CHAPTER 2

# VISION FOR FUTURE NORTH AMERICAN EMISSION INVENTORY PROGRAMS

**Chapter 2 Objective:** ***To describe the parameters that will guide the development and application of future emission inventories.***



Emission inventories are a critical foundation of air quality management activities. Future inventories must meet growing demands for ever more detailed chemical speciation, temporal and spatial resolution, data quality, data accessibility, and affordability. This chapter defines a "vision" for future emission inventory programs that is designed to achieve the goal of this Assessment: to guide the development of future inventories and to facilitate their use in atmospheric process evaluation and air pollution management. The vision follows from an understanding of emission inventory applications, the air quality management framework within which emission inventories are developed and implemented, and the issues emission inventories will need to address in the future.

Both anthropogenic activities and natural processes emit gases and particles into the atmosphere. Most pollutants emitted by anthropogenic activities, such as automobiles, electric utilities, and industrial plants, can be controlled. Natural sources such as wildfires and dust storms are usually not manageable. Anthropogenic sources are generally characterized as point, nonpoint or area, and mobile. Point sources (chemical plants, incinerators, industrial boilers, and power plants) are emitters located at fixed geographical coordinates that are large enough to be enumerated individually. A large facility, such as a chemical manufacturing plant, may have many individual point sources. Stationary sources, such as such as dry cleaners, wood stoves, and home furnaces, whose individual emissions are too small to be considered as emission points in most analyses and uses are usually treated as nonpoint sources. Agricultural tilling, controlled burning, construction activities, and dust from mining also fall into this category. Some facilities such as refineries contain both point sources and nonpoint sources. The mobile-source category includes both onroad vehicle emissions and offroad sources such as construction equipment, farm tractors, airplanes, railroads, and ships. Natural emissions include forest fire smoke, volcanic particles and gases, nitrogen oxides ($NO_x$) from lightning, volatile compounds from vegetation, sea salt particles, and wind-blown dust.

Emission inventories are developed to characterize these sources and to provide air quality managers, modelers, and other users with information on the sources of air pollutants and their precursors. Inventories are also essential for assessing whether or not air quality regulations are having the intended effect, a process often termed "accountability." Emission inventories were originally based on annual equivalent emission estimates and were developed on spatial and temporal scales generally relevant to addressing near-source, urban emissions. Early inventories supported the design and evaluation of local air pollution control programs. Later emission inventories served a much broader set of applications, ranging from identification and location of primary pollutant sources to provision of detailed, gridded emission data for air quality modeling (see Box 2.1). As even larger spatial-scale issues emerged, involving regional to global impacts (e.g., acid rain, regional haze, ground-level ozone, stratospheric ozone depletion and climate change), emission inventories were extended to cover very large areas.

**Box 2.1. Emission Inventory Applications**

- Implementation Plan or Control Strategy Development
- Compliance Determination
- Emission Cap and Trade Activities
- Early Reduction Program Design
- Emission Trends Analysis and Projections
- Permit Limit Determination
- Toxic Release Inventory Reporting
- Information for Public
- Excess Emission Reporting
- Emission Statement/Fee Collection
- Environmental Impact Modeling and Assessment
- International Treaty Reporting
- Field Study Design
- Real-time Air Quality Forecasting
- Conformity Analysis
- Accountability Assessments

Table 2.1 summarizes the temporal, spatial, species, and process-level data needed for the representative applications listed in Box 2.1. The diversity of these applications, and the differing levels of detail demanded in association with them, highlight the difficulty developers and users face in harmonizing emission data.

Calls for improving emission inventories are not new. In the United States, two recent reports issued by the U.S. NRC have highlighted the need for continued improvement in emission inventories (NRC, 2004a,b). In addition, the U.S. *Clean Air Act* Advisory Committee's (CAAAC's) Air Quality Management Working Group is working with the U.S. Environmental Protection Agency (U.S. EPA) to develop a response to the U.S. NRC's recommendations on air quality management (CAAAC, 2004). This NARSTO Assessment addresses the recommendations in the two NRC reports as they pertain to emission inventories and is intended to coordinate with the CAAAC in developing their recommendations.

The atmospheric chemistry community now recognizes that air pollution is multi-scale and that efforts to systematically characterize and manage airborne pollution and its effects often requires knowledge of emission fluxes over a wide range of spatial scales. For example, photochemical oxidant and PM pollution are significantly influenced by emissions and transport on local to continental (or greater) scales. This knowledge motivates our vision for high-quality emission inventories for North America: that they have sufficient resolution to deal with pollution issues on neighborhood to hemispheric scales.

In addition to covering a variety of spatial scales, future emission inventories will need to be more current and better able to address problems requiring higher temporal resolution. Current emission inventories are often based on information that may be several years old. Emission inventories and projections need to be dynamic and regularly and consistently updated to represent the conditions in changing population, transportation, energy, manufacturing and other important emission sectors. New types of air quality models and new uses for their output will, as discussed below, require emission inventories with both high spatial and temporal resolution.

Accurate emission inventories are necessary for characterizing and assessing current air quality and global change issues. More importantly, they are critical to the design and evaluation of cost-effective control strategies to address these problems. This includes the necessity to determine progress towards air quality goals, and make any necessary mid-course corrections in control levels. Any vision for future North American emission inventory activities

**Table 2.1. Summary of Emission Inventory Resolution by Application.**

| Emission Inventory Application | Temporal | Spatial | Species | Process-Level Data |
|---|---|---|---|---|
| Control strategy development including mid-course correction | Hourly up to annual, and projections | Gridded source and county | Criteria pollutants,[1] precursors,[2] and hazardous air pollutants (HAPs) | Detailed stack and process parameters |
| Compliance determination | Hourly up to annual | Source | Criteria pollutants & HAPs | Limited |
| Emission cap and trade activities | Hourly up to annual | Source | Criteria pollutants, mercury, and greenhouse gases (GHGs)[3] | Limited |
| Early reduction program design | Hourly up to annual | Source | Criteria pollutants and GHGs | Limited |
| Emission trend analysis and projections | Annual | Source categories at state/provincial/ national level | Criteria pollutants and GHGs | Generally none |
| Permit limit development | Hourly up to annual | Source | Criteria pollutants | Detailed process data |
| Toxic release inventory reporting | Annual | Source | Toxic species, HAPs, and GHGs | None |
| Information for public | Annual and projections | Source to state | Criteria pollutants, HAPs, and GHGs | None |
| Excess emission reporting | Hourly | Source | Criteria pollutants | Detailed |
| Emission statement/ fee collection | Hourly up to annual | Source | Criteria pollutants | Limited |
| Environmental impact modeling and assessment | Hourly up to annual and projections | Source | Criteria pollutants, HAPs, and GHGs | Limited |
| International treaty reporting | Annual and projections | National | Criteria pollutants, GHGs, and HAPs | None |
| Field study design | Episodic or long term | Regional | Criteria pollutants, HAPs, and GHGs | Limited |
| Real-time air quality forecasting | Hourly | Gridded source and county | Criteria pollutants and precursors | Detailed stack and process parameters |
| Conformity analysis | Hourly | Gridded source and county | Ozone, PM, and precursors | Detailed stack and process parameters |
| Accountability assessment | Hourly up to annual | Gridded source and county | Criteria pollutants, HAPs & GHGs | Detailed stack and process parameters |

[1] U.S. criteria pollutants for which national ambient air quality standards have been set: carbon monoxide (CO), sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), PM, ozone, and lead. As explained in Chapter 3, Canada and Mexico have similar designations.
[2] Precursors are VOCs, size-segregated PM, and ammonia ($NH_3$).
[3] The primary greenhouse gases are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), halocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$).

must recognize that the development of accurate, comprehensive, and timely emission inventory data will be driven by the requirement that they support effective air quality management decisions both now and in the future. Based on this recognition, the vision for future North American emission inventories is one that

**… includes all significant emissions from all sources, time periods and areas, with quantified uncertainties, and timely accessibility. From this vision, the overall goal is to make inventories complete, accurate, timely, transparent, and affordable.**

The following sections of this chapter summarize the current emission inventory process, the societal issues that drive it, challenges in inventory development and maintenance, and the attributes of a comprehensive emission inventory.

## 2.1 CURRENT EMISSION INVENTORY PRACTICE: A BRIEF OVERVIEW

**An emission inventory is a collection of emission data from specified sources over a specified geographic area for a specified time period.** Figure 2.1 is a flowchart of the general process employed for compiling emission inventories in Canada, the United States, and Mexico. It illustrates the complex myriad of steps in inventory development, compilation, and quality assurance. The boxes on the left of the chart list the information inputs for constructing emission inventories, while the center boxes indicate the procedural steps required for inventory construction, review, quality assurance, and completion. The right-hand side of the figure indicates some of the more important emission inventory enhancements to support their application. Feedback loops, as indicated along the bottom of the figure, involve tests, evaluations, and reviews of existing inventories which are crucial for uncertainty identification and reduction.

It is desirable to measure emissions directly for incorporation into emission inventories. However, this is not always possible. In standard practice, most emissions associated with individual sources are estimated using the following equation:

$$\textbf{Emission rate = emission factor x activity factor x control factor} \qquad \textbf{(2.1)}$$

An *emission rate* is an amount of emission per unit time, e.g., kilograms of $NO_x$ per year. An *emission factor* is a representative value that relates the amount of pollutant emitted to the atmosphere to an activity associated with that source (e.g., kilograms of $NO_x$ emitted per unit of fuel burned). An *activity factor* is a measure of the driving force for the operation that produces emissions (e.g., kilograms of fuel burned per month or time period of interest). The *control factor* is the fraction of emission reduction in that source achieved by an add-on control device (e.g., selective catalytic reduction of $NO_x$) or process modification (e.g., installation of low-$NO_x$ burners). In many cases, control factors are included within the emission factor.

*Emission models* are tools that apply the paradigm of Equation (2.1) to source categories with complex emission factors, activity data, and control factors. As explained in Chapter 4, emission models are used for onroad and offroad mobile sources, natural/biogenic emissions, and other sources. Models also allocate emissions by time, location, and chemical or physical pollutant species. Current-year inventories for some source categories are estimated by applying growth factors to previous inventories to reflect up-to-date or projected activity levels.

For development of an emission inventory, emissions are calculated or reported from the information sources on the left-hand side of Figure 2.1. These data can be developed and submitted by any stakeholder in the emission inventory process. Most of the basic emission inventory information is developed by the authority or governmental entity most familiar with the emission characteristics of the source or source category. Once the data are compiled, they are typically sent to national, state, provincial, tribal, or local agencies for review, incorporation of updates, and insertion of additional locally generated data. After local improvements and updates are applied, a revised emission inventory with the best information available is produced. After additional quality assurance, the inventory is released to the public.

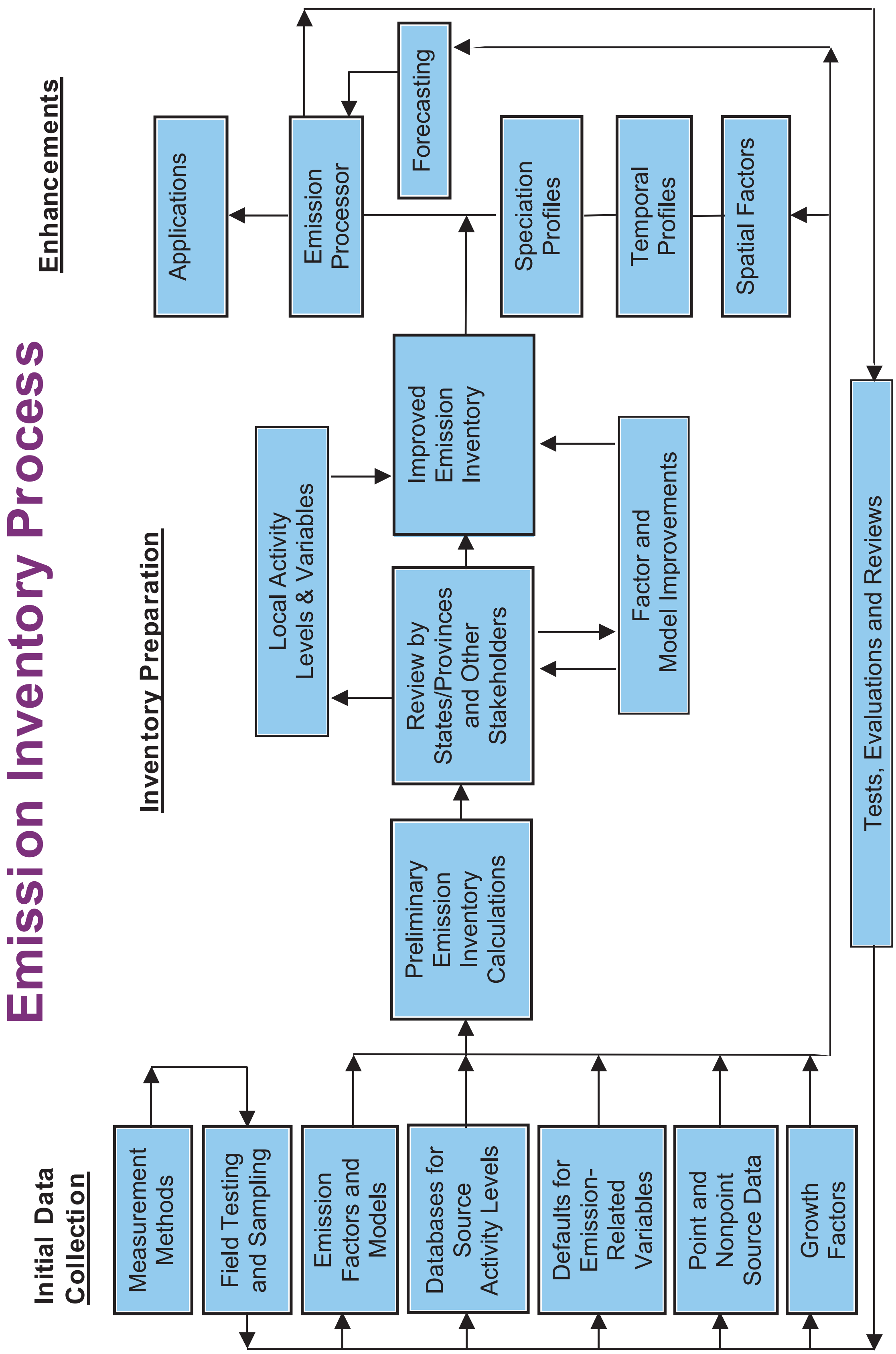


**Figure 2.1. Emission Inventory Development**

The new emission inventory can be applied by policy makers, atmospheric and economic modelers, regulators, and planners for their respective needs.

The enhancements on the right-hand side of Figure 2.1 illustrate how atmospheric modelers may apply temporal, spatial, and speciation allocation factors to the inventory to create appropriate inputs for detailed studies and other applications of emission inventories. As described in Chapter 4, *emission processors* are used to combine emission estimates and related data (e.g., chemical speciation profiles, temporal profiles, or spatial factors) for input into air quality simulation models. Forecasting future inventories is an important and complex step necessary for air quality management.

As discussed in Chapters 3 and 4, emission inventories and models are currently available for a variety of criteria and other pollutants, with various levels of temporal and spatial resolution. Acknowledged deficiencies in these inventories as well as emerging societal needs, however, provide a strong impetus for future improvement. Section 2.2 summarizes "societal drivers," which are defined in this context as important motivations for emission inventory applications.

## 2.2 SOCIETAL DRIVERS FOR FUTURE NORTH AMERICAN EMISSION INVENTORIES

The need for emission inventories derives from continuing efforts to manage air quality across North America. The issues that drive these efforts are the protection of human health, the promotion of human welfare, and the protection of natural ecosystems. This final issue – protection of ecosystems – may expand to include protection of the Earth's climate system. This section reviews the principal technical issues that are most critical to achieving these broad societal goals.

### 2.2.1 Photochemical Oxidants

The range of problems attributed to airborne pollutants has grown steadily over the last 50 years. After the pioneering work of Haagen-Smit and co-workers (Haagen-Smit, 1970) identified photochemical production of oxidants, especially ozone, as the cause of air quality degradation and vegetation damage in the Los Angeles basin in the 1950s, knowledge of both the spatial scale and the undesirable effects of photochemical smog have expanded significantly. Motivated primarily by evidence of the detrimental impacts of airborne oxidants on human health, the U.S. *Clean Air Act* Amendments of 1970 initiated efforts to reduce ozone and related oxidants in major cities across the United States. Similar efforts soon followed in Canada and Mexico (NARSTO, 2000). By the early 1990s, the U.S. NRC was able to demonstrate both that simple control of precursor anthropogenic VOCs would not be sufficient to control photochemical oxidant production in many areas and that long-range transport of photochemical oxidants and their precursors endowed the problem with a regional to semi-continental length scale (NRC, 1991). NARSTO's assessment of tropospheric ozone pollution in North America confirmed the multi-spatial scale nature of photochemical oxidant pollution episodes and raised the issue of a rising background level of ozone on the continental scale, motivating a continental perspective for the problem (NARSTO, 2000). Further, increasing evidence of the detrimental human and ecosystem health impacts of ground-level ozone and related oxidants have resulted in a more stringent national ambient air quality standards (NAAQS) for ozone in the United States, a review of the Canadian air quality standard for ozone, and an enhanced effort to enforce Mexico's ozone standard, particularly in the key Mexico City and Guadalajara metropolitan areas (Molina and Molina, 2004; Molina et al., 2004; NARSTO, 2000).

### 2.2.2 Airborne Particulate Matter (PM)

The detrimental health effects of airborne particles were recognized early in the twentieth century and were dramatically demonstrated by London's 1952 "killer fog" episode that resulted in over 4000 deaths. More recently, studies have shown that adverse health effects continue to be linked with exposure to particles, even at levels previously considered "safe" (U.S. EPA, 2004). This concern has prompted the establishment of air quality standards for airborne

PM in all three North American countries. Mexico enacted standards for particles with aerodynamic diameter less than or equal to 10 $\mu$m ($PM_{10}$) in 1993, and a proposal for a new standard to regulate particles with aerodymanic diameter less than 2.5 $\mu$m ($PM_{2.5}$) was published for public comment in the *Diario Oficial* (a publication similar to the U.S. Federal Register) on October 2002, but has not yet been enacted. Canada regulates $PM_{2.5}$. The United States originally established standards for total suspended particulates (TSP) and subsequently set both $PM_{10}$ and $PM_{2.5}$ NAAQS values in response to epidemiological evidence that higher ambient airborne PM levels correlate with premature deaths from both lung and cardiovascular diseases (NARSTO, 2004; U.S. EPA, 2004). The close tie between photochemical oxidant production and secondary PM formation through $SO_2$, $NO_x$, $NH_3$, and VOC emissions has been recognized and discussed in previous NARSTO assessments (NARSTO, 2000; NARSTO, 2004).

### 2.2.3 Toxic and Hazardous Air Pollutants

In addition to criteria air pollutants, the atmosphere in urban and industrial areas is often burdened with a range of hazardous substances that can be detrimental to both human health and ecosystem viability. Under the U.S. *Clean Air Act*, the U.S. EPA has established a program to characterize emission sources and ambient concentrations of a wide range of HAPs, currently recognizing 188 chemical species or species classes believed to be threats to human health (U.S. EPA, 2003a). Particular attention has been paid to mercury and several compounds emitted by motor vehicles that are known or suspected human carcinogens, including benzene, formaldehyde, acetaldehyde, acrolein, and 1,3 butadiene. In Canada, air pollutants such as $PM_{10}$, $NO_x$, $SO_2$, VOC, and $NH_3$ have been recently been declared toxic under the Canadian Environmental Protection Act (CEPA, 1999). Since 2002, these substances along with total PM, $PM_{2.5}$, and CO are required to be reported by the Canadian industries to the National Pollutant Release Inventory (NPRI) on an annual basis. Emission reporting requirements are also being implemented in Mexico and will likely include selected toxic air pollutants. Future emission inventories will need to track emissions of the many organic HAPs out of direct concern for their health impacts as well as for their role as precursor species for criteria air pollutants like ozone and PM. The air quality modeling of toxic and hazardous air pollutants places challenging requirements on emission inventories. In addition to the difficulty of characterizing the numerous species of interest, the temporal and spatial scales may need to be very detailed to capture the urban hot spots and community analyses that are typically of concern. Toxic air pollutant issues are also likely targets for environmental justice concerns, which represent additional challenges for the analyses including the underlying emission inventory.

### 2.2.4 Regional Haze and Visibility

Both primary and secondary PM can contribute to the formation of persistent haze conditions that degrade visibility in both urban and rural locations. Impaired visibility is often thought of as a safety issue for aircraft or an aesthetic problem that degrades the local quality of life by obscuring vistas and casting a pall on outdoor activities. The U.S. NRC has reviewed the challenge of reducing haze levels that impair visibility at major of U.S. national parks and wilderness areas (NRC, 1993). The United States has adopted regulatory requirements to restore visibility conditions in major national parks and wilderness areas (Class I areas) to "natural conditions" by 2064 (U.S. EPA, 1999). Incremental progress toward this goal is required. The U.S. EPA has established five Regional Planning Organizations (RPOs) to develop strategies to ensure progress toward this goal. To support regional haze and visibility programs, emission inventories will need to address the precursor pollutants which are generally the same as would be needed for photochemical oxidants and PM. However, due to the long term nature of the U.S. regulatory requirements, emission inventory trends must be tracked, necessitating consistency of methodologies over time and access to and potential recalculation of archival emission data.

### 2.2.5 Regional Ecosystem Effects

Acid deposition (acid rain) was the first widely recognized regional scale ecosystem impact produced by urban and industrial emissions. The process is driven by atmospheric oxidation of $NO_x$ and $SO_2$, emissions to ambient nitric and sulfuric acid ($HNO_3$ and $H_2SO_4$). Problems arise when these acid gases and the secondary sulfate/nitrate PM they form are deposited downwind on poorly buffered surface waters or soils. A range of detrimental impacts on sensitive lakes, streams, and forests as well as materials damage has been documented (NAPAP, 1990).

A closely related problem involves fertilization effects caused by the deposition of airborne fixed nitrogen species (ammonium - $NH_4^+$ - and nitrate PM and their gas-phase precursors) to buffered soils and fresh or marine surface waters that are not susceptible to acidification. Combined with fixed nitrogen and phosphorus from fertilizer, animal waste and human sewage sources, atmospheric deposition of fixed nitrogen may contribute to fertilization of soils, lakes, streams, and estuaries leading to changes in primary productivity and, potentially, to eutrophication. This problem has been documented in the Gulf of Mexico, Chesapeake Bay and other major water bodies (U.S. EPA, 2001). Atmospheric nitrogen deposition may even have impacts on the open ocean, including the stimulation of phytoplankton blooms (Molina and Molina, 2004; Molina et al., 2004). More recently, it has been documented that high levels of fixed nitrogen deposition can have significant effects on ecosystem diversity, even when deposition receptor areas are not heavily acidified (Stevens et al., 2004).

High regional emissions of fine primary PM and PM precursors may also lead to high levels of ambient fine PM with absorption and scattering properties that significantly influence both the direct and diffuse components of photosynthetically active radiation (PAR) (Bergin et al., 2001; Cohan et al., 2002). It has been suggested that attenuation of PAR by both atmospheric PM and PM deposited on plant leaves may significantly impact solar radiation available for photosynthesis in important agricultural regions in China (Chameides et al., 1999).

Finally, as noted above, it has been recognized that photochemical oxidant production increasingly becomes a regional problem as urbanization spreads (NARSTO, 2000; NRC, 1991; NAPAP, 1990). Photochemically produced oxidants and their precursors flowing out of major cities frequently produce high levels of ozone and other oxidants all the way to the next major city, subjecting the intervening towns, forests, and agricultural areas to high oxidant exposures. Exposure to ozone and related photochemical oxidants is known to damage both native and agricultural vegetation (NRC, 1991). Thus, emission inventory requirements for regional ecosystem effects are similar to the requirements for the regional pollutants of photochemical oxidants and PM.

### 2.2.6 Regional Climate Change

Radiative forcing results from an imbalance in solar radiative energy coming into the atmosphere and thermal radiation going out. A positive radiative forcing tends on average to warm the surface of the Earth, and negative forcing tends on average to cool the surface. The positive radiative forcing of greenhouse gases ($CO_2$, $CH_4$, $N_2O$, and long-lived halogenated gases like perfluorocarbons, chlorofluorocarbons, and $SF_6$) in driving climate change on a global scale is widely recognized and global scale emission inventories for these species are being actively pursued (IPCC, 2001). Less widely appreciated are the important roles of several largely secondary pollutants on climate change at a regional scale. These include tropospheric ozone, a potent greenhouse gas over and downwind of large sources of precursor emissions. They also include fine particles, usually with diameters less than 1 μm, which often can be transported over regional to hemispheric scales (Menon et al., 2002). Some of these particles absorb solar radiation and warm the atmosphere. Others cool it either by reflecting solar energy back into space or by affecting the radiative properties or the lifetimes of clouds (IPCC, 2001).

A review of regional to continental impacts of PM pollution from megacities has documented several recent studies that demonstrate depression of sunshine duration and maximum daily surface temperatures in and downwind of major urbanized areas in China and India (Molina and Molina, 2004; Molina et al., 2004). Unfortunately, the uncertainties in both the regional atmospheric PM burdens, which depend on both meteorology and precursor emission levels, and the magnitude of both direct and indirect radiative effects for PM, which depend on their composition, combine to make quantitative evaluation of their climate forcing highly uncertain (IPCC, 2001).

Characterizing the impacts of greenhouse gases and aerosols, including tropospheric ozone and PM, on regional climate change in North America will likely require emission inventories defined over different spatial and temporal scales than those needed to assess ground-level health effects from these same species. Further, emission inventories over time will be needed to address the international treaties, such as the Kyoto Protocol. This will also require consistency of methodologies over time, requiring accessibility of data. The utilization of trends from emission inventories to determine compliance with international treaties will place difficult demands on emission inventories.

### 2.2.7 Air Quality Forecasts

The need to characterize and manage each of the air quality-related issues described above will force disparate and challenging requirements on future emission-inventory activities. However, another emerging activity, the development of daily air quality forecasts for North American cities, may place even more demanding requirements on them. Air quality forecasting is currently the subject of significant research activity, including exploratory work under the auspices of the U.S. Weather Research Program (Dabberdt et al., 2004; Otte et al., 2005). Current or planned operational activities include the U.S. EPA's AIRNow program (U.S. EPA, 2003b) that provides short-term, city-specific air quality forecasts, and the U.S. National Weather Service program that is preparing to issue four-day ozone and PM forecasts for selected U.S. cities in the near future. Air quality forecasting capabilities are also being developed in Mexico and Canada. Such forecasts are generally motivated by public health concerns and are designed to provide warnings of unhealthful pollutant levels to sensitive sub-populations, as well as the general population, including those who spend much time outdoors for work or recreational activities and may need to be warned about potential exposures. The forecasts can enable sensitive individuals to alter their exposure to elevated levels of air pollutants, and concerned citizens can alter their activities which may add to pollution levels (e.g., commuting behavior). However, there is also a substantial and growing demand for air quality forecasts to inform institutional decision makers who must plan for air-quality-influenced demand changes or who might be asked to curtail emission-producing activities in an effort to manage air quality. Industrial and public sector organizations, including power generators, transportation companies, health care organizations, emergency responders, and recreation facilities, could all be heavily affected by air quality episodes (Dabberdt et al., 2004).

As air quality forecasting methods move from statistical evaluations to fully coupled, operational meteorological/atmospheric chemistry models, the demand for real-time, highly spatially resolved emission inventories will grow. Just as the physical weather cannot be reliably predicted without current data on wind, water vapor, and temperature, the chemical weather will be hard to predict accurately without current, highly spatially and temporally resolved emission fluxes of key primary pollutants and secondary pollutant precursors. Since severe air quality episodes are usually multi-day events with extreme pollution levels occurring after two to three days, their forecast will require both timely local and upwind regional emission data plus accurate meteorological prediction capabilities. It will be especially important to characterize on a near real-time basis the emissions from prescribed and wild fires, accidental chemical releases and spills, and major traffic jams.

These seven major issues will set the requirements for emission inventories in all three countries of North America for the foreseeable future. How these requirements will affect the development of emission inventories and their attributes will differ among them. Table 2.2 summarizes the more important inventory limitations that affect each country's ability to satisfy air quality management needs. The table identifies areas that need immediate emphasis, and it provides brief guidance on how these deficiencies might be resolved.

**Table 2.2. Important Inventory Limitations and Associated Needs for Immediate Emphasis in the United States, Canada, and Mexico.**

| Attribute | Canada | United States | Mexico | Resolution | Potential for Support –New Methods |
|---|---|---|---|---|---|
| Composite Emission Inventory | Refine national inventory. | Upgrade NEI and components, with improved emission factors and models. | Complete detailed national inventory. | Use established methodologies with assistance of modeling techniques, and error identification. | Improved use of measurements combined with calculation methods open opportunities |
| Pollutant Species Resolution | Particular attention to carbon (VOC, OC, BC), $PM_{2.5}$, $NH_3$, wildfires, toxics | Particular attention to carbon (VOC, OC, BC), $NH_3$, fires, HAPs | Particular attention to carbon (VOC, OC, BC), $PM_{2.5}$, $NH_3$, Biomass, toxics | High priority for measurements and emission factors, Activity development | New measurement methods and reconciliation needed to address emerging issues |
| Uncertainty quantification | Quantify uncertainties in estimates, especially industrial sources, fire, and transportation | Quantify uncertain-ties in NEI, especially transportation and area sources | Estimate uncertainties and priorities for improvement | Difficult problem, requires combined measurements, and improved estimation techniques | Measurement uncertainties and reconciliation methods applied systematically. |
| Processing Tools | Air quality model support an important driver | Air quality model is an important driver with fine spatial and temporal resolution. | Air quality model support for cities an important driver | Emission models and processes continue to evolve;-attention to transportation and dif-fuse sources. | Modeling requirements need to be met with new emission models and focus on emerging pollutant specs. |
| Spatial and Temporal Resolution | Concern for $O_3$ and $PM_{2.5}$ broaden spatial and temporal scale concerns. | Extremes in space and time scales for models crucial for health effects and for intercontinental assessment. | Ill defined area and fugitive sources need multiscale quantification. | Seek reasonable uniformity in reporting emissions by country; attention to improved estimates by scale and time. | Modeling continues to push extremes of spatial and temporal scales for improved emission estimation. |

**Table 2.2. Concluded.**

| Attribute | Canada | United States | Mexico | Resolution | Potential for Support –New Methods |
|---|---|---|---|---|---|
| Air Quality Management Requirements | Concern for health and welfare issues including transboundary transport of pollutants. | Multiscale applications with a variety of techniques will increase with stakeholder and international needs. | Regional applications become more important for transboundary issues and megacity influence. | Model applications combined with emission models will continue to evolve with more sophistication as needed. | Expect methods reconciliation to continue improvement. Improved definition and application of uncertainty analysis. |
| Data Accessibility | Increase accessibility for stakeholder use within legal constraints | Increased efficient stakeholder access important | Increase accessibility for stakeholder use | Adoption of improved data management methods for user friendly access | Application of new, efficient means of data base management. |
| Timeliness | Provide for regular update for progress tracking | Measure of progress critical element for NEI | Provide for regular update with consistent methodology | Requirement for continued stakeholder interaction and efficient use of data management skills. | Updates require continuing stakeholder attention and support, use of new methods may help obtain data more rapidly. |
| Projections | Improve ability to make emission projections. | Improve ability to make projections important element of planning | Improve ability to make emission projections | Requires integration of local and regional socio-economic and technology outlooks. | Increased stakeholder input, technological and economic forecasting, and trend analysis may improve projections. |

## 2.3 REQUIREMENTS FOR FUTURE EMISSION INVENTORIES

As discussed above, each air quality issue has intrinsic distance and time scales as well as specific pollutants that drive associated emission inventory requirements. Emission data must be provided on spatial and temporal scales that meet the requirements of the receiving model or analysis. The data must also contain the required source and chemical speciation information. As more sophisticated, high-resolution atmospheric chemistry and transport models are being used to assess air quality management options, providing these data has become more challenging. The following sections describe some of the scale, chemical speciation, uncertainty, and data compatibility issues that emission inventories will increasingly need to address.

### 2.3.1 Urban Neighborhood Scales

In order to obtain better characterization of human exposure to photochemical oxidants, PM, or toxic air pollutants, air quality model simulations may need to be focused on the urban neighborhood level. Air quality forecasts, for example, would be most useful if they could be prepared at the neighborhood scale. It is widely recognized that differences in meteorology and emission patterns can cause very significant gradients of pollutant concentrations on the urban scale. Thus, detailed "micro-scale inventories" of sources surrounding measurement sites may be needed in order to understand model performance or measurement issues in such locations. Harmonization of micro-scale and urban-scale emission inventories places additional challenges for emission inventory programs, but can serve as a valuable evaluation step in the development process. Urban-district-scale data are also necessary to estimate the impact of outdoor air pollutant concentrations on indoor air quality in households and workplaces. New techniques for continuous air quality measurement in combination with neighborhood-scale modeling and micro-scale inventories present opportunities to learn more about the causes and health effects of air pollution.

### 2.3.2 Metropolitan Area Scales

Rapid urbanization has forced the focus of urban air pollution to shift from individual municipalities to metropolitan areas. These areas can encompass high populations and very large areas. For instance, the Mexico City metropolitan area, with a population of 3 million in 1950, reached 18.7 million by 2003, and its urbanized area expanded from 118 to about 1500 $km^2$ from 1940 to 1995 (Molina and Molina, 2004; Molina et al., 2004). Large metropolitan areas like Mexico City, New York City, and Los Angeles typically expand over dozens of municipalities and may extend into several states or across national borders. In order for inventories to represent the frequently changing population and transportation patterns in these areas, they need to be dynamic and updated in a timely manner.

### 2.3.3 Regional to Continental Scales

It is increasingly clear that the effects of degraded air quality are no longer restricted to areas in or near major cities. Regional air quality modeling activities have been instrumental in pushing the development of regional emission inventories. This is evidenced by the U.S. regulatory and legislative activities regarding the acid rain program (NAPAP, 1990), Grand Canyon Visibility Transport Commission (GCVTC, 1996), Ozone Transport Assessment Group (OTAG, 1997), and the Clean Air Interstate Rule for $SO_2$ and $NO_x$ (U.S. EPA, 2005a) and the mercury rule (U.S. EPA, 2005b). International agreements have also been supported by regional emission inventories and modeling activities such as the U.S.-Canada Air Quality Agreement (U.S.-Canada, 1991) and the U.S.-Mexico Border 2012 Agreement (U.S. EPA and SEMARNAT, 2003). Photochemical oxidants and secondary fine PM produced in the plumes from major cities and industrial areas cross not only state/provincial borders but also penetrate national boundaries. Photochemical episodes as well as the pollution events caused by widespread wildfires have been observed to impact large fractions of the North American continent. The evidence that many air quality problems need to be addressed on a continental scale is compelling (NARSTO, 2000;

NARSTO, 2004). This means that North American emission inventories will need to be rationalized and coordinated on the continental scale, not just at the borders. It may be necessary to take an even broader view of emissions in the future. Because of growing emission levels and long-range transport, the lines between local, regional, continental, and global regimes are becoming increasingly blurred.

### 2.3.4 Intercontinental/Hemispheric Scales

It is becoming clear that long-range transport of fine particles and long-lived gases is affecting air quality over the entire northern hemisphere. Similar effects have also been observed in the southern hemisphere. Evidence for a systematic increase in background pollutants due to intercontinental transport is growing.

It has been shown that African dust can be transported across the Atlantic Ocean on the trade winds to the Caribbean, Mexico, and the southern United States (Prospero, 1999; Prospero and Lamb, 2003). In a major event in April 1998 (Husar et al., 2001; Wilkening et al., 2000), Asian dust from storms originating in the Gobi desert was transported over the Pacific Ocean to the North American coast and reached as far inland as Minnesota. A similar dust event occurred in April 2001 (DeBell et al., 2004) when elevated concentrations of dust were observed from this event as far east as New England. Such events have the potential to contribute to violations of ambient air quality standards for PM.

Evidence shows that the background concentration of ozone is increasing in North America (NARSTO, 2000; Lin et al., 2000). Some of this increase may be due not just to North American emissions, but also to Asian emissions transported across the Pacific Ocean (Berntsen et al., 1999; Jacob et al., 1999). Jacob et al. (1999) have shown that by 2010 the effect of rising emissions in Asia could influence monthly mean ozone concentrations in the western United States by 2 to 6 ppbv for the April-June time period. According to Jacob et al., this increase in background levels would "more than offset the benefits of 25 percent domestic reductions in anthropogenic emissions of $NO_x$ and hydrocarbons in the western United States."

It is broadly appreciated that increases in Asian and European emissions of $NO_x$ and hydrocarbons can affect tropospheric ozone concentrations over a very wide area (Wild and Akimoto, 2001; Wild et al., 2004) and that increases in PM emissions can not only increase particulate concentrations in far-removed locations but also affect local radiative forcing and influence ozone chemistry (Martin et al., 2003).

Trace elements and persistent organic species also have the potential to travel for long distances. With an atmospheric lifetime of about one year, elemental mercury emissions certainly contribute to a hemispheric background that influences concentrations in North America. It is estimated that 20 to 30 percent of the mercury deposited in the United States is of Asian origin (Seigneur et al., 2004).

All of this evidence points in the same direction: North America is not an isolated "airshed." Rather, it is a collection of emitting sources situated in a background pool of air pollution encircling the entire globe (Akimoto, 2003). When studies are undertaken of ambient air quality in North America, it may be important to take into account the contributions of sources outside North America, especially fine particles and long-lived gases, which may have significant episodic or seasonal contributions. This could be especially crucial with respect to the goals of the U.S. visibility program. To ignore such contributions may cause over-optimism regarding the provision of clean air to the people or the effectiveness of local emission control measures. Not only may future domestic attempts to reduce ozone concentrations in the United States be thwarted by a rise in global background ozone, but control of global $CH_4$ may be an effective way to reduce ozone concentrations in North America (Fiore et al., 2002). In fact, it may be necessary to consider regulating emissions and concentrations on a hemispheric scale, along the lines of the Long Range Transport of Air Pollutants Convention under the United Nations Economic Commission for Europe (Holloway et al., 2003). These developments should lead to continental-scale models utilizing boundary conditions from global models to effectively account for these interactions, which in turn will require hemispheric or global emission inventories.

### 2.3.5 Time Scales

It is increasingly clear that a better characterization of the temporal and spatial distributions of emissions will be required to assess the impact of proposed air quality management strategies and to provide reliable air quality forecasts. The long-term goal should be the maintenance of a dynamic emission inventory whose content changes in response to actual activity factors and emissions. As inputs to air quality models become more demanding, the stage is set for increased temporal resolution of emissions for major source categories.

Emission inventories were initially developed on an annual average basis. This was adequate for targeting major sectors for controls. However, as air quality models became widely used to address the atmospheric reactions contributing to acid rain and ozone, it became necessary to represent emissions with higher temporal resolution. For major source categories, this requirement was initially achieved by creating seasonal and daily emission profiles. These profiles apportioned annual emissions to weekday and weekend-day by season and used average diurnal operating profiles to achieve the desired temporal resolution (NAPAP, 1990). This approach was later extended to create the emission inventories for a typical summer day that were developed to address ozone issues (OTAG, 1997).

As controls have been implemented, it has become more important to represent actual emissions on finer and finer time scales. Seasonal allocations were replaced by monthly allocations. Field studies, which were being used to evaluate air quality models, required actual episodic emission inventories and not typical summer-day estimates (ARB, 1990; CCOS, 2000; CRPAQS, 1999-2001; TexAQS, 2000). Atmospheric modeling of fine particles will present even greater challenges. The models will require hourly emissions in order to simulate seasonal differences in secondary organic aerosol formation over an annual cycle. Meeting these emission data needs will be simplest for large utility sources as these sources are equipped with continuous emission monitoring systems (CEMS) which measure actual emissions on an hour by hour basis. Providing these data from other sources will be more challenging.

Air quality measurements in urban areas consistently show time-of-day profiles that are intimately linked to daily human activity patterns. For instance, vehicle emissions have significant temporal dynamics that tend to differ substantially for various parts of a metropolitan area. Neighborhoods containing major arterial roads will typically experience much higher rush hour emissions, with the morning emissions usually concentrated into a shorter time frame than for the evening period. Some emissions will be larger, in both flux rate and duration, when accidents or weather stall traffic. Differences in weekday and weekend traffic patterns and vehicle mix may also lead to observable "weekend effects" in air quality (Marr and Harley, 2002). Further, holiday emissions, and the resulting ambient pollutant concentrations, often vary significantly from regular workdays.

At the other end of the temporal scale it is important to document emission trends over decades. This information is required to understand the efficacy of control technologies and the evolution of air quality issues. These data are also needed to evaluate the ability to model air quality trends, and to characterize North America's contribution to global emissions.

### 2.3.6 Expanded Gaseous Species Requirements

That more chemically complete emission inventories are required to address the photochemical production of oxidants, including speciated VOC and $NO_x$ emissions, has long been recognized (NRC, 1991). The growing recognition that secondary fine PM production drives $PM_{2.5}$ levels in many environments also places a priority on increased knowledge of gaseous VOC emissions, especially aromatic and biogenic compounds whose oxidation products are known to form semivolatile species (NARSTO, 2004; NRC, 2004b). In the United States, this need could be met by improving the U.S. EPA's SPECIATE database and by increasing the number of related speciated VOC emission measurements (U.S. EPA, 2002). These improvements would benefit Canada and Mexico as well since the SPECIATE data base is used extensively across North America. Better emission inventories for precursors also will be required to characterize secondary fine PM formation (NARSTO, 2004; NRC, 2004b). The growing attention paid to ambient levels of the 188 hazardous and air pollutants and related health effects will likely require better stationary and mobile source emission inventories for a variety of aromatic (e.g. benzene, toluene), carbonyl (e.g. formaldehyde, acetaldehyde, acrolein, etc.), olefinic (e.g. 1,3 butadiene), and other priority toxic air compounds.

### 2.3.7 Expanded PM Requirements

The unsatisfactory state of current emission inventories for PM and its precursors has recently been highlighted by a U.S. NRC committee advising the U.S. EPA on research priorities for PM (NRC, 2004b). Continued progress is required to better represent the full size distribution of primary PM emissions, including ultrafine (nanoparticle) emissions from mobile sources. An improved knowledge of primary particle composition as a function of particle size is also required not only for improved understanding of the contribution of sources to ambient concentrations, but also to better understand the possible relationships between PM composition and adverse health effects. Improved characterization of direct PM emissions as well as the precursors of secondary organic aerosol formation is needed. This includes improved quantification of ammonia emissions because they are critical to understanding the formation of ammonium sulfate and ammonium nitrate. Both the elemental and organic content of primary PM requires chemical characterization. The black carbon (BC) content of PM (closely related to elemental carbon, EC) has become an important issue in determining the impact of PM on regional climate factors, including solar radiation absorption, cloud stability, and rainfall (Molina and Molina, 2004; Molina et al., 2004; Menon et al., 2002). Organic PM is known to dominate the secondary aerosol loadings in many urban areas and thus plays a key role in scattering solar radiation (IPCC, 2001).

### 2.3.8 Better Quantification of Emission Inventory Uncertainty Levels

Numerical values without well-defined error limits are basically unacceptable for any scientific purpose. Future emission inventories must be assembled with careful attention to measurement and activity factor uncertainties. Measured emissions should be evaluated to determine both statistical (measurement variability) and systematic (measurement error) uncertainties. A recent U.S. NRC report addressing PM research priorities calls for characterization of emission inventory uncertainties for both primary PM and secondary PM precursors (NRC, 2004b).

### 2.3.9 Consistent and Harmonized Data

Emission inventories are needed to address air quality issues at a variety of geographic and temporal scales. Developing compatible inventories facilitates sharing data, and improves efficiency and quality. The multiple temporal and spatial scales of current air quality issues discussed in this section show that emission inventories must be combined to characterize and manage problems that span state/provincial and national borders, and in some cases oceans. The combination of emission inventory data from different states and countries will not be possible unless their data collection and reporting practices are reasonably consistent. A harmonization of emission inventory data acquisition and reporting practice across North America and beyond will be necessary to deal effectively with many air quality issues. This harmonization will be important not only for current emission inventories but also for future ones in order to assess trends in emissions and air quality. Harmonization also will be required in procedures used to project emissions into the future. Such projections are essential for analysis of alternative control strategies. Thus, a family of consistent and harmonized data is needed over a variety of spatial and temporal scales to support the myriad of emission inventory applications. This consistency also is needed over extended time periods to support trends analysis of emission data.

Addressing all nine requirements should be the objective of future near-term emission inventory development activities in North America. Table 2.3 lists important attributes that will be required of these inventories. These attributes serve as targets for focusing emission inventory improvement activities in the three countries.

| Table 2.3. Attributes of Future Emission Inventories. | |
|---|---|
| **Category or Application** | **Attribute** |
| Criteria pollutants and their precursors | Include $SO_2$, $NO_x$, CO, size-differentiated PM, Pb, total VOCs, VOC reactive species, $NH_3$, elemental and organic carbon |
| Hazardous and toxic air pollutants | Include 188 listed HAPs plus persistent bioaccumulative and toxic chemicals (PBTs) |
| Greenhouse gases and aerosols | Include $CO_2$, $CH_4$, $N_2O$, BC, HFCs, PFCs, $SF_6$, |
| Point sources | All sources, with emphasis on sources that contribute 80 percent of the emissions of stationary-source pollutants<br>Process-level detail (e.g., source classification code, fuel burned, fuel characteristics, boiler capacity, activity indicator, age, operating schedule)<br>Name and location, and stack data (latitude, longitude, height, diameter, flow)<br>Control equipment (type, efficiency, age, and regulatory driver--MACT, BART, NSPS state) |
| Nonpoint or area sources | Source classification codes<br>County or local level activity,<br>Emission factors, controls, temporal factors<br>Census tracts for localized assessments |
| Mobile sources | Urban and county level vehicle miles traveled (VMT) and vehicle kilometers traveled (VKT) and fuel use, fleet characteristics, diurnal and seasonal temperature profiles, and nonroad equipment populations |
| Natural or biogenic sources | County or local species, daily meteorological data, emission factors, species profiles |
| Emission factors | Up-to-date and comprehensive factors for all pollutants and source categories |
| Speciation profiles | Up-to-date and comprehensive profiles for VOC species and PM size fractions with chemical composition |
| Temporal profiles | Up-to-date and comprehensive profiles representing hourly, daily, and seasonal emissions by major source categories over the annual cycle. |
| Spatial profiles | Up-to-date and comprehensive profiles for allocation of emissions by major source category to 1 km grids across the continent. |
| Measurement methods | Continuous methods for major sources<br>Accurate and affordable methods for all pollutants and sources |
| Data collection techniques | Timely and affordable survey techniques<br>Satellite data for ground cover and fires |
| Timeliness | Annual reporting of emission inventories (e.g., point sources in first quarter; mobile, area and biogenic sources in second quarter; quality assurance in third quarter; composite in fourth quarter) |
| Daily forecasting and recording | CEM data for the largest point sources<br>Load forecast for the largest emitting sources.<br>Mobile source indicators of events (major traffic events--accidents, ball games, etc)<br>Area sources (Major upset events --i.e. fires, spills, accidental releases) |
| Future year predictions and forecasting | Reliable forecasts for specific years, seasons, or other periods of interest<br>Emission forecasts for largest sources or categories linked to economic forecasts<br>Links to transportation planning |
| Analysis of trends | Annual trends for criteria and hazardous air pollutant emissions<br>Annual trends for greenhouse gases and aerosols<br>Accurate indicators of progress in emission reductions |

**Table 2.3. Concluded.**

| Category or Application | Attribute |
|---|---|
| Accessibility | Electronic reporting and data exchange among sources and governmental entities<br>Internet-based electronic access to data and exchange of information<br>Distributed network that facilitates sharing among inventory developers and users |
| Accuracy and quality control | Avoid missing sources and double entry of sources<br>Avoid sources in wrong location<br>Avoid sources with unreasonable flow rates from stacks<br>Avoid missing data on key parameters<br>Quickly recognize and correct data entry errors<br>Uncertainty indicators for all data elements and composites<br>Provide evaluation criteria with complementary measurements (e.g., tunnel studies, aircraft studies, source region studies) |
| Affordability | Software for effective data entry, data computation, data exchange, quality control, and quality assurance<br>Optimize intensive manpower and time consuming steps<br>Affordable emission factor characterization – keep step with technology changes |
| Transparency | All material documented, inventories transportable, calculations reproducible |
| National and international exchange | Electronic data exchange among<br>- United States: states, tribes, localities and regional consortiums<br>- Canada: provinces, and localities<br>- Mexico: states, and localities<br>- Europe and Asia |

## 2.4 CHALLENGES FOR DEVELOPING AND MAINTAINING ENHANCED NORTH AMERICAN EMISSION INVENTORIES

Meeting the requirements for future emission inventories calls for a number of actions to be taken by the individuals and teams who develop the inventories and by the organizations that fund them. These actions range from dealing with personnel issues to embracing the new technologies that will be needed to develop the inventories and to facilitate their accessibility by users.

### 2.4.1 Recognizing Scientific and Professional Motivation Problems

Gathering emission and activity factor data and constructing emission inventories for air quality assessment and management have not traditionally been regarded as technically glamorous pursuits. Scientists who mount successful field measurement campaigns, conduct laboratory experiments to characterize atmospheric pollution, or construct elaborate atmospheric models to explain current observations and predict future pollution levels and impacts, are far more likely to have their efforts widely recognized. Constructing and improving emission inventories is painstaking and laborious, and many field studies of ambient air quality have utilized available information without investing in additional improvements for emission inventories.

However, there is a growing recognition that insufficient knowledge of emission quantities, chemical speciation, spatial distributions, and temporal variations are seriously hampering progress in understanding and managing a wide range of air quality issues. As air quality models and measurements become more sophisticated and comprehensive, inconsistencies due to inadequate knowledge of emissions become more frequent. For example, recent measurements in Mexico City (Arriaga-Colina et al., 2004) show that the VOC/$NO_x$ and CO/$NO_x$ ratios calculated from the official 1998 emission inventory for that critical metropolitan area are low by a factor of 2.5 to 3. As a result, attempts to model air quality based on the official emission inventory do not reproduce observed photochemical oxidant levels. Recommendations have been made for significantly improving Mexico City's emission inventory (Molina and Molina, 2002), and an effort to significantly improve it is now underway. Such problems are not limited to the newly developed Mexican inventories. The Texas Air Quality Study in 2000 also found that emissions of certain VOC species from stationary sources were low by factors of 10 to 100 in the Houston area (TexAQS, 2000), leading to additional efforts to improve that inventory.

Global issues such as stratospheric ozone depletion and greenhouse-gas-driven climate change have demonstrated that sustained, international efforts are required to develop improved emission inventories for forcing species (IPCC, 2001; WMO, 2002). Administration of international treaties addressing these issues such as the Montreal Protocol and the Kyoto Protocol is dependent on accurate inventories for ozone depleting and radiative forcing substances. Consequently, the creators of those high-profile emission inventories are better supported and their contributions are recognized by publication in leading journals and inclusion in international assessments (IPCC, 2001; WMO, 2002).

Improving the completeness, accuracy, and timeliness of North American emission inventories will require dedicated and talented technical professionals equipped with innovative measurement and emission modeling tools. In order for the vision of improved North American emission inventories to be realized, high quality scientists and engineers must be recruited and supported to develop and utilize innovative and effective methods to improve and expand emission inventories. This will require enhanced and sustained support for those performing emission inventory research, development, and maintenance activities. Resource needs for achieving these improvements are discussed in more detail in Chapter 3.

### 2.4.2 Utilizing New Tools and Techniques

Part of the challenge of increasing the accuracy, coverage, resolution, and timeliness of North American emission inventories can be met by enlisting new technologies and using them to develop new strategies. Emission inventories are information, and the general advance in information technology is both rapid and profound. Revolutionary methods for acquiring data (real-time sensors, sensor networks, remote sensing), transmitting data (internet, cell phones, wireless networks), accessing data (massive electronic storage systems, search engines, relational data bases), and assessing data (expert systems, sensor fusion algorithms, pattern recognition, image analysis) are rapidly changing they way North Americans acquire and use information in their professional and personal lives. The convenience and power of evolving information technologies, broadly defined, must be harnessed to produce comprehensive and dynamic emission inventories to replace the more limited and static versions currently available. Chapter 6 of this report presents descriptions and discussions of a number of innovative measurement systems and strategies currently used in emission research activities that might be more widely utilized to produce enhanced emission inventories.

Data-gathering systems currently being deployed for other purposes might be utilized to produce higher spatial resolution and/or dynamic emission inventories. For instance, since vehicle emissions are a major source of both primary pollutants and secondary pollutant precursors, any high temporal and spatial resolution information on vehicle activity factors or vehicle emissions would be invaluable input for air quality exposure or forecast models. In many North American metropolitan areas, a surprisingly large amount of traffic data is already being gathered each day. Many major urban areas in Canada and the United States have systems of airborne (eye-in-the-sky) and/or roadside video cameras used to relay traffic reports to the commuting public and/or city transportation officials. Video systems are sometimes supplemented by pneumatic or magnetic vehicle counters deployed on key roads. The activity factors recorded by these systems could be routinely captured, their images/data analyzed and interpreted automatically, to inform a dynamic emission inventory.

Mexico City officials have recently deployed video cameras imaging over a hundred key traffic points in the Federal District. The main purpose of these surveillance cameras is to observe the vehicular congestion and adjust traffic lights as well as to monitor safety on the streets. Although not the main purpose of these surveillance cameras, a recent Mexico City air quality field measurement program used data from these cameras to assess time-resolved traffic intensity and vehicle mix to help interpret real-time ambient pollutant measurements near major roadways. There is no insurmountable technical barrier to capturing and processing these data in real-time on a daily basis.

There may even be opportunities to capture actual vehicle emission measurements. For instance, several U.S. states are experimenting with the routine deployment of cross-road remote sensing systems to "clean screen" onroad vehicles in non-attainment regions. If the NO, CO, and VOC emissions of individual vehicles are shown to be acceptable in a specified number of sensor encounters, the license plate image is used to identify the vehicle's owner who is excused from traditional exhaust inspection procedures for that year. Each "clean screen" sensor is evaluating and recording the real-time exhaust emissions for thousands of vehicles per day under certain limited operating conditions. The data may be useful for emission inventory improvement in the future. For instance, these data could be used to quickly recognize changes in onroad vehicle emissions due to a change in local fuel formulation or a variation in average vehicle speed caused by a change in road conditions or traffic patterns.

The increasing use and reliability of continuous emission monitors on major point sources also presents an opportunity to make emission inventories dynamic. The information on real-time stack emissions could be routinely transmitted to a dynamic emission inventory model that showed the variation in emissions as unit production fluctuates in response to demand. This information, coupled with forecasts of electricity generating load by plant, could provide valuable information to air quality forecasting programs.

The examples of strategies to obtain more robust and dynamic activity factor and/or emission data for future emission inventories noted above are suggestive, not comprehensive. They were selected to make the point that information technology is advancing, and that efforts to construct and maintain better emission inventories will need to take maximum advantage of society's general tendancy to gather more data in a more timely manner in many spheres of activity.

### 2.4.3 Improving Emission Models

Emission models for point, nonpoint, and mobile sources are becoming more sophisticated. Efforts to capture wider ranges of sources and better apportion emissions in time and space are bearing fruit. Nevertheless, significant weaknesses remain in representing offroad and some onroad mobile sources and stationary area sources. Also, source categories whose emissions are dominated by a small fraction of random events or high emitters can be especially difficult to characterize.

Successful deployment of emission models across North America requires not only the improvement of existing emission models but also the development of models which are consistent across countries. This requirement is most apparent for models of mobile source emissions but it also applies for many emission models for stationary nonpoint source categories.

### 2.4.4 Enhancing Data Integration and Access

Emission inventory data need to be more accessible in forms relevant for a variety of applications and users. For instance, there is a clear need to integrate emission data from multiple inventories in order to support public outreach, emission trends reporting, control strategy application studies, benefit analyses, and estimation of air quality in large regional areas. The overarching challenge in developing a comprehensive emission inventory is to integrate data that are distributed among many sources without requiring strict data format standards or introducing a new repository to centrally store and maintain the data. The objective is to create a network of data and associated tools that is:

- Distributed. Data are shared but remain distributed and maintained by their original inventory organizations. The data are dynamically accessed from multiple sources through the internet rather than collecting all emission data in a single repository.
- Non-intrusive. The technologies needed to bring inventory nodes together in a distributed network need not be intrusive in the sense of requiring substantial modifications by the emission inventory organizations in order to participate.
- Transparent. From the emission inventory user's perspective, the distributed data should appear to originate from a single database to the end user and should include supplemental documentation (metadata). One point of access and one interface to multiple data sets are desired without required special software on the user's computer.
- Flexible/Extendable. An emission network should be designed with the ability to easily incorporate new data and tools from new nodes joining the network so that they can be integrated with existing data and tools. One example would be the capability to assess the impact of changes in emission factors as technology and controls change over time.

The guiding principles of an integrated emission inventory follow those of distributed databases and distributed computing. Innovative information technologies and increasing collaboration among emission inventory organizations are leading to the creation of a network that shares data for easier access and integration while maintaining each individual inventory's existing system of data management. Spatial data should be available in a Geographical Information System (GIS) format that can display emissions from point, area, and mobile sources on a range of scales from neighborhood to hemispheric. Ideally, temporal data will be formatted so that spatially resolved movies of trends in temporal emissions can be visualized for appropriate time scales.

### 2.4.5 Fostering International Cooperation

It is clear from both the scientific and policy perspectives that effective management of air quality in North America requires cooperation among the three countries of the continent. It is also becoming apparent that oceans are ineffective barriers to air pollution, and that increasing emissions in Asia and Africa may contribute to the decline of air quality in North America. These observations suggest that there will be future requirements for each continent in the northern hemisphere to construct and maintain comprehensive, robust and dynamic emission inventories for exchange as well as internal use. Ideally, the international cooperation that has been necessary to develop accepted global emission inventories for substances that deplete stratospheric ozone (WMO, 2002) or drive global warming (IPCC, 2001) will be replicated to achieve this goal.

In North America, the environmental impacts of manufacturing and transportation activities will respond to changes stimulated by the North America Free Trade Agreement. Cooperative programs aimed at environmental improvement are supported by the Commission for Environmental Cooperation, which maintains an active air quality program that includes efforts to encourage better emission reporting from all three North American countries.

The diversity of inventory-related needs among Canada, the United States, and Mexico should be noted. Stemming from geographical and industrial differences as well as varying states of inventory development, this diversity suggests that Canada, the United States, and Mexico should place different emphases on immediate development efforts in several specific areas. Table 2.2 provides an indication of these varying emphasis levels for Canada, the United States, and Mexico. However, international cooperation should continue to be enhanced to ensure compatibility and comparability among emission inventories for North America.

### 2.4.6 Coordinating Prioritization of Enhanced Emission Inventory Development

Section 2.2 cataloged the increasing number of societal-driven air-quality issues requiring comprehensive emission inventories, and Section 2.3 outlined the expanded ranges of chemical species, spatial scales, and temporal resolutions that emission inventories must consider. This range of air quality problems that require effective management and their corresponding needs for emission inventories with enhanced chemical content, spatial coverage, and temporal resolution, will place severe demands on the chronically under-funded emission inventory community. Prioritizing resource allocation so that ongoing efforts will yield the most crucially needed inventory improvements of the three North American nations will be a continual challenge.

Efficient use of scarce resources will require an effective prioritization process that includes key stakeholders on scales from municipal, to state/provincial, regional, national and, as noted above, continental to global. Further, emission inventory priorities will change both as progress is made and as society's concern about specific air quality and global change issues shift; so today's emission inventory priority list will need updating tomorrow. Broadly based technical organizations, such as NARSTO, the CEC, and others, may be helpful in setting and reviewing emission inventory priorities and coordinating enhanced emission inventory development to meet these serious technical and financial challenges. The issue of prioritization and a set of suggested initial action plan for achieving the highest priorities in emission inventory improvement is discussed in more detail in Chapter 9.

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