EM Feature

Editor's Note: This article is a companion piece to the peer-reviewed paper, "Innovative Methods for Emission Inventory Development and Evaluation: Workshop Summary," by Mobley and Cadle, published in the November 2004 issue of the *Journal of the Air & Waste Management Association*.[1]

Innovative Methods for Emission Inventory Development and Evaluation: Workshop Synthesis

by George M. Hidy, J. David Mobley, and Steven H. Cadle

Emission inventories are key databases for evaluating, managing, and regulating air pollutants. Refinements and innovations in instruments that measure air pollutants, models that calculate emissions, and techniques for data management and uncertainty assessment are critical to enhancing the emission inventory. To facilitate improvement in emission inventories, communication and increased cooperation between developers and users are essential. The workshop "Innovative Methods for Emission Inventory Development and Evaluation," held in October 2003, provided recommendations for improving emission factors, improving emission models, and reducing inventory uncertainty, as well as improving communication among emission inventory developers and users along with policy-makers and data analysts. Emission inventories that incorporate these recommendations will have an increased probability of meeting the challenges of the future.

INTRODUCTION

Emission inventories reflect estimates of pollutants emanating from natural and anthropogenic sources. The inventories are a key foundation for air quality management activities. In this regard, emission inventories are essential for a range of activities, from enforcement to evaluation for federal, tribal, state, and local planning, and chemical transport modeling. Stakeholders have long believed that the current emission inventories using conventional methods have sufficiently large uncertainties that new approaches are needed. Two recent science assessments[2,3] recognized the importance of reliable emission inventories for Canada, Mexico, and the United States. These assessments described a number of limitations in current practice, and suggested several approaches to improve emissions estimates.

Since the 1970s, significant capabilities for generating emission inventories and verifying their reliability have developed in response to users' needs. Major improvements continue to be seen in North American inventories, with Mexico rapidly progressing toward achieving compatibility with Canada and the United States. Despite this progress, uncertainties remain in the inventories that need to be addressed, especially concerning organic species and fine particles. Significant vulnerabilities within current emission inventory programs limit their application or hamper the effectiveness for some uses. Most of these limitations are associated with the overarching challenges of (a) generalizing emission test data and activity indicators; (b) ensuring quality at a reasonable cost; (c) determining the inventory representativeness, comprehensiveness, and timeliness; and (d) applying the information to develop processing models for emission systems.

As a follow-up to the science assessments, NARSTO (formerly an acronym for North American Research Strategy for Tropospheric Ozone) and the Commission on Economic Cooperation (CEC) organized a workshop, "Innovative Methods for Emission-Inventory Development and Evaluation," which was held at the University of Texas, Austin, October 14–17, 2003. This workshop gathered together representatives of a broad emission inventory community, including regulators, modelers, instrument designers and operators, data analysts, and field investigators, and provided a unique forum for discussing new and innovative tools, techniques, and methodologies to improve the way emission inventories are developed, evaluated, and implemented. This article summarizes the results of the workshop and outlines recommendations from the participants for improving emissions data and models. A more detailed evaluation of the workshop results is published in the November 2004 issue of the *Journal of the Air & Waste*

Management Association.[1] The presentations made at the workshop are available on the NARSTO Web site.[4]

WORKSHOP OVERVIEW

The workshop was organized around a series of interlinked policy and science questions. These were framed in terms of the top-down/bottom-up nature of emission inventories. The term "bottom-up" describes emission inventories developed from measured emission rates or calculated directly for a specific source using effluent concentration, mass-flow observations, activity patterns, and emissions control data. "Top-down" refers to emissions that are inferred from ambient concentrations and ancillary measurements downwind from sources, or by calculations using aggregated or generalized emission factors at urban, regional, or national activity levels. Key topics discussed during the workshop encompassed contemporary source and flux measurements to infer emissions; mobile source characterization; ground, aircraft, and satellite observations; modeling of emissions, air quality, and receptors; and data management that takes into account emissions uncertainties.

Workshop participants described a variety of new measurement or analytical tools or techniques that enhance the knowledge of emissions from specific sources or classes of sources. Despite the rising interest in proper characterization of emissions, there appears to be no new "emission paradigm" on the horizon that will replace the conventional methodology. Nevertheless, innovative use of advances in instrumentation, specially designed field studies, and remote sensing, including satellite and aircraft observations, have improved the reliability of emissions characterization in specific areas. Advances in handling large databases, facilitated by computers and global positioning capabilities, have added to the tools for developing systems for processing emissions. The use of Internet-based communications systems has provided for broader investigator interactions and sharing of data and results, creating a veritable explosion in emissions information available to stakeholders. The sophistication in emission models of high temporal and spatial resolution for urban areas, for transportation, and for biogenic contributions has expanded dramatically in the past decade, placing added requirements on emission data processing. Except for a few cases, this progress generally has exceeded the capabilities for systematic verification of emissions estimates.

New refinements of estimation and data handling techniques developed in the past decade are available for near-term

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application as well as long-term systematic enhancements. Many of these are aimed at evaluating emission estimates derived from conventional practice and determining their uncertainties and limitations.[5] It is generally agreed that the emissions estimates of gases and particles (opacity) based on continuous emissions monitoring (CEM) of large point sources are very reliable today. Attention continues to be focused on gas and particle emissions from other source categories, including the fleet of on-road and off-road motor vehicles and internal combustion engines used for a variety of purposes. In addition, transient or upset conditions are of concern, as are area and fugitive emissions, especially for volatile organic compounds (VOCs) from industrial sources, such as refineries and chemical plants. Further, emissions from forest fires and prescribed burns are increasingly important to characterizations of fine particles and regional haze. Discussion about the evolving estimates of fine particle emissions indicates major gaps in estimating fugitive dust emissions, as well as primary and secondary particulate carbon sources. For use in fine particle applications, there are especially large uncertainties in the estimates of ammonia emissions, as well as organic precursors for organic carbon particle formation in the atmosphere. These are just a few of the key areas limiting application of emission-based air quality models for regulatory planning.

Improved measurement and analytical techniques are available across the spectrum of needs for the emission inventory field. The application of high-resolution, continuous ambient measurements or remote sensing allows for evaluation of short-term data with long-term estimates, based on conventional calculations. The application of these specialized experiments, combined with inverse modeling using chemical transport models or receptor modeling methods, provide a more formalized methodology for establishing inventory uncertainty based on consistency between ambient observations and expectations from emissions estimates. Short-term studies of this kind using ground and aircraft observations were helpful in the recent TexAQS 2000 study in Houston, TX.[6] The results from this study provided the technical basis for an important shift in ozone control strategy from emphasis on nitrogen oxides (NO_x) reductions alone to control of NO_x along with VOCs, particularly for highly variable emissions from refineries, chemical plants, and industrial cooling towers. Analogous studies of emissions from on-road vehicles using ambient data or highway tunnel studies have pointed to major inconsistencies between the observations and emissions modeling using different versions of the U.S. Environmental Protection Agency's (EPA) MOBILE and the California Air Resources Board's (CARB) EMFAC models. In general, well-designed field studies to investigate source-receptor relationships are expensive, and rely on short-term averages rather than long-term assessments. They have been used as a "court of last resort" in sensitive regulatory situations. Despite the cost and inability to assess future attainment of standards, a number of these source-receptor studies have occurred in the past decade.[1-3] Remote sensing techniques, including satellite imagery, can provide qualitative knowledge about large spatial scale emission patterns of fires and industrial or urban plumes. Recent advances in quantifying large-scale emissions of NO_x inferred from nitrogen dioxide (NO_2) column measurements and, indirectly, biogenic VOC emissions, using the atmospheric formaldehyde burden, have been gathered from satellite data.[1]

Discussion of the strengths and weaknesses of the various methods for evaluating conventional emission inventories was stimulated by reports of the use of historical data combined with long-term monitoring of key "indicator" pollutants for verification. A study of trends in ambient carbon monoxide (CO) concentrations compared with the reported long-term changes in CO emissions was cited as one example. This comparison suggests that there are important inconsistencies in the reported U.S. national emissions compared with ambient observations.[1] Such checks do not rely on new, expensive experiments, but on the investigator's knowledge of key source emissions and the expectation of consistent trends between ambient concentrations and reported emissions. Historically, other examples of this technique have identified not only issues of sampling artifacts, but also insight about changes in NO_x patterns and sulfate production relative to sulfur dioxide (SO_2) emissions.[2,3]

SUMMARY OF RESULTS

One way to sum up the results of the workshop is to examine the outcome in terms of the policy and science questions underpinning the meeting. The following are "answers" to the questions as proposed by the workshop participants.[1]

Policy Questions

What policy decisions will be made over the next several years based on current emission inventories?

Many emission inventory applications across Canada, Mexico, and the United States are expected in the next few years. These include air quality forecasting, risk assessments, control strategy development, cap and trade programs, economic incentive programs, new source review, global climate alteration, international transport, and assessments of progress to reduce pollution and its effects.

What is the vulnerability of current approaches affecting these decisions?

Significant vulnerabilities exist in the current emission inventory programs. Most of these limitations are associated with the overarching challenges of data quality, representativeness, comprehensiveness, timeliness, and cost. In many cases, the emission inventories have supported major regulatory programs and have withstood legal challenges. Nevertheless, in positioning emission inventories to address program expectations in the future, improvements to current capabilities are needed.

What new and innovative techniques can make a difference to these decision processes?

The workshop verified that science and technology advances are contributing new tools and techniques that could and should be employed. These encompass new and innovative tools and techniques, such as satellites, aircraft, and other remote sensing techniques, as well as measurement and monitoring instrumentation and protocols, including CEM systems, computer software, and hardware, the Internet, and geographic information system capabilities. Applications of analysis and application methods also include emission and air quality modeling, inverse modeling, and source-receptor analyses.

Science Questions

Do new and more innovative techniques exist on the 'technical' horizon?

New techniques are available for near-term as well as long-term enhancements; however, revolutionary changes in the "emissions estimation paradigm" are not evident. Most of the methods discussed in the workshop were not new in the sense that essentially all of the methods have been used before. However, new techniques for established methods are emerging, as are application of refinements to established methodologies.

What are they, what is their nature, and what are their limitations?

Improved measurement and analytical techniques are available across the spectrum of the emission inventory program. Emerging innovative techniques involve methods to establish inventory uncertainty using ambient data and specialized emissions studies, particularly for highly variable or inadequately characterized emissions from chemical plants, cooling towers, flares, in-use motor vehicles, and natural sources. They have been improved substantially by new sampling techniques and fast response instrumentation. They are inherently limited by resources to study a few cases for short periods of time, which precludes a robust statistical approach for long-term averaging and probability analysis. Remote sensing techniques, including satellite imagery, give qualitative knowledge about the large-scale emission patterns of fires and industrial or urban plumes. All of the methods described can be adopted in principle for evaluation of conventional inventories.

How can these methods best be combined with conventional methods, as well as with other, more modern techniques?

Emission systems programs are integrating many improvements on an ongoing basis. The methods can be combined with conventional methods by intercomparison of the results expected from emission models used for air quality modeling, or consistency checks with ambient data, for example, using ratios of concentrations representative of specific sources. The results to date still rely heavily on the conventional approach of establishing emission factors, activity patterns, and emission control estimates. There is a need to commission intercomparison methods for establishing the reliability of international consistency of inventories for many applications.

Exploration of the potential for new or refined methods for the development and improvement of emission inventories that began at the NARSTO workshop will be continued in a newly commissioned NARSTO Emission Inventory Assessment.[4] This assessment is intended to provide a summary of current strengths and weaknesses in North American emission inventories. In addition, it will provide a roadmap for improving inventories, promoting efficient and effective stakeholder use of inventories, and guidance for future applications of emission inventories in air quality management. The resources and priority allocated to emission inventories also will be examined, along with key areas in need of enhancement. The NARSTO Emission Inventory Assessment is scheduled to be issued in 2005,[7] and should help guide and promote better characterization of emissions in the future.

REFERENCES

1. Mobley, J.D.; Cadle, S.H. Innovative Methods for Emission Inventory Development and Evaluation: Workshop Summary; *J. Air & Waste Manage. Assoc.* **2004**, *54* (11), 1422-1439.
2. *Assessment of Tropospheric Ozone Pollution: A North American Perspective;* NARSTO Coordination Office, Kennewick, WA, 2000; also Report #1000040, EPRI, Palo Alto, CA.
3. *Particulate Matter Science for Policy Makers;* NARSTO Coordination Office, Kennewick, WA, 2003; Cambridge University Press; In press.
4. NARSTO. See http://www.cgenv.com/narsto/.
5. *Introduction and Use of the EIIP Guidance for Emission Inventory Development. Emission Inventory Improvement Program (EIIP);* U.S. Environmental Protection Agency, Research Triangle Park, NC, 1997.
6. Texas Air Quality Study (TexAQS) 2000. See http://www.utexas.edu/research/ceer/texasaqs/.
7. *Improving Emission Inventories for Effective Air Quality Management Across North America — A NARSTO Assessment;* NARSTO Review Draft, October 2004; NARSTO Coordination Office: Kennewick, WA, 2004. See http://www.cgenv.com/narsto/.

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