

APPENDIX A. EMISSION CALCULATIONS AND INVENTORY LISTINGS

This appendix contains two components that supplement the discussion in Chapter 4. The first component is a summary of the methods for calculating emissions, including uncertainties in the methods. The second component is a listing of the emission inventories for the United States and Canada by detailed source category.

A.1 HOW ARE EMISSIONS CALCULATED?

The methods for emission-inventory preparation are generally similar in the three nations. Historically they derive from work begun in the 1960s in the United States, represented in three early documents that set the stage for continuing development and refinement of present-day inventories (U.S. HEW, 1965; U.S. HEW, 1966; U.S. HEW, 1968). The basic method for estimating emissions follows a simple conceptual formula described by:

$$E = A \times EF (1-ER/100),$$

where E = emission rate,

A = the activity rate,

EF = the emission factor, and

ER = overall emission reduction factor (%).

A.1.1 Emission and Emission Reduction Factors

The emission factors (EF) can be as simple as an average rate per unit process input. In most cases, EFs depend on many variables such as process parameters, effluent temperature, ambient temperature, wind speed, and soil moisture. In these cases the formula is applied to estimate emissions for a particular set of conditions. Under some circumstances, such as the current inventorying of

PM_{2.5}, EFs and estimation techniques are applied for analyses other than those for which they were developed. This arises most frequently when emerging air-quality issues overtake the rate of test-data acquisition. Emission factors represent an average of a range of emission rates corresponding to a specific technology under various operating conditions, or to engineering estimation of facility operations or processes within facilities. The EFs are derived for units of different capacity, and often processes are reviewed over a period of years to capture changes in operating conditions and modifications in the technology either from maintenance, or from wear and tear during use. The accuracy and representativeness of the EF are determined by the reliability of the testing methodology, how uniformly it is applied across sources, or the engineering process information used to derive the EFs. Differences arise between nations, and for different geographical or climatic conditions. Examples of such differences include factors for motor vehicles, fugitive-dust generation from unpaved roads, and dust or NH₃ emissions from agricultural operations. Data on representative EFs are available from national regulatory sources; e.g., U.S. EPA (2001); EPA (1999); EPA (2000).

Spatial and temporal resolutions of point and areal sources are limited in the current inventories, which are compiled typically on an annual-census division basis. Improved spatial resolution is accomplished by assigning a location of major sources according to conventional survey mapping, the use of population census, GIS positioning, and characteristic meteorological conditions, using stack geometry, effluent temperature and velocity, combined with ambient conditions, including temperature, plume buoyancy, and wind speed.

Emission factors for some emission categories are more reliable than others. In some cases an EF may not be available for a source category because of insufficient or unacceptable data for generalization across source type. Often it is difficult to determine precisely what the certainty in the EF is. Thus, the

application of EFs requires subjectivity and judgment from cognizant technical staff for the application of concern. While documented EFs are used to complete areally coarse inventories for various purposes, the generic values may be quite unreliable and are not necessarily recommended by federal or state agencies for finer-scale applications needed to study the impacts of specific sources. Users of EFs in national, regional- and urban-scale studies should be cognizant of their potential limitations, and other techniques should be considered to improve the confidence in the emission inventories. Several such approaches have been developed: continuous emission-monitoring sensors (CEMs, e.g., for SO₂ and NO_x from large utility boilers), material balances, specialized source profiling for composition and compositional material balances, source sampling to obtain improved particle-size distributions and location-specific emission rates, near-source ambient characterization, and (especially) source-apportionment techniques as discussed in Chapter 7.

The reliability of EF estimation decreases when only a few source tests are used as the basis of the factor, or when judgmental decisions are made from analogy between technologies. Differences in EF estimates also can develop if the current operations or processes are significantly different from those upon which the original EFs were derived. A good example of this is the recent re-evaluation of hazardous air pollution (HAP) emissions from power plants, which showed major differences between EF literature values and measurements from current plants (EPRI, 1994). As a result of the application of the newly acquired data, the risk of exposure to HAPs from current power plants was shown generally to be less than indicated by the original EFs. However, the cost of obtaining the emission information for representative U.S. plants was very high for EPRI and the U.S. Department of Energy, amounting to more than \$40 million over about four years.

The emission-reduction factor (ER) accounts for emission controls employed on a source. These include 1) various effluent exit devices such as bag house filters and electrostatic precipitators for removal of particles, 2) scrubbers for SO₂ removal, 3) low-NO_x combustors in boilers or selective NO_x-reduction technologies, and 4) VOC absorbers, or effluent-gas combustors. Emission-control devices

have pollutant ERs for PM that generally exceed 98 percent for precipitators and filters, but can be much lower for scrubbers and cyclones. Post-combustion devices for SO₂, VOC and NO_x have ERs in the range of 50 to over 95 percent depending on their design and performance.

Like other process equipment, emission controls have variable operating performance depending on their design, maintenance, and the nature of the process controlled. Thus like EFs, values of ERs are overall averages for specific processes and emission-control designs based on limited testing. Actual values of ERs vary in time and by process in an undocumented manner, adding uncertainty to emission estimates.

A.1.2 Activity Patterns

Activity patterns (A) describe the average temporal operating characteristics of a process, including estimates of the down time for maintenance or process failure. Values of A for point, area, and transportation sources are each obtained in different ways owing to the differing nature of the sources.

Most point sources or industrial sources operate with local permits, and these require information about process emissions, including temporal characteristics. For sources with CEMs installed for monitoring SO₂, NO_x, and opacity (roughly proportional to fine PM loading), such as large electric utility boilers, real-time data are available to derive activity patterns, and deduce emission variability over extended time periods. Furthermore, point sources keep (and report) records of output during operating periods, and maintenance or other down times. One of the difficulties in obtaining point-source information in Canada and Mexico, is these countries' restriction on confidentiality of operating data. In the United States, these data are generally more available for regulatory analyses.

There is a great deal of complexity in acquiring activity data for area sources, which are diverse in character, individually small, and often intermittent, but collectively significant. Though such sources are difficult to characterize, they are generally important to PM emission estimation because their aggregated mass emissions can be large and their chemical

composition may be important for estimating source attribution. One example of such sources is commercial frying or char-broiling, which has been found to be a surprising large contributor to $PM_{2.5}$ and VOC emissions in such cities as Los Angeles (e.g., Hildemann et al., 1994). Another areal source is fugitive-dust generation from road traffic, or agricultural operations, which again is a large contribution to primary $PM_{2.5}$. Forest and brush fires, as well as agricultural burning, are other potentially large sources of ambient primary PM. Another areal source is fugitive-dust generation from road traffic, construction, and agricultural operations, which again are large contributions to primary $PM_{2.5}$. Forest and brush fires, burning of land-clearing debris, and agricultural burning are also potentially large sources of ambient primary PM.

Temporal resolution depends on allocation of emissions aggregated seasonally, weekly, daily or by diurnal variation, depending on use and industry activity patterns. The temporal allocations allow for improved approximation of the actual temporal patterns that can be important not only for precise annual averaging using seasonal or daily allocations, but also for short-term health exposures or visibility impairment taken over periods of 24 hours or less. "Typical" temporal variations for different sources have been developed from surveys, activity analyses and expert consensus. These temporal models are approximations that may deviate substantially from actual emissions in a given location. Depending on the requirements for precision in estimations, local testing through observations and activity data may be required, not only for large point or area sources, but for smaller ones that may be of special interest.

For areal sources, emissions can be estimated coarsely from "top-down" measures of activity at the provincial- state- or national-level demographics, land use, and economic activity. The construction industry, for example, is based on the total annual expenditures at the province or (U.S. EPA) region level. These estimates are then allocated by census unit or county, using a procedure linked with construction costs and estimated area under construction. The construction-industry emission estimates in Canada, for example, are based on the total annual expenditures at the province level. These estimates are then allocated by census unit or county

using a procedure linked with construction costs and estimated area under construction. This approach clearly results in approximations of varying degrees of accuracy at the county level. In contrast, in the United States, these data are obtained at the county level and are thus more spatially reliable.

Because of their potential importance as PM sources, considerable effort has been devoted recently to the characterization of emissions and activity patterns for areal sources, both in Canada and the United States. The Canadian effort as applied to forest fires and fugitive dust from agricultural sources contains more detail than the U.S. counterpart. In Mexico, one of the recognized important limitations in emission estimation to date is fugitive dust.

Estimation of emissions from fires depends upon knowledge of the time, location and areal extent of the burn, fuel loading, types of combustible material and moisture content. Several federal, state, and provincial agencies, as well as private landowners, conduct managed burns, and accidental wild land fires occur frequently. Thus far, the knowledge base is incomplete and a concentrated effort is needed to compile a timely database of these data.

Residential wood burning also is an important local source. Quantification of emissions from this source category has been approached through acquisition of data on how much fuel is burned in fireplaces and stoves using national consumption estimates. Where this source is especially large, local surveys of firewood use may be conducted. In some areas, residential or industrial open burning may occur; this is handled in a similar way with local surveys to augment larger scale estimates (e.g., The Valley of Mexico).

Mobile source-emission estimation is a complex issue in urban areas. The EF for vehicles, for example, is given in terms of mass per vehicle-mile traveled, or mass per mass of fuel consumed. It is obviously impractical to trace vehicle-use patterns, operational differences, and fleet emissions in every city. Therefore, characteristic information has been compiled using standardized vehicle laboratory simulations that represent average vehicle-use behavior. A similar complexity is apparent in the EFs and usage of non-road equipment, e.g., tractors,

APPENDIX A

construction equipment, lawn mowers. These EF and activity data have been synthesized using national mobile activity models such as the MOBILE and Non Road (NR) emission models.

Despite continued refinements to MOBILE and NR, mobile-source emission estimation remains one of the largest areas of controversy in emission characterization. Part of this issue stems from vehicle EFs, which are known to change with the model, age and maintenance of the vehicle, and part stems from the assumed activity profile. The variation over a period of time is poorly documented for both of the activity patterns and EFs. Driving patterns in urban areas vary somewhat by season, by workday vs. weekend, and by specific city. The emission model adopts a “universal” activity profile based on a combination of average driving patterns and the results of laboratory engine testing, both of which cannot capture local or national practices. The mobile-source models are continuously being modified and upgraded using new data. However, their ability to quantitatively capture PM and reactive-gas emissions from a changing fleet of vehicles used in many different ways remains problematic. With the exception of California, which uses the EMFAC model, the MOBILE model is used universally in the United States, Canada, and Mexico for making emission estimates of light-duty, on-road vehicles. However, both the EFs and the activity component are unlikely to apply without modification for cross-national driving conditions. Canada has made certain modifications (MOBILE VC) for its use. Mexico has used a modified version of MOBILE V for application in border cities like Juarez. However, mobile-source emissions remain a major uncertainty for all urban areas in Mexico, which currently is working on additional modifications of MOBILE that will better reflect its driving and fleet conditions.

A.1.3 Spatial Allocation

The national, provincial, and state emission inventories have spatial disaggregation to census level or to county. For many spatially resolved analyses, however, emissions are required in a uniform geographic grid that necessitates assignment

of emissions into the grid from the county or census unit data. This can be done readily for point sources, which are identified by latitude and longitude or some other specific locator. However, the majority of area, mobile, and natural-emission categories are not as geographically discrete as point sources. Thus, spatial allocation is required to estimate their location within a domain of interest. This is accomplished through emission-processing systems (EPS). To facilitate this, each category is assigned a spatial surrogate based on a probability of occurrence for each source category. For example, water surface area is typically thought to be a spatial surrogate for allocating shipping and marine pleasure craft. Many categories use population as their allocation surrogate. However, a number of categories don't have highly correlated spatial surrogates, e.g., residential wood combustion and land clearing.

Natural emissions currently are based on spatially resolved data, or estimated from emission models. These sources are typically based on emission factors applied to land use and vegetative cover defined at the census or county level, or within a CTM grid. Currently the biogenic emission-inventory system (BEIS) has been adopted by all three nations to estimate VOC and soil-NO_x emissions (e.g., Geron et al., 2000). In the United States, for example, this model can be used on a one-kilometer resolved vegetation database. The natural NO_x and VOC emissions are generally calculated with spatial resolution within the CTM framework, and are not generally reported in the national inventories. Of most concern in recent modeling for secondary PM_{2.5} production are terpenes and other high molecular-weight volatile compounds of biogenic origin.

Many mobile-source categories have geographically based surrogates, or linear transportation networks (e.g., road maps), for which emissions are assigned. For these sources, emissions can be adjusted to represent activity occurring along each particular segment of the link. Highway vehicles are assigned to road networks, commercial marine vessels are assigned to shipping lanes, and locomotives are assigned to railway routes. Each of these networks is reviewed for updating when new roads, channels, or other linkages are deployed.

A.1.4 Processing for Model Applications.

As noted above, the emission input for air-quality modeling (CTMs) generally requires manipulation of the national inventory data to prepare appropriate temporal and spatial resolution for model computations. The CTMs basically yield four-dimensional numerical solutions for the coupled mass-balance equations for the major contributing species making up PM; these include hourly, and spatial grid-resolved estimates to 50 km or less. To convert the conventional inventory into the needed input for the CTMs, the EPS software is required, including primary PM sources and gaseous precursors, as well as estimations of reactive chemical species, such as VOC categories by source type (e.g., Dickson and Oliver, 1991). Chemical speciation is particularly important for VOCs, where the inventories report only total emissions while the CTMs require more detailed emission information for individual VOCs or groups of VOC species. The ability of the EPS to bridge the differences between the emission-inventory characteristics and the CTM requirements makes them a useful means for merging and analyzing emission information.

A number of EPSs are available, including CEPS, MEPS and SMOKE. These have certain common features including:

- Estimation of the variation of emissions by season defined in terms of a sequence of three calendar months with winter beginning in December.
- Estimation of species and source categories outside the inventory listing to accommodate missing information from inventory files, for example, NH_3 emissions and on-road mobile-source emissions for SO_2 , $\text{PM}_{2.5}$ and PM_{10} .
- Estimation of emissions as a function of space and time, including the effective height of injection into the atmosphere.
- Estimations of biogenic VOC and NO_x emissions from vegetation and soils, including the influence of meteorological conditions and land use.
- Estimation of potential VOC contributions to PM.

Typically biogenic VOC and NO_x emissions are estimated hourly for mid-season months, January, April, July and October. These are based on three-hour gridded, objectively analyzed meteorological fields for North America for each day of the four months, and then are summed for each month and multiplied by three to scale to annual emissions. While a simplification, the emission estimates from BEIS are believed to be sufficiently representative to provide a relative comparison with emissions of anthropogenic source types. While biogenic sulfur emissions are known to exist and can be large locally, particularly in coastal areas, or inter-tidal zones, they are not currently estimated in the EPS.

To facilitate estimation of potential VOC contributions to PM mass concentration, a detailed CTM species set is used in the EPS. Five gas-phase groups, SO_2 , NH_3 , NO_x , VOC, and CO are currently tabulated by the CEPS into 80 to 90 gas-phase species for the AURAMS model, including individual or aggregated VOC species. The higher molecular-weight fraction or the aromatic grouping then can be separated from the oxidant, producing components to estimate PM formation.

A.1.5 Limitations and Uncertainties

Certain fundamental issues limit the application of estimation methods and should be kept in mind. With regard to the EFs, average emissions differ significantly from source-to-source even within the same category and, therefore, EFs may not provide adequate estimates of average emissions for a specific source. The extent of between-source variability that exists, even among similar individual sources, can be large depending on source type. Although the causes of this variability are considered in EF development, this type of information is seldom included in emission-test reports used to develop factors for the U.S. EPA AP-42 emission-inventory manual (U.S. EPA, 2001). As a result, some EFs are derived from tests that may vary by an order of magnitude or more. Even when the major process variables are accounted for, the EFs developed may be the result of averaging tests that differ by factor of five or more.

APPENDIX A

Air-pollution control techniques also may cause differing emission characteristics, both in rate and in variation in emitted size distributions and chemical composition. These variations are not well documented even for large point sources in the AP-42 manual. Often the nature of the variables are not documented in test reports, at least in a form conducive to detailed analysis of parameter variation, and thus cannot be accounted for the EF estimates. In the case of fugitive emissions, the type and volume of traffic, road-cleaning techniques, the use of different roadbed material for unpaved roads, soil type and moisture all influence the material suspended. In the case of windblown dust, a “reservoir effect” where loose materials are removed initially can limit the duration of a wind event. This effect is also a factor in paved-road emissions.

Using EFs to estimate short-term emissions adds further uncertainty to emission estimates: short-term emissions from a specific source, within-source variability, fluctuations in process operating conditions, control-device operating conditions, raw material characteristics, ambient conditions and other factors. EFs generally are developed to represent long-term average emissions, so testing is usually conducted under normal operating conditions. Parameters that can cause short-term fluctuations are generally avoided in testing and are taken into account in test evaluation. Thus, using EFs to estimate short-term emissions will create increased uncertainty in the inventory. To assess within-source variability and the range of short-term emissions from a source, a number of tests are needed over an extended period of time, or continuous monitoring is required. This kind of testing is rarely done without continuous monitoring because of the costs.

Uncertainty in activity patterns for a given source category varies as well, with type of source, averaging time, and normal vs. upset conditions, including shutdowns for maintenance. The idealized diurnal, weekly, or seasonal patterns can deviate substantially from real conditions so that estimates are usually considered long-term representations of normal operating conditions. The extent of random or non-random deviations is rarely documented in emission

inventories, even in cases where short-term modeling is done.

The information resulting in EF and activity profiles, as well as profiles of chemical composition, are obviously a concern, representing large uncertainty in the inventories. In addition to the possibility that technology improvements or emission controls may have changed, it is often not known whether or not comparable testing methods were used for equivalent emission estimates. In most cases the testing methods or equipment add uncertainties in themselves, and these usually are not well documented in time. This is particularly the case of carbonaceous material. In one example, VOC (C_2 - C_{12}) profiles available in the inventories are responsive to photochemical modeling for oxidant formation. Above carbon number 6, the range of compounds increases dramatically, and many found in the atmosphere have not been identified. The VOC profiles focus on low molecular-weight species affecting the total VOC volume concentration rather than the smaller volume fraction representing high molecular-weight material relevant to particles. These organic compounds of carbon number 6 and higher are particularly difficult to identify and quantify by routine analytical methods. Nevertheless, observations of at least some of the higher molecular-weight organic vapors are now underway in research programs of Canada and the United States.

Canada and the United States have made sustained progress in assigning accurate spatial and temporal profiles for most point sources and many area (transportation) sources, as has Mexico for the case of Mexico City. However, EFs for many area and non-road sources remain to be characterized, especially in Mexico. To improve spatial and temporal resolution, continued investigation of such categories as domestic and small commercial enterprises to open sources, such as agricultural activity for dust and NH_3 , open burning or vegetation fires, dust emissions from different road configurations, and windblown dust releases are important to all three countries. Improvements are warranted for these sources at the local, provincial and state levels as well as in the national inventories.

A.2 EMISSION INVENTORIES BY DETAILED SOURCE CATEGORY

This appendix section provides a detailed listing of 1999 national emissions for the United States (Table A.1) and Canada (Table A.2). The listing is intended to supplement the summary emissions found in Chapter 4 and to provide the reader with knowledge about the emission categories used by the two countries, so that they may be compared.

APPENDIX A

Table A.1. 1999 U.S national emissions for PM and related pollutants (thousand short tons).

Source Category	NO_x	VOC	PM₁₀	PM_{2.5}	SO₂	NH₃
FUEL COMB. ELEC. UTIL	5,715	56	225	128	12,698	7
Coal	4,935	29	194	102	11,856	0
bituminous	3,229	0	131	61	8,806	0
subbituminous	1,504	0	46	30	2,427	0
anthracite & lignite	202	0	17	11	623	0
other	0	29	0	0	0	0
Oil	202	5	5	4	657	3
residual	199	0	5	4	651	v
distillate	3	0	0	0	6	0
other	0	5	0	0	0	3
Gas	385	9	1	1	12	4
natural	367	0	0	0	0	0
process	18	0	0	0	0	0
other	0	9	1	1	12	4
Other	26	1	7	3	115	0
Internal Combustion	167	11	19	19	58	0
FUEL COMB. INDUSTRIAL	3,136	178	236	151	2,805	34
Coal	542	7	74	24	1,317	0
bituminous	370	0	44	18	890	0
subbituminous	46	0	5	3	64	0
anthracite & lignite	18	0	1	0	57	0
other	108	7	23	2	306	0
Oil	214	8	43	24	757	4
residual	129	0	35	20	574	0
distillate	73	0	7	4	159	0
other	11	8	1	0	24	4
Gas	1,202	60	43	39	576	25
natural	985	0	28	25	0	0
process	214	0	14	14	0	0
other	3	60	0	0	576	25
Other	118	35	60	49	135	0
wood/bark waste	82	0	53	43	0	0
liquid waste	8	0	1	0	0	0
other	28	35	6	5	135	0
Internal Combustion	1,059	69	17	15	20	5
FUEL COMB. OTHER	1,175	670	568	487	588	7
Commercial/Institutional Coal	37	1	17	7	196	0
Commercial/Institutional Oil	80	3	9	4	246	2
Commercial/Institutional Gas	266	15	8	7	11	1
Misc. Fuel Comb. (Except Residential)	28	10	81	81	6	0
Residential Wood	40	608	431	374	6	0
fireplaces	0	512	359	359	0	0
woodstoves	0	39	36	14	0	0
other	40	57	35	0	6	0

EMISSION CALCULATIONS AND INVENTORY LISTINGS

Table A.1. 1999 U.S national emissions for PM and related pollutants (thousand short tons) (continued).

Source Category	NO _x	VOC	PM ₁₀	PM _{2.5}	SO ₂	NH ₃
FUEL COMB. OTHER (continued)						
Residential Other	723	34	22	14	123	4
distillate oil	175	0	0	0	98	0
natural gas	433	0	0	0	18	0
other	116	34	22	14	6	4
CHEMICAL & ALLIED PRODUCT MFG	131	395	66	40	262	133
Organic Chemical Mfg	21	138	30	12	4	0
ethylene oxide mfg	0	0	0	0	0	0
terephthalic acid mfg	0	11	0	0	0	0
phenol mfg	0	2	0	0	0	0
ethylene mfg	0	5	0	0	0	0
charcoal mfg	0	32	0	0	0	0
socmi reactor	0	29	0	0	0	0
socmi distillation	0	4	0	0	0	0
socmi batch	0	0	0	0	0	0
socmi air oxidation processes	0	1	0	0	0	0
socmi fugitives	0	42	0	0	0	0
other	21	12	30	12	4	0
Inorganic Chemical Mfg	6	3	4	3	179	0
pigments; TiO ₂ chloride process: reactor	0	0	0	0	0	0
sulfur compounds	0	0	0	0	177	0
other	6	3	4	3	2	0
Polymer & Resin Mfg	3	124	3	2	1	0
polypropylene mfg	0	2	0	0	0	0
polyethylene mfg	0	17	0	0	0	0
polystyrene resins	0	3	0	0	0	0
synthetic fiber	0	83	0	0	0	0
styrene/butadiene rubber	0	7	0	0	0	0
leaks from polymer mfg.	0	0	0	0	0	0
other	3	13	3	2	1	0
Agricultural Chemical Mfg	53	8	9	6	1	118
Ammonium Nitrate/Urea Mfg.	0	0	0	0	0	44
other	53	8	9	6	1	73
Paint, Varnish, Lacquer, Enamel Mfg	0	8	1	0	0	0
paint & varnish mfg	0	6	0	0	0	0
other	0	2	1	0	0	0
Pharmaceutical Mfg	0	8	0	0	0	0
Other Chemical Mfg	47	107	19	17	76	15
carbon black mfg	0	28	0	0	0	0
printing ink mfg	0	1	0	0	0	0
fugitives unclassified	0	13	0	0	0	0
carbon black furnace: fugitives	0	0	0	0	0	0
other	47	65	19	17	76	15

APPENDIX A

Table A.1. 1999 U.S national emissions for PM and related pollutants (thousand short tons) (continued).

Source Category	NO _x	VOC	PM ₁₀	PM _{2.5}	SO ₂	NH ₃
METALS PROCESSING	88	77	147	103	401	5
Non-Ferrous Metals Processing	12	20	35	23	272	0
aluminum anode baking	0	0	0	0	0	0
prebake aluminum cell	0	0	0	0	0	0
aluminum	0	0	0	0	56	0
lead production	0	0	2	2	114	0
copper production	0	0	6	4	97	0
zinc production	0	0	2	1	0	0
lead battery manufacture	0	0	0	0	0	0
lead cable coating	0	0	0	0	0	0
other	12	20	25	15	5	0
Ferrous Metals Processing	70	46	93	67	113	5
basic oxygen furnace	0	0	0	0	0	0
carbon steel electric arc furnace	0	0	0	0	0	0
coke oven door & topside leaks	0	6	0	0	0	0
coke oven by-product plants	0	5	0	0	0	0
coke oven charging	0	0	0	0	0	0
gray iron cupola	0	0	0	0	0	0
iron ore sinter plant windbox	0	0	0	0	0	0
coke manufacturing	0	0	0	0	0	0
ferroalloy production	0	0	0	0	0	0
iron production	0	0	0	0	0	0
steel production	0	0	0	0	0	0
gray iron production	0	0	0	0	0	0
primary	0	0	67	50	0	0
secondary	0	0	26	17	0	0
other	70	36	0	0	113	5
Metals Processing NEC	6	10	19	14	17	0
PETROLEUM & RELATED INDUSTRIES	143	424	29	17	341	17
Oil & Gas Production	88	271	1	1	90	0
natural gas	0	0	0	0	89	0
other	88	271	1	1	1	0
Petroleum Refineries & Related Industries	48	149	17	12	244	17
vacuum distillation	0	3	0	0	0	0
cracking units	0	16	12	8	162	17
petroleum refinery fugitives	0	27	0	0	0	0
other	48	101	5	4	82	0
process unit turnarounds	0	2	0	0	0	0
Asphalt Manufacturing	7	4	11	4	7	0
OTHER INDUSTRIAL PROCESSES	470	449	343	191	418	45
Agriculture, Food, & Kindred Products	5	111	61	22	5	4
vegetable oil mfg	0	10	0	0	0	0
whiskey fermentation: aging	0	16	0	0	0	0
bakeries	0	43	0	0	0	0
soybean mills	0	0	7	3	0	0
wheat mills	0	0	2	1	0	0
other grain mills	0	0	5	3	0	0
country elevators	0	0	5	1	0	0
terminal elevators	0	0	2	0	0	0
feed mills	0	0	3	1	0	0
other	5	51	36	14	5	4

EMISSION CALCULATIONS AND INVENTORY LISTINGS

**Table A.1. 1999 U.S national emissions for PM and related pollutants (thousand short tons)
(continued).**

Source Category	NO _x	VOC	PM ₁₀	PM _{2.5}	SO ₂	NH ₃
OTHER INDUSTRIAL PROCESSES (continued)						
Textiles, Leather, & Apparel Products	1	10	1	0	0	0
Wood, Pulp & Paper, & Publishing Products	93	167	80	56	109	1
sulfate pulping: rec. furnace/evaporator	0	0	41	33	0	0
sulfate (kraft) pulping: lime kiln	0	0	0	0	0	0
other	93	167	39	23	109	1
Rubber & Miscellaneous Plastic Products	0	52	4	2	1	0
rubber tire mfg	0	6	0	0	0	0
green tire spray	0	2	0	0	0	0
other	0	44	4	2	1	0
Mineral Products	356	32	168	93	288	0
cement mfg	213	0	24	11	183	0
surface mining	0	0	17	7	0	0
glass mfg	78	0	0	0	0	0
stone quarrying/processing	0	0	24	9	0	0
other	65	32	103	66	106	0
Machinery Products	3	12	5	2	0	0
Electronic Equipment	0	1	1	1	0	0
Transportation Equipment	0	4	0	0	0	0
Construction	0	0	0	0	0	0
Miscellaneous Industrial Processes	12	61	22	15	14	40
SOLVENT UTILIZATION	3	4,825	6	6	1	0
Degreasing	0	371	0	0	0	0
open top	0	4	0	0	0	0
conveyorized	0	2	0	0	0	0
cold cleaning	0	11	0	0	0	0
other	0	354	0	0	0	0
Graphic Arts	1	293	1	1	0	0
letterpress	0	6	0	0	0	0
flexographic	0	15	0	0	0	0
lithographic	0	13	0	0	0	0
gravure	0	44	0	0	0	0
other	1	214	1	1	0	0
Dry Cleaning	0	168	0	0	0	0
perchloroethylene	0	63	0	0	0	0
petroleum solvent	0	97	0	0	0	0
other	0	8	0	0	0	0
Surface Coating	2	2,136	5	4	0	0
industrial adhesives	0	148	0	0	0	0
fabrics	0	10	0	0	0	0
paper	0	51	0	0	0	0
large appliances	0	22	0	0	0	0
magnet wire	0	2	0	0	0	0
autos & light trucks	0	106	0	0	0	0
metal cans	0	113	0	0	0	0
metal coil	0	49	0	0	0	0

APPENDIX A

Table A.1. 1999 U.S national emissions for PM and related pollutants (thousand short tons) (continued).

Source Category	NO _x	VOC	PM ₁₀	PM _{2.5}	SO ₂	NH ₃
SOLVENT UTILIZATION (continued)						
Surface Coating (continued)						
wood furniture	0	130	0	0	0	0
metal furniture	0	58	0	0	0	0
flatwood products	0	18	0	0	0	0
plastic parts	0	16	0	0	0	0
large ships	0	19	0	0	0	0
aircraft	0	5	0	0	0	0
misc. metal parts	0	40	0	0	0	0
steel drums	0	4	0	0	0	0
architectural	0	483	0	0	0	0
traffic markings	0	93	0	0	0	0
maintenance coatings	0	85	0	0	0	0
railroad	0	4	0	0	0	0
auto refinishing	0	104	0	0	0	0
machinery	0	20	0	0	0	0
electronic & other electrical	0	82	0	0	0	0
general	0	107	0	0	0	0
miscellaneous	0	32	0	0	0	0
thinning solvents	0	54	0	0	0	0
Other	2	282	5	4	0	0
Other Industrial	0	113	0	0	1	0
rubber & plastics mfg	0	40	0	0	0	0
other	0	72	0	0	1	0
Nonindustrial	0	1,743	0	0	0	0
cutback asphalt	0	147	0	0	0	0
other asphalt	0	46	0	0	0	0
pesticide application	0	412	0	0	0	0
adhesives	0	250	0	0	0	0
consumer solvents	0	883	0	0	0	0
other	0	5	0	0	0	0
Solvent Utilization NEC	0	2	0	0	0	0
STORAGE & TRANSPORT	16	1,240	85	31	5	1
Bulk Terminals & Plants	2	203	0	0	1	0
fixed roof	0	6	0	0	0	0
floating roof	0	11	0	0	0	0
variable vapor space	0	0	0	0	0	0
efr with seals	0	2	0	0	0	0
ifr with seals	0	3	0	0	0	0
underground tanks	0	2	0	0	0	0
area source: gasoline	0	157	0	0	0	0
other	2	22	0	0	1	0

EMISSION CALCULATIONS AND INVENTORY LISTINGS

Table A.1. 1999 U.S national emissions for PM and related pollutants (thousand short tons) (continued).

Source Category	NO _x	VOC	PM ₁₀	PM _{2.5}	SO ₂	NH ₃
STORAGE & TRANSPORT (continued)						
Petroleum & Petroleum Product Storage	8	108	1	0	0	1
fixed roof gasoline	0	1	0	0	0	0
fixed roof crude	0	10	0	0	0	0
floating roof gasoline	0	11	0	0	0	0
floating roof crude	0	2	0	0	0	0
efr / seal gasoline	0	9	0	0	0	0
efr / seal crude	0	3	0	0	0	0
ifr / seal gasoline	0	3	0	0	0	0
ifr / seal crude	0	1	0	0	0	0
variable vapor space gasoline	0	0	0	0	0	0
area source: gasoline	0	0	0	0	0	0
area source: crude	0	0	0	0	0	0
other	8	68	1	0	0	1
Petroleum & Petroleum Product Transport	0	120	0	0	2	0
gasoline loading: normal / splash	0	3	0	0	0	0
gasoline loading: balanced / submerged	0	7	0	0	0	0
gasoline loading: normal / submerged	0	14	0	0	0	0
gasoline loading: clean / submerged	0	0	0	0	0	0
marine vessel loading: gasoline & crude	0	34	0	0	0	0
other	0	62	0	0	2	0
Service Stations: Stage I	0	320	0	0	0	0
Service Stations: Stage II	0	412	0	0	0	0
Service Stations: Breathing & Emptying	0	45	0	0	0	0
Organic Chemical Storage	4	25	1	1	0	0
Organic Chemical Transport	0	5	0	0	0	0
Inorganic Chemical Storage	0	1	1	0	0	0
Inorganic Chemical Transport	0	0	0	0	0	0
Bulk Materials Storage	2	1	82	30	2	0
storage	0	0	27	11	0	0
transfer	0	0	54	18	0	0
combined	0	0	0	0	0	0
other	2	1	0	0	2	0
Bulk Materials Transport	0	0	0	0	0	0
WASTE DISPOSAL & RECYCLING	91	586	587	525	37	88
Incineration	58	51	92	47	30	0
conical wood burner	0	0	0	0	0	0
municipal incinerator	0	0	0	0	0	0
industrial	0	0	0	0	7	0
commercial/institutional	0	0	0	0	0	0
residential	0	0	63	31	0	0
other	58	51	28	16	24	0
Open Burning	30	356	492	476	5	0
industrial	0	0	0	0	0	0
commercial/institutional	0	0	0	0	0	0
residential	0	149	188	173	0	0
other	30	207	303	303	5	0

APPENDIX A

Table A.1. 1999 U.S national emissions for PM and related pollutants (thousand short tons) (continued).

Source Category	NO _x	VOC	PM ₁₀	PM _{2.5}	SO ₂	NH ₃
WASTE DISPOSAL & RECYCLING (continued)						
Wastewater treatment	0	0	0	0	0	87
other	0	50	0	0	0	0
Industrial Waste Water	0	21	0	0	0	0
POTW	0	50	0	0	0	87
TSDf	0	42	0	0	0	0
industrial	0	0	0	0	0	0
other	0	42	0	0	0	0
Landfills	2	36	3	2	1	0
industrial	0	0	0	0	0	0
other	2	36	3	2	0	0
Other	1	30	1	0	0	0
ON-ROAD VEHICLES	8,590	5,297	295	229	363	260
Light-Duty Gas Vehicles & Motorcycles	2,859	2,911	59	34	137	174
light-duty gas vehicles	2,846	2,870	58	34	136	0
motorcycles	13	42	0	0	0	0
Light-Duty Gas Trucks	1,638	1,722	36	22	91	76
ldgt1	1,110	1,132	25	15	68	0
ldgt2	529	589	11	7	24	0
Heavy-Duty Gas Vehicles	459	375	12	8	17	4
Diesels	3,635	289	189	166	118	6
hddv	3,620	284	186	164	0	0
lddt	6	2	1	1	0	0
iddv	8	3	1	1	0	0
NON-ROAD ENGINES AND VEHICLES	5,515	3,232	458	411	936	10
Non-Road Gasoline	187	2,593	89	82	28	1
recreational	8	185	3	3	0	0
construction	6	51	2	2	0	0
industrial	13	30	0	0	0	0
lawn & garden	78	845	20	19	0	0
farm	4	15	0	0	0	0
light commercial	34	172	2	2	0	0
logging	5	369	23	21	0	0
airport service	0	0	0	0	0	0
railway maintenance	0	0	0	0	0	0
recreational marine vessels	37	924	39	36	0	0
other	0	0	0	0	28	1
Non-Road Diesel	2,707	372	253	233	507	3
recreational	5	1	1	1	0	0
construction	1,247	185	128	118	0	0
industrial	237	39	33	30	0	0
lawn & garden	83	17	12	11	0	0
farm	906	94	54	50	0	0
light commercial	123	20	15	14	0	0
logging	610	8	6	5	0	0

EMISSION CALCULATIONS AND INVENTORY LISTINGS

Table A.1. 1999 U.S national emissions for PM and related pollutants (thousand short tons) (continued).

Source Category	NO _x	VOC	PM ₁₀	PM _{2.5}	SO ₂	NH ₃
NON-ROAD ENGINES AND VEHICLES (continued)						
Non-Road Diesel (continued)						
airport service	10	2	1	1	0	0
railway maintenance	4	1	1	0	0	0
recreational marine vessels	31	5	2	2	0	0
other	0	0	0	0	507	3
Aircraft	175	183	38	27	12	4
Marine Vessels	1,007	34	46	40	273	1
coal	0	1	3	1	0	0
diesel	995	33	42	38	0	0
residual oil	0	0	0	0	0	0
gasoline	12	1	1	0	0	0
other	0	0	0	0	273	1
Railroads	1,204	49	30	27	113	1
Other	235	0	2	2	3	0
liquified petroleum gas	206	0	1	1	0	0
compressed natural gas	29	0	0	0	0	0
other	0	0	0	0	3	0
NATURAL SOURCES	0	0	0	0	0	35
Biogenic	0	0	0	0	0	35
MISCELLANEOUS	320	716	20,634	4,454	12	4,322
Agriculture & Forestry	0	8	4,888	948	0	4,322
agricultural crops	0	0	4,298	860	0	3,552
agricultural livestock	0	0	590	89	0	769
other	0	8	0	0	0	0
Other Combustion	320	702	1,007	872	12	0
structural fires	0	15	21	19	0	0
agricultural fires	0	53	104	94	0	0
slash/prescribed burning	0	311	621	526	0	0
forest wildfires	0	319	261	233	0	0
other	320	3	0	0	12	0
Catastrophic/Accidental Releases	0	5	0	0	0	0
Repair Shops	0	0	0	0	0	0
Health Services	0	1	0	0	0	0
Cooling Towers	0	1	3	3	0	0
Fugitive Dust	0	0	14,736	2,631	0	0
unpaved roads	0	0	9,360	1,411	0	0
paved roads	0	0	2,728	682	0	0
construction	0	0	1,956	391	0	0
other	0	0	692	146	0	0
TOTAL ALL SOURCES	25,393	18,145	23,679	6,773	18,867	4,964

APPENDIX A

Table A.2. 1999 Canadian emission inventory for PM and related pollutants (Ktonnes/yr).

CATEGORY / SECTOR	PART	PM ₁₀	PM _{2.5}	SO _x	NO _x	VOC	NH ₃
Industrial Sources							
Abrasives Manufacture	0.8	0.4	0.3	2.8	0.2	1.5	0.0
Aluminum Industry	11.8	7.8	5.3	46.2	1.1	1.0	0.2
Asbestos Industry	0.1	0.0	0.0	0.8	0.2	0.0	0.0
Asphalt Paving Industry	32.9	5.5	2.0	2.4	2.0	3.3	0.0
Bakeries					0.0	6.0	0.0
Cement and Concrete Industry	21.1	8.5	3.8	34.0	32.2	0.4	0.2
Chemicals Industry	4.5	2.6	1.4	6.4	24.1	9.4	20.8
Clay Products Industry	2.6	0.6	0.2	0.0	0.1	0.0	0.0
Coal Mining Industry	11.7	8.8	6.3	5.3	3.2	1.8	0.0
Ferrous Foundries	0.7	0.4	0.4	1.7	0.0	1.8	0.0
Grain Industries	58.3	11.7	1.7	0.0	0.0	0.0	
Iron and Steel Industries	20.7	10.8	7.1	62.8	25.5	28.3	0.4
Iron Ore Mining Industry	39.4	21.3	7.6	54.6	7.8	0.8	0.0
Mining and Rock Quarrying	86.0	11.5	3.2	20.8	14.6	0.7	0.2
Non-Ferrous Mining and Smelting Industry	15.6	13.2	9.8	891.7	3.5	0.1	0.3
Oil Sands	3.9	1.8	1.4	160.9	16.5	0.1	0.8
Other Petroleum and Coal Products Industry	0.3	0.1	0.1	0.6	0.4	0.1	0.0
Paint & Varnish Manufacturing	0.1	0.1	0.0		0.0	2.0	0.0
Petrochemical Industry	1.3	0.7	0.3	1.3	11.6	16.5	0.2
Petroleum Refining	6.5	5.0	3.3	41.1	26.9	47.7	1.7
Plastics & Synthetic Resins Fabrication	0.2	0.1	0.1	0.3	0.4	6.7	0.0
Pulp and Paper Industry	74.4	50.8	39.3	77.0	58.1	23.3	6.1
Upstream Oil and Gas Industry	2.1	2.0	1.9	387.3	314.9	689.4	0.0
Wood Industry	153.7	86.0	52.6	2.6	16.0	47.1	1.7
Other Industries	72.6	37.5	23.8	49.0	60.9	53.0	2.1
Total Industrial Sources	621.2	287.3	171.8	1,949.6	620.4	940.8	34.7

EMISSION CALCULATIONS AND INVENTORY LISTINGS

**Table A.2. 1999 Canadian emission inventory for PM and related pollutants (Ktonnes/yr)
(continued).**

CATEGORY / SECTOR	PART	PM ₁₀	PM _{2.5}	SO _x	NO _x	VOC	NH ₃
Non Industrial Fuel Combustion							
Commercial Fuel Combustion	3.4	3.0	2.7	13.0	29.3	1.7	0.5
Electric Power Generation (Utilities)	78.8	34.9	18.6	534.3	255.0	3.0	1.0
Residential Fuel Combustion	4.8	4.0	3.7	17.3	36.7	2.3	0.6
Residential Fuel Wood Combustion	137.8	137.3	131.8	1.8	12.2	400.1	0.8
Total Non Industrial Fuel Combustion	224.9	179.1	156.9	566.4	333.2	407.1	2.9
Transportation							
Air Transportation	2.0	1.1	0.8	2.3	34.0	11.6	0.0
Heavy-duty diesel vehicles	32.1	32.1	29.5	32.8	378.3	48.5	0.1
Heavy-duty gasoline trucks	0.5	0.5	0.4	0.6	15.1	11.8	0.1
Light-duty diesel trucks	1.3	1.3	1.2	1.5	5.6	2.6	0.0
Light-duty diesel vehicles	0.4	0.4	0.3	0.6	2.0	0.7	0.0
Light-duty gasoline trucks	2.6	2.5	2.0	4.4	112.4	142.4	5.4
Light-duty gasoline vehicles	4.9	4.7	3.3	11.0	273.4	355.9	13.3
Marine Transportation	8.4	8.1	7.4	58.0	118.6	37.4	0.1
Motor cycles	0.0	0.0	0.0	0.0	0.6	2.0	0.0
Off-road use of diesel	17.1	17.1	15.7	16.1	209.2	22.6	0.5
Off-road use of gasoline	4.4	3.9	3.4	1.0	25.4	93.1	0.2
Rail Transportation	19.5	19.5	17.9	7.2	115.6	5.6	0.0
Tire wear & Brake lining	4.4	4.3	1.4				
Total Transportation	97.6	95.5	83.3	135.7	1,290.2	734.4	19.7

APPENDIX A

**Table A.2. 1999 Canadian emission inventory for PM and related pollutants (Ktonnes/yr)
(continued).**

CATEGORY / SECTOR	PART	PM ₁₀	PM _{2.5}	SO _x	NO _x	VOC	NH ₃
Incineration							
Crematorium	0.0	0.0	0.0	0.0	0.0		
Industrial & Commercial Incineration	0.1	0.1	0.0	0.6	0.8	0.7	0.1
Municipal Incineration	0.4	0.4	0.4	0.5	1.3	0.7	0.1
Wood Waste Incineration	1.8	1.0	0.7	0.0	0.3	4.6	0.2
Other Incineration & Utilities	0.2	0.0	0.0	0.1	0.2	0.3	0.1
Total Incineration	2.5	1.5	1.1	1.3	2.5	6.3	0.5
Miscellaneous							
Cigarette Smoking	1.0	1.0	1.0		0.0	0.0	0.0
Dry Cleaning					0.0	7.8	0.0
Fuel Marketing	0.0	0.0	0.0	0.0	0.3	98.5	
General Solvent Use						274.9	0.0
Human							7.6
Marine Cargo Handling Industry	3.1	1.4	0.4			0.0	
Meat Cooking	1.6	1.6	1.6				
Pesticides and Fertilizer Application	10.5	5.2	1.5		0.8	0.1	180.1
Printing						29.1	0.0
Structural Fires	5.3	5.2	4.8		0.0	5.1	
Surface Coatings						134.2	
Total Miscellaneous	21.5	14.4	9.2	0.0	1.1	549.7	187.6

EMISSION CALCULATIONS AND INVENTORY LISTINGS

**Table A.2. 1999 Canadian emission inventory for PM and related pollutants (Ktonnes/yr)
(continued).**

CATEGORY / SECTOR	PART	PM ₁₀	PM _{2.5}	SO _x	NO _x	VOC	NH ₃
Open Sources							
Agriculture (Animals)	248.7	141.0	22.3		13.0	294.1	
Agriculture Tilling and Wind Erosion	1,754.4	848.4	20.7				
Construction Operations	2,402.1	528.4	10.7				
Dust from Paved Roads	2,549.5	511.2	129.5				
Dust from Unpaved Roads	6,833.7	2,020.7	300.6				
Forest Fires	835.4	706.1	585.0	0.5	211.0	902.4	14.0
Landfills Sites	4.7	0.4	0.1		5.1		
Mine Tailings	46.9	3.7	0.9				
Prescribed Burning	41.4	33.0	26.9	0.1	5.6	16.3	0.3
Total Open Sources	14,716.9	4,792.9	1,096.8	0.6	216.6	936.9	308.4
NATIONAL TOTAL	15,685	5,371	1,519	2,654	2,464	3,575	554

Note: Numbers may not add to totals, due to rounding.

A.3 REFERENCES

- Dickson, R., Oliver, W., 1991. Emissions models for regional air quality studies. *Environmental Science and Technology* 25, 1533-1535.
- Environmental Protection Service (Canada) (EPS), 1999. 1995 Criteria Air Contaminants Emissions Inventory Guidebook. Environment Canada, Preliminary Draft. Hull, QC.
- EPRI, 1994. Electric Utility Trace Substances Synthesis Report. Report TR-104614, EPRI, Palo Alto, CA.
- EPS, 2000. Canadian Emissions Inventory of Air Contaminants (1995). (Draft). Pollution Data Branch, Environment Canada, Hull, QC.
- ERG/Radian, 2000. Proposed Protocol for Development of Mexico Emissions Inventory.
- Geron, C., Guenther, A., Pierce, T., 2000. An improved model for estimating emissions of VOC from forests in the eastern United States. *Journal of Geophysical Research* 99, 12,773-12,792.
- Hildemann, L., Kleindinst, D., Klouda, G., Currie, L., Cass, G., 1994. Sources of urban contemporary aerosol. *Environmental Science and Technology* 28, 1565-1576.
- U.S. EPA, 2001. Compilation of Air Pollution Emission Factors. Report AP-42. Internet Edition.
- U.S. Dept. of Health Education and Welfare (U.S. HEW), 1965. Compilation of Air Pollutant Emission Factors for Combustion Processes, Gasoline Evaporation, and Selected Industrial Processes. U.S. Dept. of Health, Education and Welfare, Cincinnati, OH.
- U.S. HEW, 1966. Atmospheric Emissions from Coal Combustion. U.S. Dept. of Health, Education and Welfare, Cincinnati, OH.
- U.S. HEW, 1968. Compilation of Air Pollution Emission Factors. Report AP-42. U.S. Dept. of Health, Education and Welfare, Durham, NC.