCAB (MATES-II)*; South Coast Air Quality Management District: Diamond Bar, CA, 2000.
90. Chow, J.C.; Watson, J.G.; Pritchett, L.C.; Pierson, W.R.; Frazier, C.A.; Purcell, R.G. The DRI Thermal/Optical Reflectance Carbon Analysis System: Description, Evaluation and Applications in U.S. Air Quality Studies; *Atmos. Environ.* **1993**, *27*, 1185-1201.
91. Chow, J.C.; Watson, J.G.; Chen, L.-W.A.; Chang, M.C.O.; Robinson, N.F.; Trimble, D.; Kohl, S.D. The IMPROVE_A Temperature Protocol for Thermal/Optical Carbon Analysis: Maintaining Consistency with a Long-Term Database; *J. Air & Waste Manage. Assoc.* **2007**, *57*, 1014-1023; doi: 10.3155/1047-3289.57.9.1014.
92. Mauderly, J.L.; Chow, J.C. Health Effects of Organic Aerosols; *Inhal. Toxicol.* **2008**, *20*, 257-288.
93. Mauderly, J.L.; Burnett, R.T.; Castillejos, M.; Ozkaynak, H.; Samet, J. M.; Stieb, D.M.; Vedal, S.; Wyzga, R.E. Commentary: Is the Air Pollution Health Research Community Prepared to Support a Multipollutant Air Quality Management Framework? *Inhal. Toxicol.* **2010**, *22*(Suppl 1), 1-19.
94. U.S. EPA. 40 CFR Part 51: Regional Haze Regulations: Final Rule. *Fed. Regist.* **1999**, *64* (126), 35714-35774; available at *http://frwebgate.access.gpo.gov/cgi-bin/getpage.cgi?position=all&page=35714&dbname=1999_register* (accessed July 2010).
95. U.S. EPA. 40 CFR Parts 69, 80, and 86: Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements—Final Rule. *Fed. Regist.* **2001**, *66* (12), 5001-5193.
96. Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel: Final Rule: 40 CFR Parts 9, 86, 89. *Fed. Regist.* **2004**, *69* (124), 38958-39273.
97. Gates, H.P., Jr.; Goldmuntz, L.A. Expected Decline in Carboxyhemoglobin Levels as Related to Automobile Carbon Monoxide Emission Standards; *J. Air Pollut. Control Assoc.* **1976**, *26*, 891-892.
98. Horvath, S.M.; Bedi, J.F. Alteration in Carboxyhemoglobin Concentrations during Exposure to 9-ppm Carbon Monoxide for 8 Hours at Sea Level and 2134 m Altitude in a Hypobaric Chamber; *J. Air Pollut. Control Assoc.* **1989**, *39*, 1323-1327.
99. Yankel, A.J.; von Lindern, I.H.; Walter, S.D. The Silver Valley Lead Study: The Relationship between Childhood Blood Lead Levels and Environmental Exposure; *J. Air Pollut. Control Assoc.* **1977**, *27*, 763-767.
100. Snee, R.D. Silver Valley Lead Study: Further Analysis of the Relationship between Blood Lead and Air Lead; *J. Air Pollut. Control Assoc.* **1982**, *32*, 170-175.
101. Brunekreef, B.; Noy, D.; Biersteker, K.; Boleij, J. Blood Lead Levels of Dutch City Children and Their Relationship to Lead in the Environment; *J. Air Pollut. Control Assoc.* **1983**, *33*, 872-876.
102. Barth, D.S.; Romanovsky, J.C.; Knelson, J.H.; Altshuller, A.P.; Horton, R.J.M. Discussion—"National Air Quality Standards for Automotive Pollutants"; *J. Air Pollut. Control Assoc.* **1971**, *21*, 544-548.
103. Heuss, J.M.; Nebel, G.J.; Colucci, J.M. National Air Quality Standards for Automotive Pollutants—a Critical Review; *J. Air Pollut. Control Assoc.* **1971**, *21*, 535-544.
104. Schneider, E.W. Detection of Leaded-Gasoline Usage in Catalyst-Equipped Vehicles: A Gamma-Ray Transmission Gauge for Measuring Catalytic Converter Lead Contamination; *J. Air Pollut. Control Assoc.* **1982**, *32*, 521-525.
105. Kitman, J.L. The Secret History of Lead: Special Report. *The Nation* **2000**, *March*, 11-45; available at *http://www.thenation.com/doc/20000320/kitman* (accessed July 2010).
106. Joumard, R.; Andre, M. Cold Start Emissions of Traffic; *Sci. Total Environ.* **1990**, *93*, 175-182.
107. Westerholm, R.; Christensen, A.; Rosen, A. Regulated and Unregulated Exhaust Emissions from Two Three-Way Catalyst Equipped Gasoline Fueled Vehicles; *Atmos. Environ.* **1996**, *30*, 3529-3536.
108. Singer, B.C.; Kirchstetter, T.W.; Harley, R.A.; Kendall, G.R.; Hesson, J.M. A Fuel-Based Approach to Estimating Motor Vehicle Cold-Start Emissions; *J. Air & Waste Manage. Assoc.* **1999**, *49*, 125-135.
109. Chase, R.E.; Duszkiewicz, G. J.; Jensen, T.E.; Lewis, D.; Schlaps, E.J.; Weibel, A.T.; Cadle, S.H.; Mulawa, P. Particle Mass Emission Rates from Current-Technology, Light-Duty Gasoline Vehicles; *J. Air & Waste Manage. Assoc.* **2000**, *50*, 930-935.
110. Cadle, S.H.; Mulawa, P.; Groblicki, P.; Laroo, C.; Ragazzi, R.A.; Nelson, K.; Gallagher, G.; Zielinska, B. In-Use Light-Duty Gasoline Vehicle Particulate Matter Emissions on Three Driving Cycles; *Environ. Sci. Technol.* **2001**, *35*, 26-32.
111. Cotte, H.; Bessagnet, B.; Blondeau, C.; Mallet-Hubert, P.Y.; Momique, J.C.; Walter, C.; Boulanger, L.; Deleger, D.; Jouvenot, G.; Pain, C.; Rouveirolles, P. Cold-Start Emissions from Petrol and Diesel Vehicles According to the Emissions Regulations (from Euro 92 to Euro 2000); *Int. J. Vehicle Des.* **2001**, *27*, 275-285.
112. Mathis, U.; Mohr, M.; Forss, A.M. Comprehensive Particle Characterization of Modern Gasoline and Diesel Passenger Cars at Low Ambient Temperatures; *Atmos. Environ.* **2005**, *39*, 107-117.
113. Weilenmann, M.; Soltic, P.; Saxer, C.; Forss, A.M.; Heeb, N. Regulated and Nonregulated Diesel and Gasoline Cold Start Emissions at Different Temperatures; *Atmos. Environ.* **2005**, *39*, 2433-2441.
114. Cook, R.; Touma, J.S.; Fernandez, A.; Brzezinski, D.; Bailey, C.; Scarbro, C.; Thurman, J.; Strum, M.; Ensley, D.; Baldauf, R. Impact of Underestimating the Effects of Cold Temperature on Motor Vehicle Start Emissions of Air Toxics in the United States; *J. Air & Waste Manage. Assoc.* **2007**, *57*, 1469-1479; doi: 10.3155/1047-3289.57.12.1469.
115. Baumgardner, D.; Raga, G.; Peralta, O.; Rosas, I.; Castro, T.; Kuhlbusch, T.; John, A.; Petzold, A. Diagnosing Black Carbon (BC) Trends in Large Urban Areas Using Carbon Monoxide Measurements; *J. Geophys. Res.* **2002**, *107*; doi: 10.1029/2001JD000626.
116. Jacobson, M.Z. Control of Fossil-Fuel Particulate BC Plus Organic Matter, Possibly the Most Effective Method of Slowing Global Warming; *J. Geophys. Res.* **2002**, *107*; doi: 10.1029/2001JD001376.
117. Lawson, D.R.; Groblicki, P.J.; Stedman, D.H.; Bishop, G.A.; Guenther, P.L. Emissions from In-Use Motor Vehicles in Los Angeles: A Pilot Study of Remote Sensing and the Inspection and Maintenance Program; *J. Air & Waste Manage. Assoc.* **1990**, *40*, 1096-1105.
118. Pierson, W.R.; Gertler, A.W.; Bradow, R.L. Comparison of the SCAQS Tunnel Study with Other On-Road Vehicle Emission Data; *J. Air & Waste Manage. Assoc.* **1990**, *40*, 1495-1504.
119. Bishop, G.A.; Zhang, Y.; McLaren, S.E.; Guenther, P.L.; Beaton, S.P.; Peterson, J.E.; Stedman, D.H.; Pierson, W.R.; Knapp, K.T.; Zweidinger, R.B.; Duncan, J.W.; McArver, A.Q.; Groblicki, P.J.; Day, F.J. Enhancements of Remote Sensing for Vehicle Emissions in Tunnels; *J. Air & Waste Manage. Assoc.* **1994**, *44*, 169-175.
120. Singer, B.C.; Harley, R.A. A Fuel-Based Motor Vehicle Emission Inventory; *J. Air & Waste Manage. Assoc.* **1996**, *46*, 581-593.
121. Gertler, A.W.; Sagebiel, J.C.; Dippel, W.A.; O'Connor, C.M. The Impact of California Phase 2 Reformulated Gasoline on Real-World Vehicle Emissions; *J. Air & Waste Manage. Assoc.* **1999**, *49*, 1339-1346.
122. Fujita, E.M.; Zielinska, B.; Campbell, D.E.; Arnott, W.P.; Sagebiel, J.C.; Mazzoleni, L.R.; Chow, J.C.; Gabele, P.A.; Crews, W.; Snow, R.; Clark, N.N.; Wayne, W.S.; Lawson, D.R. Variations in Speciated Emissions from Spark-Ignition and Compression-Ignition Motor Vehicles in California's South Coast Air Basin; *J. Air & Waste Manage. Assoc.* **2007**, *57*, 705-720; doi: 10.3155/1047-3289.57.6.705.
123. Frey, H.C.; Kim, K.; Pang, S.H.; Rasdorf, W.J.; Lewis, P. Characterization of Real-World Activity, Fuel Use, and Emissions for Selected Motor Graders Fueled with Petroleum Diesel and B20 Biodiesel; *J. Air & Waste Manage. Assoc.* **2008**, *58*, 1274-1287; doi: 10.3155/1047-3289.58.10.1274.
124. Cadle, S.H.; Ayala, A.; Black, K.N.; Graze, R.R.; Koupal, J.; Minassian, F.; Murray, H.B.; Natarajan, M.; Tennant, C. J.; Lawson, D.R. Real-World Vehicle Emissions: A Summary of the 18th Coordinating Research Council On-Road Vehicle Emissions Workshop; *J. Air & Waste Manage. Assoc.* **2009**, *59*, 130-138; doi: 10.3155/1047-3289.59.2.130.
125. Frey, H.C.; Kuo, P.Y. Real-World Energy Use and Emission Rates for Idling Long-Haul Trucks and Selected Idle Reduction Technologies; *J. Air & Waste Manage. Assoc.* **2009**, *59*, 857-864; doi: 10.3155/1047-3289.59.7.857.
126. Nussbaum, N.J.; Zhu, D.; Kuhns, H.D.; Mazzoleni, C.; Chang, M.-C.O.; Moosmüller, H.; Watson, J.G. The In-Plume Emissions Test-Stand: A Novel Instrument Platform for the Real-Time Characterization of Combustion Emissions; *J. Air & Waste Manage. Assoc.* **2009**, *59*, 1437-1445; doi: 10.3155/1047-3289.59.12.1437.
127. Zhu, D.Z.; Nussbaum, N.J.; Kuhns, H.D.; Chang, M.C.O.; Sodeman, D.; Uppapalli, S.; Moosmüller, H.; Chow, J.C.; Watson, J.G. In-Plume Emission Test Stand 2: Emission Factors for 10- to 100-kW U.S. Military Generators; *J. Air & Waste Manage. Assoc.* **2009**, *59*, 1446-1457; doi: 10.3155/1047-3289.59.12.1446.
128. Farrell, A.; Keating, T.J. Transboundary Environmental Assessment: Lessons from the Ozone Transport Assessment Group (OTAG); *Environ. Sci. Technol.* **2002**, *36*, 2537-2544.
129. Farrell, A. Multi-Lateral Emission Trading: Lessons from Inter-State NO_x Control in the United States; *Energy Policy* **2001**, *29*, 1061-1072.
130. Gego, E.; Gilliland, A.; Godowitch, J.; Rao, S.T.; Porter, P.S.; Hogrefe, C. Modeling Analyses of the Effects of Changes in Nitrogen Oxide Emissions from the Electric Power Sector on Ozone Levels in the

Eastern United States; *J. Air & Waste Manage. Assoc.* **2008**, *58*, 580-588; doi: 10.3155/1047-3289.58.4.580.

131. Gilliland, A.B.; Hogrefe, C.; Pinder, R.W.; Godowitch, J.M.; Foley, K.L.; Rao, S.T. Dynamic Evaluation of Regional Air Quality Models: Assessing Changes in O_3 Stemming from Changes in Emissions and Meteorology; *Atmos. Environ.* **2008**, *42*, 5110-5123.
132. Majeed, M.A. Methodologies for Estimating Emissions for the U.S. EPA's NO_x SIP Call, CER Rule, and Other Complexities; *Environ. Sci. Technol.* **2001**, *35*, 4408-4413.
133. McClenny, W.A.; Williams, E.J.; Cohen, R.C.; Stutz, J. Preparing to Measure the Effects of the NO_x SIP Call: Methods for Ambient Air Monitoring of NO, NO_2, NO_y, and Individual NO_z Species; *J. Air & Waste Manage. Assoc.* **2002**, *52*, 542-562.
134. Evans, D.A.; Hobbs, B.F.; Oren, C.; Palmer, K.L. Modeling the Effects of Changes in New Source Review on National SO_2 and NO_x Emissions from Electricity-Generating Units; *Environ. Sci. Technol.* **2008**, *42*, 347-353.
135. List, J.A.; Millimet, D.L.; McHone, W. The Unintended Disincentive in the Clean Air Act; *Adv. Econ. Anal. & Policy* **2004**, *4*; available at *http://www.bepress.com/bejeap* (accessed July 2010).
136. Wilson, J.H.; Mullen, M.A.; Bollman, A.D.; Thesing, K.B.; Salhotra, M.; Divita, F.; Neumann, J.E.; Price, J.C.; DeMocker, J. Emission Projections for the U.S. Environmental Protection Agency Section 812 Second Prospective Clean Air Act Cost/Benefit Analysis; *J. Air & Waste Manage. Assoc.* **2008**, *58*, 657-672; doi: 10.3155/1047-3289.58.5.657.
137. Civerolo, K.L.; Hogrefe, C.; Lynn, B.; Rosenzweig, C.; Goldberg, R.; Rosenthal, J.; Knowlton, K.; Kinney, P.L. Simulated Effects of Climate Change on Summertime Nitrogen Deposition in the Eastern U.S.; *Atmos. Environ.* **2008**, *42*, 2074-2082.
138. Palmer, K.; Burtraw, D.; Shih, J.S. The Benefits and Costs of Reducing Emissions from the Electricity Sector; *J. Environ. Manage.* **2007**, *83*, 115-130.
139. Schakenbach, J.; Vollaro, R.; Forte, R. Fundamentals of Successful Monitoring, Reporting, and Verification under a Cap-and-Trade Program; *J. Air & Waste Manage. Assoc.* **2006**, *56*, 1576-1583.
140. *Regulatory Impact Analysis for the Final Clean Air Interstate Rule*; EPA-452/R-05-002; U.S. Environmental Protection Agency; Office of Air and Radiation; Air Quality Strategies and Standards Division; Emission Monitoring and Analysis Division; and Clean Air Markets Division: Washington, DC, 2005.
141. *Technical Support Document for the Final Clean Air Interstate Rule—Air Quality Modeling*; U.S. Environmental Protection Agency; Office of Air Quality Planning & Standards: Research Triangle Park, NC, 2005.
142. *U.S. EPA. 40 CFR Parts 51, 72, et.al. Rule to Reduce Interstate Transport of Fine Particulate Matter and Ozone (Clean Air Interstate Rule); Revisions to Acid Rain Program; Revisions to the NO_x SIP call; Final Rule*; U.S. Environmental Protection Agency: Washington, DC, 2005.
143. Heidorn, K.C. A Chronology of Important Events in the History of Air Pollution Meteorology to 1970; *Bull. Am. Meteor. Soc.* **1978**, *59*, 1589-1597.
144. Davidson, C.I. Air Pollution in Pittsburgh: A Historical Perspective; *J. Air Pollut. Control Assoc.* **1979**, *29*, 1035-1041.
145. Englund, H.M. Looking Back; *J. Air Pollut. Control Assoc.* **1979**, *29*, 594-595.
146. Stern, A.C. History of Air Pollution Legislation in the United States; *J. Air Pollut. Control Assoc.* **1982**, *32*, 44-61.
147. Reitze, A.W., Jr. The Legislative History of U.S. Air Pollution Control; *Houston Law Review* **1995**, *36*, 679.
148. Stradling, D. *Smokestacks and Progressives: Environmentalists, Engineers, and Air Quality in America, 1881–1951*; Johns Hopkins University: Baltimore, MD, 1999.
149. Dewey, S.H. *Don't Breathe the Air. Air Pollution and U.S. Environmental Politics, 1945–1970*; Environmental History Series 16; Texas A&M University Press: College Station, TX, 2000.
150. Beck, B. Coal and the Battle against Smoke: The Early Days of A&WMA; *J. Air & Waste Manage. Assoc.* **2007**, *57*, 382-383.
151. Beck, B. The First Half-Century: Pre- and Post-World War II Growth; *J. Air & Waste Manage. Assoc.* **2007**, *57*, 636-639; doi: 10.3155/1047-3289.57.5.636.
152. Altshuller, A.P. Regional Transport and Transformation of Sulfur Dioxide to Sulfates in the U.S.; *J. Air Pollut. Control Assoc.* **1976**, *26*, 318-324.
153. Altshuller, A.P. Association of Oxidant Episodes with Warm Stagnating Anticyclones; *J. Air Pollut. Control Assoc.* **1978**, *28*, 152-155.
154. Cleveland, W.S.; Graedel, T.E. Photochemical Air Pollution in the Northeast United States; *Science* **1979**, *204*, 1273-1278.
155. Hidy, G.M.; Mueller, P.K.; Tong, E.Y. Spatial and Temporal Distributions of Airborne Sulfate in Parts of the United States; *Atmos. Environ.* **1978**, *12*, 735-752.
156. Hidy, G.M. Critical Review: Source Receptor Relationships for Acid Deposition: Pure and Simple; *J. Air Pollut. Control Assoc.* **1984**, *34*, 518-531.
157. Hidy, G.M. *Atmospheric Sulfur and Nitrogen Oxides. Eastern North American Source-Receptor Relationships*; Academic: San Diego, CA, 1994.
158. Husain, L.; Samson, P.J. Long-Range Transport of Trace Elements; *J. Geophys. Res.* **1979**, *84*, 1237-1240.
159. Leaderer, B.P.; Bernstein, D.M.; Daisey, J.M.; Kleinman, M.T.; Kneip, T.J.; Knutson, E.O.; Lippmann, M.; Lioy, P.J.; Rahn, K.A.; Sinclair, D.; Tanner, R.L.; Wolff, G.T. Summary of the New York Summer Aerosol Study (NYSAS); *J. Air Pollut. Control Assoc.* **1978**, *28*, 321-327.
160. MacCracken, M.C. MAP3S: An Investigation of Atmospheric, Energy Related Pollutants in the Northeastern United States; *Atmos. Environ.* **1978**, *12*, 649-659.
161. Mueller, P.K.; Hidy, G.M.; Watson, J.G.; Baskett, R.L.; Fung, K.K.; Henry, R.C.; Lavery, T.F.; Warren, K.K. *The Sulfate Regional Experiment (SURE): Report of Findings (Vols. 1, 2, and 3)*; EA-1901; Electric Power Research Institute, Palo Alto, CA, 1983.
162. Pierson, W.R.; Brachaczek, W.W.; Truex, T.J.; Butler, J.W.; Korniski, T.J. Ambient Sulfate Measurements on Allegheny Mountain and the Question of Atmospheric Sulfate in the Northeastern United States; *Ann. NY Acad. Sci.* **1980**, *338*, 145-173.
163. Samson, P.J.; Neighmond, G.; Yencha, A.J. The Transport of Suspended Particulates as a Function of Wind Direction and Atmospheric Conditions; *J. Air Pollut. Control Assoc.* **1975**, *25*, 1232-1237.
164. Wolff, G.T.; Monson, P.R.; Ferman, M.A. On the Nature of the Diurnal Variation of Sulfate at Rural Sites in the Eastern United States; *Environ. Sci. Technol.* **1979**, *13*, 1271-1276.
165. Wolff, G.T.; Lioy, P.J. Development of an Ozone River Associated with Synoptic Scale Episodes in the Eastern United States; *Environ. Sci. Technol.* **1980**, *14*, 1257-1260.
166. *Emissions Measurement Center*; U.S. Environmental Protection Agency: Research Triangle Park, NC, 2010; available at *http://www.epa.gov/ttn/emc* (accessed July 2010).
167. Brown, J.E.; Clayton, M.J.; Harris, D.B.; King, F.G., Jr. Comparison of Particle Size Distribution of Heavy Duty Diesel Exhaust Using a Dilution Tailpipe Sampler and an In-Plume Sampler during On-Road Operations; *J. Air & Waste Manage. Assoc.* **2000**, *50*, 1407-1416.
168. Maricq, M.M.; Chase, R.E.; Xu, N. A Comparison of Tailpipe, Dilution Tunnel, and Wind Tunnel Data in Measuring Motor Vehicle PM; *J. Air & Waste Manage. Assoc.* **2001**, *51*, 1529-1537.
169. Maricq, M.M.; Chase, R.E.; Xu, N.; Podsiadlik, D.H. A Constant-Volume Rapid Exhaust Dilution System for Motor Vehicle Particulate Matter Number and Mass Measurements; *J. Air & Waste Manage. Assoc.* **2003**, *53*, 1196-1203.
170. Jiang, P.; Lignell, D.O.; Kelly, K.E.; Lighty, J.S.; Sarofim, A.F.; Montgomery, C.J. Simulation of the Evolution of Particle Size Distributions in a Vehicle Exhaust Plume with Unconfined Dilution by Ambient Air; *J. Air & Waste Manage. Assoc.* **2005**, *55*, 437-445.
171. Robert, M.A.; Kleeman, M.J.; Jakober, C.A. Size and Composition Distributions of Particulate Matter Emissions. Part 2: Heavy-Duty Diesel Vehicles; *J. Air & Waste Manage. Assoc.* **2007**, *57*, 1429-1438; doi: 10.3155/1047-3289.57.12.1429.
172. Joumard, R.; Laurikko, J.; Le Han, T.; Geivanidis, S.; Samaras, Z.; Meretei, T.; Devaux, P.; Andre, J.M.; Cornelis, E.; Lacour, S.; Prati, M.V.; Vermeulen, R.; Zallinger, M. Accuracy of Exhaust Emission Factor Measurements on Chassis Dynamometer; *J. Air & Waste Manage. Assoc.* **2009**, *59*, 695-703; doi: 10.3155/1047-3289.59.6.695.
173. Chang, M.-C.O.; Yi, S.M.; Hopke, P.K.; England, G.C.; Chow, J.C.; Watson, J.G. Measurement of Ultrafine Particle Size Distributions from Coal-, Oil-, and Gas-Fired Stationary Combustion Sources; *J. Air & Waste Manage. Assoc.* **2004**, *54*, 1494-1505.
174. Corio, L.A.; Sherwell, J. In-Stack Condensible Particulate Matter Measurements and Issues; *J. Air & Waste Manage. Assoc.* **2000**, *50*, 207-218.
175. England, G.C.; Watson, J.G.; Chow, J.C.; Zielinska, B.; Chang, M.-C.O.; Loos, K.R.; Hidy, G.M. Dilution-Based Emissions Sampling from Stationary Sources. Part 1: Compact Sampler, Methodology and Performance; *J. Air & Waste Manage. Assoc.* **2007**, *57*, 65-78.
176. England, G.C.; Watson, J.G.; Chow, J.C.; Zielinska, B.; Chang, M.-C.O.; Loos, K.R.; Hidy, G.M. Dilution-Based Emissions Sampling from Stationary Sources. Part 2: Gas-Fired Combustors Compared with Other Fuel-Fired Systems; *J. Air & Waste Manage. Assoc.* **2007**, *57*, 79-93.
177. Sheya, S.A.; Glowacki, C.; Chang, M.-C.O.; Chow, J.C.; Watson, J.G. Hot Filter/Impinger and Dilution Sampling for Fine Particulate Matter Characterization from Ferrous Metal Casting Processes; *J. Air & Waste Manage. Assoc.* **2008**, *58*, 553-561; doi: 10.3155/1047-3289.58.4.553.
178. *List of Designated Reference and Equivalent Methods*; U.S. Environmental Protection Agency: Research Triangle Park, NC, 2010; available at *http://www.epa.gov/ttn/amtic/files/ambient/criteria/reference-equivalent-methods-list.pdf* (accessed July 2010).
179. Ouyang, Z.; Noll, R.J.; Cooks, R.G. Handheld Miniature Ion Trap Mass Spectrometers; *Anal. Chem.* **2009**, *81*, 2421-2425.
180. Contreras, J.A.; Murray, J.A.; Tolley, S.E.; Oliphant, J.L.; Tolley, H.D.; Lammert, S.A.; Lee, E.D.; Later, D.W.; Lee, M.L. Hand-Portable Gas Chromatograph-Toroidal Ion Trap Mass Spectrometer (GC-TMS) for

Detection of Hazardous Compounds; *J. Am. Soc. Mass Spec.* **2008**, *19*, 1425-1434.

181. Gao, L.; Sugiarto, A.; Harper, J.D.; Cooks, R.G.; Zheng, O.Y. Design and Characterization of a Multisource Hand-Held Tandem Mass Spectrometer; *Anal. Chem.* **2008**, *80*, 7198-7205.
182. Pitchford, M.L.; Poirot, R.L.; Schichtel, B.A.; Malm, W.C. Characterization of the Winter Midwestern Particulate Mitrate Bulge; *J. Air & Waste Manage. Assoc.* **2009**, *59*, 1061-1069; doi: 10.3155/1047-3289.59.9.1061.
183. Bein, K.J.; Zhao, Y.; Wexler, A.S. Conditional Sampling for Source-Oriented Toxicological Studies Using a Single Particle Mass Spectrometer; *Environ. Sci. Technol.* **2009**, *43*, 9445-9452.
184. Unger, N.; Bond, T.; Wang, J.; Koch, D.; Menon, S.; Shindell, D.; Bauer, S. Attribution of Climate Forcing to Economic Sectors; *Proc. Natl. Acad. Sci.* **2010**, *107*, 3382-3387.
185. Foley, G.J.; Georgopoulos, P.G.; Lioy, P.J. Accountability within New Ozone Standards; *Environ. Sci. Technol.* **2003**, *37*, 392-399.
186. Demerjian, K.; Roth, P.; Blanchard, C. *A New Approach for Demonstrating Attainment of the Ambient Ozone Standard*; EPA/600/R-96/134; U.S. Environmental Protection Agency: Research Triangle Park, NC, 1995.
187. *An Assessment of Tropospheric Ozone Pollution—a North American Perspective*; NARSTO: Pasco, WA, 2000; available at *http://www.cgenv.com/Narsto* (accessed July 2010).

About the Authors

Judith C. Chow is the Nazir and Mary Ansari Chair in Science and Entrepreneurialism and a research professor at DRI in Reno, NV. John D. Bachmann is Primary at Vision Air Consulting in Chapel Hill, NC. John D. Kinsman is Senior Director of Environment at the Edison Electric Institute in Washington, DC. Allan H. Legge is President of Biosphere Solutions in Calgary, Alberta, Canada. John G. Watson is a research professor at DRI. George M. Hidy is Principal at Envair/Aerochem in Placitas, NM. William T. Pennell is now the NARSTO Management Coordinator in Pasco, WA, after retiring as Director of Atmospheric Sciences and Climate Change from Pacific Northwest National Laboratory. Please address correspondence to: Judith C. Chow, Division of Atmospheric Sciences, Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512; phone: +1-775-674-7050; fax: +1-775-674-7009; e-mail: judith.chow@dri.edu.