Project Report

North American Black Carbon Emissions Estimation Guidelines:

Recommended Methods for Estimating Black Carbon Emissions

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List of Abbreviations and Acronyms

AEO	Annual Energy Outlook (United States)
APEI	Air Pollutant Emission Inventory report (Canada)
BC	black carbon
BCR	Black Carbon Report (Canada)
CANA	Cremation Association of North America
CCAC	Climate and Clean Air Coalition
CIFFC	Canadian Interagency Forest Fire Centre
CEC	Commission for Environmental Cooperation
CHIEF	Clearinghouse for Inventories and Emission Factors
CNG	compressed natural gas
Conafor	*Comisión Nacional Forestal (Mexico)* (National Forest Commission)
DGGCARETC	*Dirección General de Gestión de la Calidad del Aire y Registro de Emisiones y Transferencia de Contaminantes* (Mexico) (General Directorate of Air Quality Management and Pollutant Release and Transfer Register)
EC	elemental carbon
EEA	European Environmental Agency
EF	emission factor
EIA	US Energy Information Administration
EIIP	US Emission Inventory Improvement Program
EMEP	European Monitoring and Evaluation Program
EPA	US Environmental Protection Agency
ERG	Eastern Research Group, Inc.
EU	European Union
FAA	US Federal Aviation Administration
FIRE	Factor Information Retrieval System (US EPA)
FVRD	Fraser Valley Regional District (Canada)
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies Model (International Institute for Applied Systems Analysis—IIASA)
GHGs	greenhouse gases
GIS	geographic information system
GJ	gigajoule(s)
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model
GVRD	Greater Vancouver Regional District (Canada)
IEA	International Energy Agency
IIR	Informative Inventory Report (Canada)
INECC	*Instituto Nacional de Ecología y Cambio Climático* (Mexico) (National Institute of Ecology and Climate Change)
INEGI	*Instituto Nacional de Estadística y Geografía* (Mexico) (National Institute for Statistics and Geography)
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram(s)
kJ	kilojoule(s)
kWh	kilowatt-hour(s)
lb(s)	pound(s)
LPG	liquefied petroleum gas
LTO	landing and take-off
MOVES	Motor Vehicle Emissions Simulator model (US EPA)

MSW	municipal solid waste
NEI	US National Emissions Inventory
NIR	National Inventory Report (Canada)
NPRI	National Pollutant Release Inventory (Environment Canada)
^{o}C	degrees Celsius
OC	organic carbon
OTAQ	Office of Transportation and Air Quality (US EPA)
Pemex	*Petróleos Mexicanos*
PM	particulate matter
PM_{10}	particulate matter less than 10 micrometers in diameter
$PM_{2.5}$	particulate matter less than 2.5 micrometers in diameter (i.e., fine particulate matter)
RESD	Report on Energy Supply and Demand (Canada)
RWC	residential wood combustion
Sagarpa	*Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación* (Mexico) (Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food)
SCT	*Secretaría de Comunicaciones y Transportes* (Mexico) (Secretariat of Communications and Transport)
Semarnat	*Secretaría de Medio Ambiente y Recursos Naturales* (Mexico) (Secretariat of the Environment and Natural Resources)
Sener	*Secretaría de Energía* (Mexico) (Secretariat of Energy)
SLCF	short-lived climate forcer
SNAP	Supporting National Planning for Action on Short-Lived Climate Pollutants (Mexico)
SPECIATE	EPA database
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
USDA	US Department of Agriculture
VKT/VMT	vehicle kilometers traveled/vehicle miles traveled
VOC	volatile organic compound

Abstract

The Commission for Environmental Cooperation (CEC) has developed black carbon emission estimation guidelines for North America. These guidelines are intended to provide a consistent methodology for developing black carbon inventories between the United States, Mexico and Canada, in order to improve cross-border comparisons and mitigation assessments. The guidance also provides recommendations for further research to align the capabilities of the three countries, with a special focus on Mexico. The first stage of the project included a literature review and comparative evaluation of black carbon and underlying particulate matter emission inventory methods and data sources in North America, Europe and Asia. This evaluation culminated in a series of recommendations for "best practice" approaches by major sector (mobile, open burning, residential, energy/industrial and other) and alternatives where best practice is not feasible in the short term. An expert panel was then convened to review and provide comments on these initial recommendations to ensure consensus on the proposed methods and data sources. Based on this initial work and expert panel input, the guidelines were compiled to fill in specific sources of emission factors, activity and speciation factors, with the goal of providing sufficient detail to allow inventory developers across North America to construct black carbon emissions inventories for all sectors.

Executive Summary

Emission inventories are important tools for helping researchers and policy makers to assess the magnitude of air pollutant emissions, the contribution of different source categories, and the most promising mitigation strategies. First-generation black carbon (BC) inventories have been developed in recent years in Canada, Mexico, and the United States. Assessing these inventories, the Commission for Environmental Cooperation (CEC) concluded that a consistent method for calculating BC emissions is lacking, and discrepancies among countries hinder cross-border comparisons and mitigation assessments (CEC 2012). To address this, in 2013 CEC initiated a project to produce BC emissions estimation guidelines. These guidelines provide a consistent set of methods to improve the accuracy of North American BC emissions estimates, with the goal of providing reliable and consistent inventories with which to establish baselines and determine reduction priorities by source category or location. Eastern Research Group (ERG) and partners Dr. Joyce Penner of the University of Michigan and Veronica Garibay-Bravo of ORG+CO, Inc. were contracted by CEC to produce these guidelines.

Task 1 of this project involved a comprehensive literature review of BC studies performed in North America, Europe, Asia, and Africa. From this review, the team evaluated methods and data sources from studies and documents focused on Canada, Europe, Mexico, and the United States, and developed initial recommendations for approaches for each of the major source sectors. ERG's initial search on both online databases resulted in about 8,000 studies. This list was narrowed down to a master candidate study list for detailed review. The list included journal articles and reports and comprehensive emission inventories from various agencies such as the US Environmental Protection Agency (EPA), Mexico's National Institute of Ecology and Climate Change (*Instituto Nacional de Ecología y Cambio Climático*—INECC); the European Environmental Agency (EEA); CEC; the Arctic Council; and academic institutions. The master list included major inventory documents for BC and PM. This is because for nearly all emission sectors, BC emission inventories are derived from underlying PM emission inventories. The methods and data sources used for PM, therefore, form the basis of the recommended BC emission inventory guidelines. Complete guidelines for developing BC emission inventories will need to address disparities in PM inventory methods and data sources among the three North American countries. The sources reviewed under Task 1 therefore focused concurrently on methods and data sources for the most recent PM emissions in each country, and on the BC emissions derived from these sources.

Task 2 solicited expert opinion on the review and initial recommendations compiled in Task 1. A review panel was convened comprising expertise across the major source sector categories (residential, biomass, onroad motor vehicles, nonroad mobile sources, power/industrial sources, and other sources) and experience in emissions research and inventory development in North America, Europe, and Asia. A series of consultations was held with the panel to solicit comments on the adequacy of the literature review and proposed methods and data sources for each sector. Twenty-nine individuals with BC inventory expertise spread across major source sectors were recruited for the expert panel. The panel was also chosen to ensure representation from North America, Europe, and Asia, and to bring perspective on measurement and speciation issues, as well as inventory development. Panel members agreed to review the Task 1 report and provide comments through online surveys, webinars, or in written communications. The results of these consultations and how comments were addressed were submitted to CEC in December 2014.

The present document is the final product of the CEC project, under Task 3: guidelines for practitioners in North America to develop BC emission inventories that are comprehensive and reflect the latest methods and data sources. The guidelines provide the recommended methods and data sources that can be used in Canada, Mexico, and the United States for major source categories. The guidelines follow the format used by the International Panel on Climate Change (IPCC) and adopted by the European community of practitioners, to establish best practice methods (and alternatives, where data are not available), relative to three "tiers." Tiers are distinguished in IPCC and European inventory guidance documents (IPCC 2006, EMEP/EEA 2013) by the level of detail required for activity and emission factors, and resulting

inventory—Tier 1 being the most aggregate, and Tier 3 being the most detailed. The tiers allow inventory developers options for producing inventory estimates, depending on available data and/or purpose of the inventory. For major subsectors, the guidelines provide references to the method and specific data sources (activity, emission factors, and speciation) that would support each tier. A Tier 1 method generally consists of national-level fuel data or other aggregated activity data used in conjunction with $PM_{2.5}$ emission factors and BC speciation factors. Tier 2 is similar to Tier 1, but the activity data and emission factors are categorized by technology type. Tier 3 methods, where available, are generally considered the most accurate, and are based on a much finer level of detail than Tier 1 or Tier 2. Tier 3 methods may look similar to Tier 2 methods, but use more-specific activity data (e.g., crop-specific fuel loadings, modeled emission rates, technology-specific fuel consumption, etc.). Most methods are based on estimation of $PM_{2.5}$ emissions, which are then converted to BC emissions using a speciation factor. For Tier 1 methods, tables of recommended emission and speciation factors will be found in the tables in Appendix B. A discussion of inventory validation and uncertainty, as well as best practices for data management and reporting, is also provided.

Recommendations for further research are also included as part of the guidelines, in general and by individual sector. Perhaps the most important area for further research is the improvement of speciation factors for BC, both in terms of accounting for light-absorbing properties, and aligning these factors with the level of detail found in underlying PM emission factors. A long-term goal would be speciation factors based on a consistent definition and measurement protocol relative to light-absorbing carbon, and complete alignment between the level of detail in speciation factors and underlying PM emission factors. Research programs focused on these goals are required to reduce the significant uncertainty currently associated with using speciation factors to produce BC inventories.

1 Introduction

1.1 Background

Emission inventories are important tools for helping researchers and policy makers to assess the magnitude of air pollutant emissions, the contribution of different source categories, and the most promising mitigation strategies. First-generation black carbon (BC) inventories have been developed in recent years in Canada, Mexico, and the United States. Assessing these inventories, the Commission for Environmental Cooperation (CEC) concluded that a consistent method for calculating BC emissions is lacking, and discrepancies among countries hinder cross-border comparisons and mitigation assessments (CEC 2012). To address this, in 2013 CEC initiated a project to produce BC emissions estimation guidelines. These guidelines provide a consistent set of methods to improve the accuracy of North American BC emissions estimates, with the goal of providing reliable and consistent inventories with which to establish baselines and determine reduction priorities by source category or location. Eastern Research Group (ERG) and partners Dr. Joyce Penner of the University of Michigan and Veronica Garibay-Bravo of ORG+CO, Inc., were contracted by CEC to produce these guidelines.

Task 1 of this project involved a comprehensive literature review of BC studies performed in North America, Europe, Asia, and Africa. From this review, the team evaluated methods and data sources from studies and documents focused on Canada, Europe, Mexico, and the United States, and developed initial recommendations for approaches for each of the major source sectors. The results of Task 1, detailing ERG's review of emission inventories, methods and existing guidance for BC emissions, and initial recommendations for emission inventory guidelines, were submitted to CEC in July 2014 in an unpublished report entitled "North American Black Carbon Emissions Estimation Guidelines: Review of Methods for Estimating Black Carbon Emissions."

Task 2 solicited expert opinion on the review and recommendations compiled in Task 1. A review panel was convened comprising expertise across the major source sector categories (residential, biomass, onroad motor vehicles, nonroad mobile sources, power/industrial sources, and other sources) and experience in emissions research and inventory development in North America, Europe, and Asia. A series of consultations was held with the panel to solicit comments on the adequacy of the literature review and proposed methods and data sources for each sector. The results of these consultations and how comments were addressed were submitted to CEC in December 2014 in an unpublished report entitled "North American Black Carbon Emissions Estimation Guidelines: Summary of Expert Panel Comments, and Changes to Initial Emission Estimation Recommendations."

The present document is the final product of the CEC project, under Task 3: guidelines for practitioners in North America to develop BC emission inventories that are comprehensive and reflect the latest methods and data sources. The guidelines provide the recommended methods and data sources that can be used in Canada, Mexico, and the United States for major source categories. A discussion of inventory validation and uncertainty, as well as best practices for data management and reporting, is also provided. Recommendations for future research are also included, based on the largest data gaps identified during the course of this project.

1.2 Objectives of the Guidelines

The BC emissions estimation guidelines are intended to provide a set of consistent methods for developing BC inventories in Canada, Mexico, and United States in order to improve cross-border comparisons and mitigation assessments. The guidelines offer specific methods and data sources for users to reference in constructing a bottom-up BC emission inventory. The guidelines also provide recommendations for further research to align the capabilities of the three countries, with a special focus on Mexico. The guidelines provide inventory developers and decision-makers with the tools to produce a BC emission inventory covering all source sectors. Consideration of how inventories will be used (use cases) is discussed, to help practitioners determine the level of detail needed for their analysis. The guidelines follow the format used by the International Panel on Climate Change (IPCC) and adopted by the European community of practitioners, to establish best practice methods (and alternatives, where data are not available), relative to three “tiers.” Tiers are distinguished in IPCC and European inventory guidance documents (IPCC 2006, EMEP/EEA 2013) by the level of detail required for activity and emission factors, and resulting inventory—Tier 1 being the most aggregate, and Tier 3 being the most detailed. The tiers allow inventory developers options for producing inventory estimates, depending on available data and/or purpose of the inventory. For major subsectors, the guidelines provide references to the method and specific data sources (activity, emission factors, and speciation) that would support each tier.

This guidelines document also provides general guidance on emissions data management (in Appendix A) and emissions validation and uncertainty, including tables of emission and speciation factors for Tier 1 black carbon emission estimation methods (in Appendix B).

1.3 Overview of Review, Evaluation and Expert Consultation (Tasks 1 and 2)

1.3.1 Literature Review and Initial Recommendations (Task 1)

Under Task 1, ERG performed a broad literature review to identify published literature on BC emissions and estimation methods. ERG performed the literature review from several different perspectives, evaluating source categories, geographic scope, and established and experimental methods for primary inventory components (e.g., emission factors, speciation profiles, activity data, and projection approaches). ERG’s project team was composed of subject matter experts in each of the major BC emission sectors that were the focus of the review. The team was asked to compile a list of major BC and/or particulate matter reports that would be essential to consider for this project. Simultaneously, ERG staff performed literature searches to identify additional BC and particulate matter (PM) studies, using the online scientific literature databases ScienceDirect and ProQuest.

ERG’s initial search on both online databases resulted in about 8,000 studies. This list was then filtered to include only journal articles and studies published in 2004 and later. This resulted in about 1,200 studies. Of these, 584 had available abstracts that could be downloaded into a batch text file. ERG reviewed these abstracts and chose the most relevant studies. For the studies without available abstracts, ERG chose studies based on their titles. Studies that did not include any information on BC estimation methods, emission factors, or mitigation techniques were excluded from further analysis. Also, studies that focused solely on source apportionment and concentration measurements were excluded from further analysis, as they were judged to be less relevant to emission inventory development.

After this review process, ERG chose 138 studies for further review by the ERG team, CEC, and the project steering committee. Project team members assessed each study, and also identified other studies that should be included in the Task 1 review. On the basis of team members’ feedback (i.e., inclusions and exclusions), a master candidate study list was developed. The list included journal articles and reports and comprehensive emission inventories from various agencies such as the US Environmental Protection Agency (EPA), Mexico’s National Institute of Ecology and Climate Change (*Instituto Nacional de Ecología y Cambio Climático*—INECC); the European Environmental Agency (EEA); CEC; the Arctic Council; and academic institutions.

ERG staff also contacted Environment Canada to identify BC and $PM_{2.5}$ emission inventories, reports, and available guidelines for analysis under Task 1 of this project. According to Environment Canada, for many sectors the methods, activity data, and emissions data used for Canadian inventories are similar to those employed in the United States. For this report, Canadian methods were assumed to be similar to US methods (i.e., those of the US National Emissions Inventory [NEI] and the EPA's *Report to Congress on Black Carbon*), if sufficient detail on Canadian inventories was not available in the literature.

From the master candidate study list identified above, the reports and studies were assigned to the following categories: 1) those that would provide complete methods and data sources for developing a comprehensive BC emission inventory, 2) those that would provide supplementary or underlying data on PM emissions, 3) new sources of emission factors, and 4) local or regional BC characterizations. Detailed reviews focused on categories 1 and 2: they were judged to provide the most-complete information from which to draw initial recommendations on overall inventory methods, emission factors, and activity data sources for the major BC emission sectors. Sources identified under categories 3 and 4 were viewed as potential enhancements to the core approaches used as the basis for recommendations.

From the master candidate study list, the following were chosen for detailed review by ERG subject matter experts:

- *Report to Congress on Black Carbon* (EPA 2013a)
- US National Emissions Inventory (NEI), 2002, 2005, 2008, 2011 (EPA 2006, 2008, 2011a, 2013b)
- *Assessment of Emissions and Mitigation Options for Black Carbon for the Arctic Council* (Arctic Council 2011)
- *Supporting National Planning of Short-Lived Climate Pollutants in Mexico* (INECC 2013)
- *Inventario de emisiones de la Zona Metropolitana del Valle de México, 2010—Gases de Efecto Invernadero y Carbono Negro* (SEDEMA 2012)
- *Assessment of the Comparability of Greenhouse Gas and BC Emission Inventories in North America, 2012* (CEC 2012)
- *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2013* (EMEP/EEA 2013)
- "A Technology-Based Global Inventory of Black and Organic Carbon Emissions from Combustion" (Bond et al. 2004)
- *Extension of the GAINS Model to Include Short-Lived Climate Forcers* (Heyes et al. 2011)
- "Emission Factors for Open and Domestic Biomass Burning for Use in Atmospheric Models" (Akagi et al. 2011)
- "Trace Gas and Particle Emissions from Domestic and Industrial Biofuel Use and Garbage Burning in Central Mexico" (Christian et al. 2010)
- "Trace Gas and Particle Emissions from Open Biomass Burning in Mexico" (Yokelson et al. 2011)
- "Fuel-Based Fine Particulate and Black Carbon Emission Factors from a Railyard Area in Atlanta" (Galvis et al. 2013)
- *Life Cycle Analysis of Conventional and Alternate Marine Fuels in GREET* (Adom et al. 2013)
- *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories* (EPA 2009a)
- *Investigation of Appropriate Control Measures (Abatement Technologies) to Reduce Black Carbon Emissions from International Shipping* (Lack et al. 2012)

- "An Algorithm to Estimate Aircraft Cruise Black Carbon Emissions for Use in Developing a Cruise Emission inventory" (Peck et al. 2013)
- "Estimation of County-level BC Emissions and Its Spatial Distribution in China in 2000" (Qin and Xie 2011)

The list above includes major inventory documents for BC and PM. This is because for nearly all emission sectors, BC emission inventories are derived from underlying PM emission inventories. PM inventories have been developed in Canada, Mexico, and the United States as part of air quality planning at the national, regional, and local levels for many years. The methods and data sources used for PM, therefore, form the basis of the recommended BC emission inventory guidelines. Complete guidelines for developing BC emission inventories will need to address disparities in PM inventory methods and data sources among the three North American countries. The sources reviewed under Task 1 therefore focused concurrently on methods and data sources for the most recent PM emissions in each country, and on the BC emissions derived from these sources. In this light, the list of studies that underwent detailed review is shown in Table 1.3-1, grouped by country and paired with underlying PM inventories.

Table 1.3-1. Primary Reviews: Comprehensive Sources

Country/ies	Primary Black Carbon Inventory	Underlying PM Inventories
United States	EPA *Report to Congress on Black Carbon* (EPA 2013a)	• EPA NEI 2002/2005 • EPA NEI 2011 • Regional planning organization inventories (biomass specifics)
Canada	*Assessment of Emissions and Mitigation Options for Black Carbon for the Arctic Council* (Arctic Council 2011)	APEI, including facility-reported data from the NPRI
Mexico	*Supporting National Planning of Short-Lived Climate Pollutants in Mexico* (INECC 2013)	• *2005 Mexico National Emissions Inventory* (Semarnat 2012) • *2008 Mexico National Emissions Inventory* (Semarnat 2015, online)
All European countries	*EMEP/EEA Air Pollutant Emission Inventory Guidebook 2013* (EMEP/EEA 2013)	Same as EMEP/EEA Guidebook
Global	*A Technology-Based Global Inventory of Black and Organic Carbon Emissions from Combustion* (Bond et al. 2004)	Within BC model
	Extension of the GAINS Model to Include Short-Lived Climate Forcers (Heyes et al. 2011)	Within BC model

The reviewers are listed below.

- Dr. Joyce Penner, University of Michigan
    - Open biomass burning; subsectors: wildfires, agricultural burning, prescribed burning
- Paula Fields Simms, ERG
    - Residential sources; subsectors: fuel combustion (biomass/wood, oil, coal, liquefied petroleum gas [LPG], kerosene, natural gas)
- John Koupal, ERG
    - Mobile sources; subsector: onroad

- Rick Baker, ERG
  - Mobile sources; subsector: nonroad
- Richard Billings, ERG
  - Mobile sources; subsectors: marine, locomotives, aircraft
- Regi Oommen, ERG
  - Energy and Industrial sources; subsectors: public electricity and heat production, petroleum refining, manufacturing industries/construction, commercial/institutional, venting/flaring, solid fuel transformation, cement production, lime production, glass production, chemical industry, iron and steel production, ferroalloys production, aluminum production, copper production, asphalt roofing, pulp and paper production, waste incineration
- Gopi Manne, ERG
  - Other sources; subsectors: charbroiling/commercial cooking, cremation, structure and vehicle fires, municipal solid waste combustion
- Veronica Garibay-Bravo, ORG+CO
  - Mexican sources; review of all Mexico-focused documents

1.3.2 Overview of Major Documents Reviewed

This section discusses review findings for the documents listed in the preceding section, for each North American country, Europe, and global emission inventories.

United States

Report to Congress on Black Carbon

The EPA's *Report to Congress on Black Carbon* was published in 2013 and is the most comprehensive document on BC published in the United States. The report details the effect of BC on climate and public health and presents observational data and extensive discussions of mitigation options and benefits. It also presents detailed sector-by-sector emission inventories covering open biomass burning, mobile source, residential, industrial, energy/power, and other categories for a base year 2005, with projections to future years.

While the BC emission inventories cover the breadth of important emission sources and provide complete estimates of BC emissions in the United States, the inventory method in the report generally focuses on how BC emissions were derived from existing PM inventories. For the majority of individual emission sectors, the report describes how PM emissions from the 2005 NEI were used to estimate 2005 BC emissions based on speciation factors (i.e., ratios of BC to total PM) derived from existing sources. In this sense, the report generally does not present new emission, activity, or speciation factors; rather, it is a broad compilation of existing estimates pulled together to generate a comprehensive national estimate.

US National Emissions Inventory

Understanding the methods and data sources for the US BC emission inventory requires understanding the methods and sources for the PM estimates in the NEI. EPA compiles the NEI to provide a comprehensive nationwide estimate of annual air emissions of criteria pollutants (i.e., pollutants for which National Ambient Air Quality Standards have been established) and their precursors, and hazardous pollutants from all sectors. The NEI is developed on a three-year cycle, reporting annual emissions retrospectively for every third calendar year. The year for the most recent estimates is 2011; the *Report to Congress on Black Carbon* relied on estimates for calendar year 2005, the most recent available at the time the report was drafted. During the development cycle, EPA works closely with state, local, and tribal environmental agencies to compile emission inventories for each county in the United States, down to very detailed subsector levels. The resulting compilation is the official US national emission inventory and serves as the basis for numerous efforts, including trends analysis, air quality planning, regulation development, and health exposure analyses.

The NEI is not published as a stand-alone report per se; instead, EPA maintains the Clearinghouse for Inventories and Emission Factors (CHIEF) website as a central source for NEI emissions estimates and underlying analyses and documentation (EPA 2015a). For sectors where PM emissions from the 2005 NEI were identified as the basis for BC estimates in the EPA's *Report to Congress*, ERG's team reviewed the documentation available on the CHIEF website. The team also reviewed documentation for the subsequent 2008 and 2011 NEI to identify updated methods or data sources that would improve on the 2005 estimates used in the EPA's *Report to Congress*.

Mexico

Supporting National Planning of Short-lived Climate Pollutants

This report was written by INECC and the Molina Center for Strategic Studies in Energy and the Environment. The report supports the Supporting National Planning for Action on Short-lived Climate Pollutants (SNAP) initiative of the United Nations Environment Program's Climate and Clean Air Coalition (CCAC). The SNAP initiative helps developing countries integrate mitigation of short-lived climate pollutants into national planning frameworks. The CCAC was formed in 2012 to address these pollutants (primarily methane, BC, and many hydrofluorocarbons) and currently has 82 partners.

The report includes national estimates of methane and BC emissions for nine key sectors for 2010 and a baseline projection for 2010–2030, as well as two mitigation scenarios. For this project, the team reviewed BC emissions estimates from oil and gas (flaring), onroad transport, cookstoves, open burning of municipal waste, forest and grassland fires, agriculture (sugarcane pre-harvest burning), power generation, energy demand from service sectors (residential, commercial, agriculture) and industrial sectors (steel, chemical, paper and cellulose, food, beverage and tobacco, cement, construction, mining, coke production), and brick kilns. Appendix D of the report describes estimates for each category in terms of the method, emission factors, activity data, and main assumptions. It includes main areas of opportunity and a comprehensive list of references for emission factors and activity data.

After consultation with INECC staff, ERG also analyzed the 2013 update to the SNAP inventory (INECC 2013). Although the report for this updated version has not been finalized, the method was shared with the ERG team. INECC provided 11 datasheets for the following subsectors: oil and gas, power generation, industry, agricultural fires, open waste burning, hazardous and biological waste incineration, forest fires, onroad transport, aircraft, marine, and locomotive. All of these methods and their associated data sources and emission factors were reviewed and incorporated, as appropriate, into the guidelines.

Mexico National Emissions Inventory

For those sectors not included in the SNAP report, but considered significant sources of BC in either the European guidance or the US *Report to Congress*, the team reviewed the results of the 2008 NEI for Mexico, developed by the Secretariat of the Environment and Natural Resources (*Secretaría de Medio Ambiente y Recursos Naturales*—Semarnat). The most recent update of Mexico's NEI includes BC emissions estimates for several sectors (the report for this 2008 inventory has yet to be published). However, the method used for the 2005 Mexico National Emissions Inventory (Semarnat 2012) was useful for understanding how $PM_{2.5}$ estimates for the 2008 NEI were developed. This was later complemented with information from Semarnat staff on how BC emissions were estimated: mainly using $BC/PM_{2.5}$ ratios from several sources (Battye et al. 2002; Bond et al. 2004). Emissions estimates for the following categories were analyzed: aircraft, marine, and locomotive emissions; charbroiling; structural fires; and agricultural and construction equipment.

Canada

The Canadian government submitted a BC emission inventory report to the United Nations Economic Commission for Europe (UNECE) in February 2015, along with an Informative Inventory Report (IIR) that included $PM_{2.5}$ emissions, and supported the Arctic Council Task Force in developing an inventory as part of the report *Assessment of Emissions and Mitigation Options for Black Carbon for the Arctic Council* (Arctic Council 2011). The approach to developing the BC inventory was similar to that of the US *Report to Congress*, in that speciation factors were applied to underlying PM emission inventories, compiled as part of Canada's Air Pollutant Emission Inventory (APEI), to estimate BC emission inventories. The APEI includes all Canadian air pollutant emissions from anthropogenic sources, including facility-reported point source data, and mobile and area sources. PM inventories for domestic, onroad mobile source (transport), and open biomass burning sectors were developed to supplement the industry and energy sector data. The Air Pollutant Emission Inventory (APEI) report covers the aforementioned anthropogenic sources of air pollution (Environment Canada 2014). Canada's *First Black Carbon Inventory* report (BCR) covers BC emissions for key emission sectors for the 2013 reporting year (Environment Canada 2015a).

Beyond the analysis in the Arctic Council report, however, little detail is available on the methods and data used or planned by Canada for developing PM emission inventories that might be used in developing updated estimates of BC emissions. Environment Canada did explain to ERG that its methods for developing national PM inventories are generally comparable to those of EPA and Europe, particularly in those sectors responsible for the majority of BC carbon emissions (e.g., transportation and industrial combustion). Accordingly, this report does not address Canada's inventory approaches, except where detailed in the Arctic Council report and through information exchanges with Environment Canada inventory compilers. During the development of this guidelines document, Environment Canada developed a BCR for 2013 (Environment Canada 2015a) during the 2015 reporting cycle. For sectors where little detail was available, the methods and data sources from the United States were assumed to be similar to those used in Canada, as well.

Europe

Black carbon emission inventory development in Europe is included recently as part of the broader air emission inventory program overseen by the European Monitoring and Evaluation Programme (EMEP) and European Environmental Agency (EEA). Within this program, the Task Force on Emission Inventories and Projections has developed and published an updated and comprehensive guidebook on developing emission inventories in Europe, referred to as the *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2013* (EMEP/EEA 2013). This guidebook includes methods for BC in response to the Convention on Long-Range Transboundary Air Pollution's EMEP program. The EMEP/EEA guidebook provides detailed methods, emission factors, and activity data sources for all major BC emissions sectors.

Global Inventories

The team reviewed two major global BC emission inventories, which are prominent in the literature and are cited as references in several of the studies and reports outlined above. The Bond study contains details on the development of a global BC emission inventory from combustion sources (Bond et al. 2004). The specific emissions sources considered in this study are fossil fuels, biofuels, open biomass burning, and burning of urban waste. Apart from fuel-use data, the study also considers combustion practices such as combinations of fuels, combustion types, and emissions controls. Fuel combustion sources include residential, commercial, industrial, brick kilns, cookstoves, motor vehicles, etc.

The Greenhouse Gas Air Pollution Interactions and Synergies (GAINS) model estimates historic emissions of 10 air pollutants and six GHGs for each of 48 European countries, Asia (China and India), and Annex I countries of the United Nations Framework Convention on Climate Change (UNFCCC).

Results of the initial extension of the model to address short-lived climate forcers (SLCFs), including BC, are based on the 2006 European (EMEP) emission inventory (Heyes et al. 2011). The model estimates impacts of reductions in GHGs from European country emissions in the northern hemisphere, the EMEP model domain, and the Arctic and Alpine glaciers.

1.3.3 Evaluation and Initial Recommendations

Based on these reviews, the ERG team concluded that the guidance template established under the IPCC guidelines, and elaborated and expanded on in the EMEP/EEA guidance, is a good starting point for North American guidelines as well. The EMEP/EEA guidance encompasses the IPCC approach and extends it to include PM and BC, so it is referenced here as the primary document for comparison. For each sector, the EMEP/EEA guidance provides multiple tiers for inventory developers to choose from when compiling an inventory. The tiers are generally differentiated by the level of aggregation of activity data available for the analysis. Emission factors are from the same source, creating consistency among the tiers, but are aggregated for each tier commensurate with the level of activity data aggregation. The guidance is then presented in the form of a decision tree, which steers the inventory developer toward a particular tier, based on the detail of available data. According to the EMEP/EEA guidance, for some emissions sectors defined as key categories only Tier 2 or 3 may be used; this is also reflected in the decision tree.

The EMEP/EEA guidance provides a good template for the North American guidance because inventory developers in Canada, Mexico, and the United States are faced with the same challenges in data availability, and are driven toward different approaches by what data are available. Defining tiers provides a consistent way to address the lack of data for any given sector. A three-tier approach defines best practice as Tier 3, and the lowest acceptable approach as Tier 1 (e.g., for a country with no emissions estimates for a particular sector). The tier approach provides a blueprint for data collection efforts, since advancing from Tier 1 → Tier 2 → Tier 3 is generally a function of having more details on the activity and emissions of a particular sector. Another advantage of adopting this approach is that it provides a basis for consistency among the North American countries, and with Europe.

As a first step toward adapting tiers to North America, the team came up with a matrix to systematize the comparison of methods across countries, to be populated for each subsector. The matrix first summarized the EMEP/EEA tiers. The Canadian, Mexican, and United States inventory approaches were then overlaid in relation to the EMEP/EEA tiers, based on the team's judgment. The matrix required comparison of overall method, emission factors, activity data sources, speciation factors, projections, and mitigation approaches in each country. The result was an evaluation of how each North American country compared to the European tiers, and to other North American countries, at a detailed level. The matrices included "< Tier 1" and "> Tier 3" categories to denote where North American methods and data sources were judged to be beyond the European Tier 3 level, or lower than the European Tier 1 level.

The final step of Task 1 was to develop initial recommendations for emission inventory guidelines, by sector. For this purpose, each reviewer used the evaluation matrices described herein to define Tier 1, 2, and 3 level approaches appropriate for North America. The process for adapting the tiers to North America depended on the evaluation of Canadian, Mexican, and United States methods and data sources compared to the EMEP/EEA tiers. While the EMEP/EEA tiers provided a useful reference point, they were not always used directly in developing the recommended levels for North America. This was particularly true when one of the North American countries was assessed to be "> Tier 3,"—that is, the best practice in North America was judged to be ahead of that in Europe. The EMEP/EEA Tier 1 levels were often used directly to represent North American Tier 1.

The full details on the literature review, cross-evaluation, and initial recommendations by sector were compiled in the Task 1 report provided to CEC in July 2014, entitled "North American Black Carbon Emissions Estimation Guidelines: Review of Methods for Estimating Black Carbon Emissions."

1.3.4 Expert Consultation (Task 2)

The focus of Task 2 was to solicit expert review and comments on the Task 1 findings and ERG's initial recommendations for methods to estimate BC emissions in North America. To identify experts, ERG worked through the CEC and project steering committee members in Canada, Mexico, and the United States. In order to promote the effort and recruit panel members, ERG staff also presented the Task 1 findings at the 16th Global Emissions Initiative (GEIA) conference held in Boulder, Colorado, in June, 2014, and solicited experts at that time.

Through an online survey and follow-up contact through email and telephone calls, 29 individuals with BC inventory expertise spread across the five major source sectors (i.e., biomass, industry/energy, mobile sources, residential sources, and other) were recruited for the expert panel. The panel was also chosen to ensure representation from North America, Europe, and Asia, and to bring perspective on measurement and speciation issues, as well as inventory development. Including end users of the guidelines document was also a priority. Panel members agreed to review the Task 1 report and provide comments through online surveys, webinars, or in written communications. The recruited panel members are listed in Table 1.3-2.

A kick-off webinar was held for the entire panel in August 2014 for the ERG team to present an overview of the Task 1 report and recommendations, and to discuss the review process. Further webinars, held through August and September 2014, focused on detailed discussions relating to each of the major sectors. While the entire panel was invited to each webinar, the webinars were targeted toward receiving comments from the panel members who indicated expertise in the specific topic area. A meeting was also held in Mexico City in October 2014 to focus on Mexico's efforts on BC emission inventories and receive comments on the Task 1 initial recommendations from INECC and Mexican expert panel members. This meeting was led by Verónica Garibay-Bravo of ERG's team and Luis Conde of INECC.

Before each meeting, ERG sent a survey to each expert that asked several questions. These questions, listed below, were aimed at generating conversation on the main topics, as well as getting feedback that we could use in revising our initial recommendations for BC emission estimation methods:

- Did the literature review miss any key studies that should be considered for determining inventory methods or data sources? If "yes," then please provide additional studies.
- Do you agree that the Tier 3 method recommended in the Task 1 report represents a "best practice" approach for estimating BC emissions? If "no," then please explain why.
- Do the Tier 1 and Tier 2 approaches reflect reasonable and pragmatic alternatives to best practice? If "no," then please explain why.
- Do you have concerns with data availability for implementing the proposed methods in Canada, Mexico, and the United States? If "yes," then please explain why.

In November 2014 a webinar was held to present the Task 2 report in draft form and review the comments received during the sector webinars, responses to the comments as documented in the draft report, and the ERG team's final recommendations. A few additional clarifying comments were received from the expert panel at that time; these were incorporated into the final report. The comments and the ways in which recommendations were updated were compiled into the Task 2 report to CEC, *Summary of Expert Panel Comments, and Changes to Initial Emission Estimation Recommendations,* December 2014. The highlights are as follows:

- Overall, reviewers agreed with the recommended methods for inventory development.
- Reviewers highlighted uncertainty in emission inventories and speciation factors, and requested that this be addressed in the guidelines.

- Several new studies were identified for review by ERG, particularly in the area of biomass burning. In Mexico, major updates to the Mexican NEI and BC inventory work by INECC led to significant updates in the recommendations for Mexico.
- Solid waste burning was added as a subsector in the "other" category.

The expert panel recommendations have been incorporated into the guidelines presented in this document.

Table 1.3-2. Experts on Black Carbon Emissions Estimation Methods

Name	Employer/Organization	Expertise
José Andrés Aguilar	INECC (Mexico)	Mobile
Michelle Bergin	Duke University (United States)	Mobile/locomotive
Steigvile Bycenkiene	Center for Physical Sciences and Technology (Lithuania)	Mobile
Beatriz Cárdenas	Comisión Ambiental de la Megalópolis (Mexico)	Biomass, other
Santa Centeno	INECC (Mexico)	Industrial/energy
Serena Chung	Washington State University (United States)	Biomass
Jason Blake Cohen	National University of Singapore (Singapore)	Biomass, other
John Crouch	Hearth, Patio and Barbeque Association (United States)	Residential, other
Xóchitl Cruz Núñez	UNAM (Mexico)	Biomass, mobile, other
Nancy French	Michigan Tech Research Institute (United States)	Biomass
Luis Gerardo Ruiz Suárez	UNAM (Mexico)	Residential
Savitri Garivait	JGSEE-KMUTT (Thailand)	Biomass
Wei Min Hao	US Forest Service	Biomass, other
Brooke L. Hemming	US EPA/ORD	Biomass, SPECIATE
Min Huang	Caltech/JPL (United States)	Biomass, mobile, industrial/energy, residential
Edward Hyer	US Naval Research Laboratory	Biomass
Carolina Inclán	INECC (Mexico)	Biomass, other
Jim Jetter	US EPA/ORD	Biomass, residential
Matthew Johnson	Carleton University (Canada)	Industrial/energy
Karin Kindbom	IVL Swedish Environmental Research Institute (Sweden)	Biomass, residential
Jessica McCarty	Michigan Tech Research Institute (United States)	Biomass
Luisa Molina	Molina Center of Energy and the Environment (Mexico)	All sectors
Abraham Ortínez	INECC (Mexico)	Biomass, other
Sean Raffuse	Sonoma Technology, Inc. (United States)	Biomass
Vankatesh Rao	US EPA/OAR	Biomass, industrial/energy, residential, other
Joshua Schwarz	CIRES/NOAA (United States)	Measurement/ characterization

Table 1.3-2. Experts on Black Carbon Emissions Estimation Methods

Name	Employer/Organization	Expertise
Peter Sheldon	Global Fire Monitoring Center (Germany)	Biomass, other
Darrell Sonntag	US EPA/OAR	Mobile, PM speciation
Don Stedman	University of Denver (United States)	Mobile
Carlo Trozzi	Techne Consulting (Italy)	Biomass, mobile, industrial/energy, residential
Fang Yan	Argonne National Laboratory (United States)	Mobile, industrial/energy
Bob Yokelson	University of Montana (United States)	Biomass, residential, other

CIRES/NOAA = Cooperative Institute for Research and Environmental Sciences/National Oceanic and Atmospheric Administration
EPA = Environmental Protection Agency
INECC = *Instituto Nacional de Ecología y Cambio Climático* (Mexico) (National Institute of Ecology and Climate Change)
JGSEE-KMUTT = the Joint Graduate School of Energy and the Environment–King Mongkut's University of Technology Thonburi
JPL = Jet Propulsion Laboratory
OAR = US Office of Air and Radiation
ORD = US Office of Research and Development
SPECIATE = EPA database
UNAM = *Universidad Nacional Autónoma de México* (National Autonomous University of Mexico)

2 Use of the Black Carbon Emissions Estimation Guidelines

This guidelines document is the result of the extensive review in Task 1 and expert consultation in Task 2. The guidelines were developed according to basic principles established in the course of reviewing and evaluating current inventory methods. During this process, the ERG team made some general observations that helped form initial judgments about the scope, form, and focus of BC inventory guidelines for North America:

- Guidelines for BC emission inventories will focus on PM emission inventories, as the development of PM emission inventories is an ongoing process for all three North American countries. The approach of developing BC inventories by speciating PM emissions is the global standard for nearly every sector; however, as discussed later in this section, current practice has typically used surrogates for BC, such as elemental carbon (EC), due to measurement limitations. This point needs to be acknowledged in the development of BC inventories.

- The detailed reviews confirm that the BC emission inventory method common across sectors, for the North American countries and Europe, follows the same general "bottom-up" inventory approach. The following equation is a general synthesis of the approach used in all of the inventory source documents reviewed under Task 1:

$$\text{Emissions}_{\text{BC}} = \text{Emission Factor}_{\text{PM}} \times \text{Activity (or Surrogate)} \times \text{Speciation Factor}_{\text{BC}}$$

- Emissions data that are generally obtained from published studies or models are more readily shared across countries, accounting for country-specific controls and factors. Activity data tend to be country-specific and are generally obtained from government-collected or -compiled data outside the agencies responsible for emission inventory development. A very useful element of the guidelines is to identify best practice emission factors by individual sector, to allow inventory developers to focus resources on gathering country-specific activity data.

- On a sector basis, the guidelines for BC emission inventories in North America should focus on identifying best practice methods and data sources, deviations from best practice in each country, and short-term versus long-term recommendations for improving inventories.

These observations led to the development of initial recommendations for emission inventory guidance based on adapting the "tier" approach from IPCC and EMEP/EEA emission inventory guidance to North America, with a focus on underlying PM emissions as the basis for BC emission inventories (IPCC 2006). In both the IPCC and EMEP/EEA guidance documents, emission inventory development is presented by major sectors, addressing overall method, emission factors, activity sources, and speciation data sources. How these tier-based guidelines can be used by practitioners will depend on the purpose of the inventory, and the data available for constructing the inventory. Important considerations for constructing a BC inventory also include the definition of BC and the role of speciation. An overview of the tier framework and discussion of these considerations are presented in the following sections.

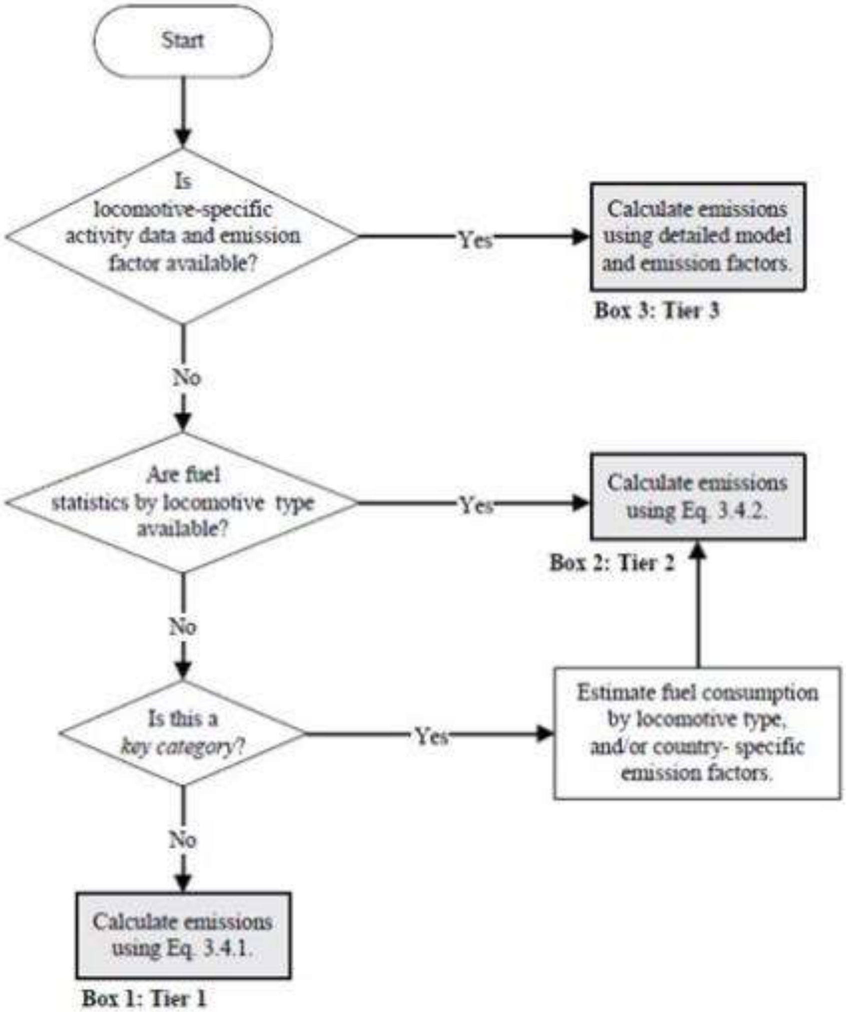
2.1 Tier Framework

Based on the review of methods in Task 1, the ERG team concluded that the guidance template established under the IPCC guidelines, and elaborated and expanded in the EMEP/EEA guidance, is a good approach for North American guidelines as well. The EMEP/EEA guidance encompasses the IPCC approach and extends it to include PM and BC, so it is referred to here as the primary document for comparison. For each sector, the EMEP/EEA guidance provides multiple tiers of approaches for inventory developers to choose from when compiling an inventory. The tiers are generally differentiated by the level of aggregation of activity data available for the analysis. In the EMEP/EEA guidance, emission factors across the tiers are often from the same source for consistency, but are aggregated for each tier commensurate with the level of activity data aggregation. The guidance is then presented in the form of a decision tree, which steers the inventory developer toward a particular tier, from the top down, based on the detail of available data. According to the EMEP/EEA guidance, for some emissions sectors defined as key categories only Tier 2 or 3 may be used; this is also reflected in the decision tree.

An example decision tree, for locomotives, from the EMEP/EEA guidance is shown in Figure 2.1-1. For the locomotive example, the top level, Tier 3, of the decision tree involves the most-detailed data on activity, locomotive-specific activity, and emission factor. If such data are not available, the information is examined for the next level, Tier 2, which is defined by fuel consumption, by locomotive type. If these data are also not available, then this inventory rests on the Tier 1 approach, which is based on a single estimate of locomotive fuel consumption in the country.

Though decision trees are not laid out in this guidelines document, the approach is implicit in the Tier 1, 2 and 3 methods provided for each sector. The decision of which tier to apply will always depend on what data are available to produce the inventory, and the intended use of the inventory; this is discussed in detail in Section 2.3.

Figure 2.1-1. Example Decision Tree for Locomotives



Source: EMEP/EEA 2013.

While the EMEP/EEA decision process can be applied to the North American guidelines as well, some differences in approach from that of EMEP/EEA were identified in developing the tiers for North America. While the goal of the EMEP/EEA guidance was a set of consistent emission factors applicable to all European Union (EU) countries, for North America these guidelines do reflect different emission factors by country, as appropriate.

2.2 Understanding Limitations in Black Carbon Emissions Estimation

Before embarking on the production of a BC inventory, it is important for the developers to understand the limitations of the current state of practice in estimating BC emissions. A foremost limitation is that air pollutant inventories are focused on mass emissions, while BC is defined based on optical properties, and measurements that form the basis of underlying emission, and speciation factors do not provide a complete accounting for these optical properties. Another limitation is that post-hoc speciation factors do not match the level of detail of PM emission factors in many sectors, introducing additional error to the process. These issues are discussed in the following sections.

2.2.1 Black Carbon Definition

What is referred to as "black carbon" varies in the literature, and in measurement practice; the definition also depends on whether a BC analysis is focused on climate-forcing or health-based outcomes. From a climate-forcing perspective, the term black carbon may be used for the broader metric of "light absorbing carbon" (LAC), comprising both light-absorbing elemental carbon (EC) and light-absorbing organic carbon (OC) (i.e., brown carbon). From a health perspective, BC has typically been defined only as the mass of EC (i.e., the graphitic component of PM). So, BC may refer to the mass of EC only, or to the broader, optically-defined LAC.

Compounding this inconsistency are limitations in measurement of both EC and LAC. Photo-acoustic measurements can estimate optical properties of LAC, but characterizing the mass of LAC is limited by the difficulty in converting these optical properties to mass, given variations in particle size, concentration, shape, age, and composition. EC mass is measured using thermo-optical methods that strip away OC in the process. The correlation of EC mass estimated from the thermo-optical approach to BC mass estimated from photo-acoustic measurements has been shown to be good for sources where EC dominates total PM, such as diesel engines. However, this correlation has not been good for sources with high OC fraction, such as wildfires and gasoline engines (Hemming and Sonntag 2015).

To date, BC inventory studies (e.g., the *Report to Congress on Black Carbon*, EPA 2013a) have tended to use the EC-based approach, because currently there are more data available for EC mass than for LAC. Because it does not include all LAC, EC has been acknowledged as only a proxy for BC until improved measurement methods and data become available. As discussed, using EC as a proxy for LAC is a poor surrogate for sources that are high in organic carbon, such as wildfires.

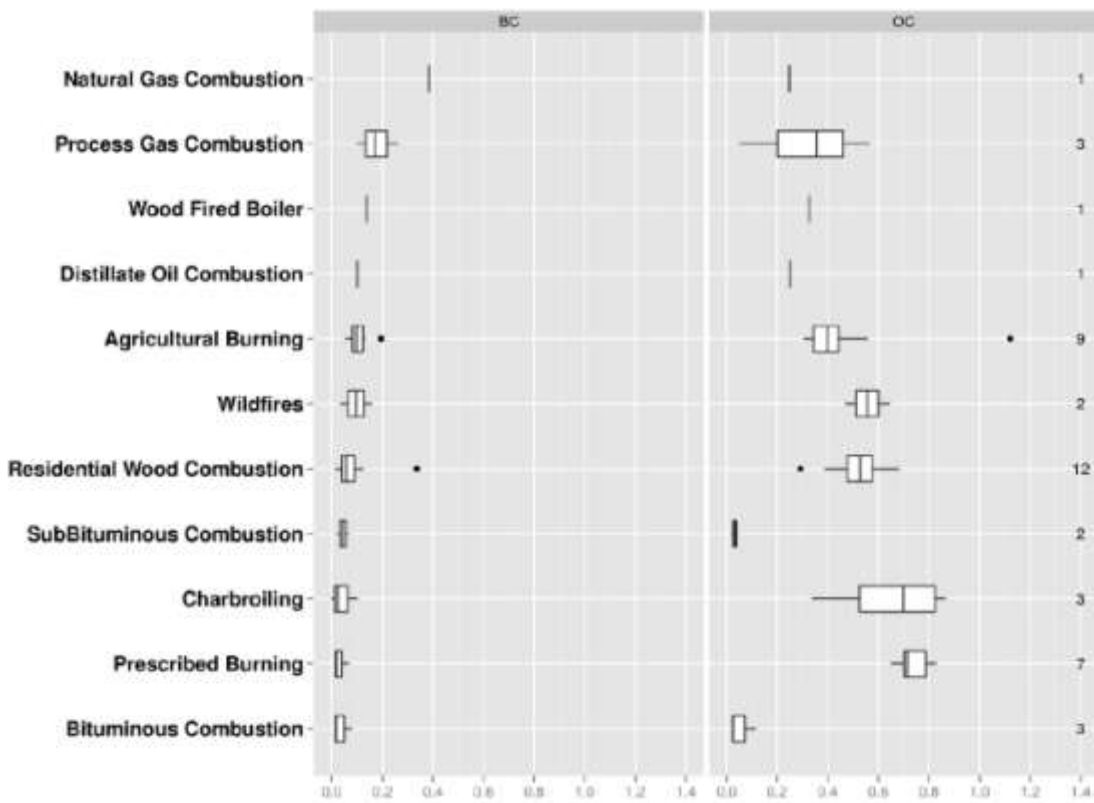
This guidelines document has been developed for flexibility; the equations presented in the document can be applied to an EC-based or LAC-based speciation factor. However, the speciation factors that are recommended for use are ultimately dictated by current techniques, primarily in EPA's SPECIATE database (EPA 2011b). The SPECIATE database is presently focused on EC mass, as this has been the state-of-practice. EPA hopes to update SPECIATE to include data and conversion factors that would allow estimation of LAC where these data are available, giving inventory developers more choice in the speciation factors to use, depending on the purpose of the inventory. Currently, SPECIATE is based on data from published papers. The EPA has proposed to update SPECIATE to include BC emission factors based on the more recent alternative characterizations of BC (including photo-acoustic, laser-induced incandescence, and optically based measurements), and to expand the BC and other speciation factors to include more source types. The degree of expansion and improvement in the database will depend on resources, and engagement by the research community in improving BC estimates.

2.2.1 Uncertainty in Speciation

In addition to the definition of BC, inventory developers should understand how the process of speciation itself adds uncertainties in BC inventories. BC inventories are unique among air pollutant inventories, in that current state-of-practice is to calculate total PM emissions, a superset of BC, then apply fractions (known as speciation factors) post hoc to estimate BC. This is because direct measurement of BC is not a common practice (it is not required for regulation), and requires specialized equipment and/or post-measurement analysis not standard in PM measurement systems and research programs. Speciation factors for BC are derived from research programs that provide these data, which tend to reflect smaller samples and more-limited test conditions than underlying PM emission factor programs. This means the speciation factors are usually not completely aligned with underlying PM inventories, introducing a new source of error and increasing inventory uncertainty.

The fraction of BC to total PM varies greatly by source category. The largest BC fraction is for diesel-fueled mobile sources, where EC is a good proxy for BC; as reported in EPA 2013a, elemental carbon comprises about 75 percent of PM directly emitted by heavy-duty diesel trucks. This fraction drops considerably for vehicles equipped with diesel particulate filters, which eliminate much of the black carbon produced by the engine. For non-mobile sources, the range of speciation factors across sources, and within each source, is shown in the estimates used in EPA 2013a (Figure 2.2-1). In this figure, the boxes represent the 25th and 75th percentiles, whiskers the 10th and 90th percentiles, as noted.

Figure 2.2-1. Black Carbon and Organic Carbon Fractions of $PM_{2.5}$ Emissions for the Highest Black Carbon–Emitting Non-mobile Source Categories in the United States



Source: EPA 2013a.
Note: BC = black carbon; OC = organic carbon. Boxes represent the 25th and 75th percentiles, whiskers the 10th and 90th percentiles. The vertical lines within the boxes represent the median values for that source category; and dots represent outliers.

As shown in the figure, for non-mobile source sectors the BC fraction is less than 0.4, meaning BC is less than 40 percent of overall PM. The range in speciation factors shows the uncertainty inherent in a speciation approach. This is compounded by the limited number of speciation profiles available; for the US BC inventory, approximately 300 factors from SPECIATE were applied to roughly 3,400 source categories. SPECIATE is EPA’s repository of volatile organic gas and PM speciation profiles of air pollution sources. Among the many uses of speciation data, these emission source profiles are used to create speciated emission inventories for regional haze, PM, climate, and photochemical air quality modeling, as well as BC.

As discussed in Section 4, the process of speciation, though essential at this stage of BC inventory development, adds a large amount of uncertainty to BC inventory estimates. For this reason, we consider improved and widespread measurement of light-absorbing carbon for use in estimating inventories without speciation to be the top-priority long-term research goal.

2.3 Inventory Use Cases

Development of a BC emission inventory (and the inventory of any pollutant) must take into consideration the purpose of the inventory. The fundamental elements of inventory scope (e.g., timeframe, geographic area, temporal resolution, level of detail in source sectors) must consider the level of detail needed by end users of the inventory. Inventories have a broad range of uses—known as use cases (e.g., national to regional, retrospective to future projections, comprehensive aggregations to detailed sector-specific estimates). This guidelines document has been developed to support a range of options, so that practitioners can assess the needed scope and detail of the final inventory. At times the desired use case of the inventory will not be supported by the level of detail of available data—that is, aggregate emission inventories may not be sufficient, depending on the use case. The appropriate tier will be determined by the scope and detail of data available and the scope and detail of the data needed for the intended use.

The major use cases for BC inventories, and considerations for applying this guidelines document, are discussed in the following sections.

2.3.1 The Need for Spatial and Temporal Resolution

Starting from a benchmark of national/annual emissions totals, the need for spatial and temporal detail will depend on the inventory use case, and on whether aggregate totals can be improved with a more detailed bottom-up accounting. Inventories for national reporting, regional accounting, or mitigation analyses may not require detailed spatial and temporal resolution. Use of inventories for assessing climatic impacts will require more-detailed resolution, as the location of emissions is an important factor in assessing these impacts. Spatial and temporal detail may improve aggregate totals for some sectors.

In cases where BC inventories are based on existing PM inventories, the level of spatial and temporal detail will be constrained by what was done for the PM inventory; BC inventories will not be more detailed than underlying PM inventories. Well-constructed PM inventories will account for important spatial and temporal factors such as regional location of sources, seasonal changes in activity, and effects of weather on emissions.

This guidelines document has been constructed to present methods that can be applied at different levels of spatial and temporal detail. The bottom-up methods are generally “scaleable” from finer breakdowns (e.g., region/day) to more aggregate breakdowns, but the ability to do this will depend on the detail available in activity data.

2.3.2 National Reporting

The objective of the UNFCCC is to stabilize GHG concentrations in the atmosphere at a level that would prevent and reduce dangerous human-induced interference with the climate system. The ability of the international community to achieve this objective is dependent on an accurate knowledge of GHG emissions trends, and on the collective ability to alter these trends. Parties to the Convention submit to the Secretariat national inventories of anthropogenic emissions by sources and removals by sinks of GHGs not controlled under the Montreal Protocol. In addition, Parties provide inventory data in summary form in their national communications under the Convention. These inventories are subject to an annual technical review process (UNFCCC 2015).

The national inventories of GHGs, submitted to satisfy UNFCCC requirements, are retrospective annual inventories (from 1990 forward) that are aggregate totals, by major-source sector (energy, industrial processes, agriculture, etc.). Sectors are broken down into specific subsectors (e.g., energy may contain broad sources such as production of fossil fuels, and fossil fuel combustion by transportation and residential sources), with emissions reported in total. This use case therefore requires an inventory that is comprehensive in accounting for all emission sources that exist within national boundaries, but not at detailed spatial or temporal resolution. More-aggregate approaches to inventory development can be employed for this use, allowing Tier 1, 2, or 3 methods to be used, depending on data availability. Although BC emission inventories are not required for submission to the UNFCCC, this BC guidelines document can support developers of national inventories by providing methods for all broad source categories, as well as alternative methods, depending on data available. The methods and data sources in this guidelines document could be applied at a national/annual level, though in many cases building up an inventory to account for regional and seasonal variation will improve emission inventory estimates, even if the final product is only required at the national/annual level.

2.3.3 Regional Inventories

Regional inventories are undertaken by state and local governments to assess local air quality and GHG contributions, projections, and controls. For criteria pollutants in the United States, the level of detail, methods, and emission factors may be dictated by regulatory requirements (e.g., state implementation plans required to show attainment with National Ambient Air Quality Standards) and/or inputs needed for air quality modeling. Methods for developing local BC inventories are not standardized (though existing PM inventories that will generally form the basis of BC inventories may have been developed according to such requirements), so the breadth and detail of regional BC inventories depends on the specific goals and uses of the inventory (e.g., climate change regulatory development, climate modeling analyses). Regional GHG inventories are generally developed for planning purposes—to understand current emissions, business-as-usual projections, and assess the impacts of different mitigation strategies. The inventory may not include all source sectors, if the region does not include those sources. The availability of activity data to support certain sectors and tiers may be more restricted than for national inventories, unless inventory developers have access to region-specific studies of the activity. For these analyses, Tiers 1, 2, or 3 may be used, depending on availability of data and inventory use; if a regional inventory is desired for mitigation analysis, as discussed in Section 2.3.5, a Tier 3 level of detail is generally required.

2.3.4 Precursor to Impact Analyses

The impacts of BC emissions on climate have been studied through application of BC emissions data in climatic models that assess radiative forcing, snow/ice albedo, and other factors. For these analyses, the composition, spatial, and temporal details of the inventories are important for determining impacts. This is particularly true for assessing impacts of BC in the Arctic region, where seasonal variations in emissions and transport of emissions from outside the region can influence radiative forcing and albedo impacts (Arctic Council 2011). For impact analyses, more-detailed emission inventories produced using Tier 3 methods may therefore be necessary.

2.3.5 Projection and Mitigation Analyses

For mitigation analyses, emission inventories require a level of detail at the same level of specificity as the controls being evaluated. In general, this means that mitigation analyses for some sources will require Tier 3 inventories. For example, specific controls on point sources may require data on process-level emissions in order to estimate the impacts of that particular control. Evaluating the impact of diesel vehicle retrofit requires estimating the number of vehicles to be retrofitted and their ages. In both examples, the required level of detail is found only in the Tier 3 approach. Tier 2 approaches may be appropriate as long as the mitigation strategy can be analyzed at the level of aggregation specified for activity and emission factors in the affected sector.

2.3.6 Application of Tiers to Inventory Use Cases

Table 2.3-2 shows the level of detail required in the emission inventory developed for the broad-use cases discussed in Section 2.3.

Table 2.3-2. Tiers Applicable for Broad-use Cases

Tier	National Reporting	Regional Inventories	Impact Analyses	Mitigation Analyses
1	✓	✓		
2	✓	✓		✓
3		✓	✓	✓

3 Sector-specific Black Carbon Emission Estimation Methods

This section presents BC emission estimation methods by sector and tier. A Tier 1 method generally consists of national-level fuel data or other aggregated activity data used in conjunction with $PM_{2.5}$ emission factors and BC speciation factors. Tier 2 is similar to Tier 1, but the activity data and emission factors are categorized by technology type. Tier 3 methods, where available, are generally considered the most accurate, and are based on a much finer level of detail than Tier 1 or Tier 2. Tier 3 methods may look similar to Tier 2 methods, but use more-specific activity data (e.g., crop-specific fuel loadings, modeled emission rates, technology-specific fuel consumption, etc.)

Most methods are based on estimation of $PM_{2.5}$ emissions, which are then converted to BC emissions using a speciation factor. In most cases, the recommended source for speciation factors is EPA's SPECIATE database (EPA 2011b). As discussed in Section 2.2, SPECIATE does not contain factors to convert $PM_{2.5}$ to LAC directly; rather the factors are for a $PM_{2.5}$ to EC conversion. EPA is considering updates to SPECIATE to include factors for estimating LAC as well, and the equations presented in this section were developed to allow either approach, depending on the needs of the inventory developer.

The methods presented here, by sector, for each tier, also include information on potential sources of activity data, emission factors, and speciation factors. This information is not exhaustive, but is intended to direct the users to resources that may be appropriate for use in the various methods in their area. As with any emission inventory effort, the inventory developer should strive to use the most reliable, current and accurate information as possible and which enables them to meet the objectives of the inventory being developed, whether that be for an "order or magnitude" estimate, an air quality plan, use in an air quality model, or other purposes.

For Tier 1 methods, a table of recommended emission and speciation factors is provided for each subsector in the tables in Appendix B.. The level of detail precluded this for Tier 2 and 3, but this section does provide clear detail and references for the emissions and speciation factors for these levels as well.

3.1 Biomass Burning

Biomass burning includes wildfires, forest fires, and prescribed burning (i.e., categories generally referred to as open burning), along with agricultural residue burning. In North America, the burning of wood and plant waste is a significant source of BC emissions. In the United States alone, biomass burning is responsible for approximately 35 percent of the BC emissions; and globally, two-thirds of all BC emissions come from biomass burning and residential sources (EPA 2013a).

3.1.1 Open Burning

Tier 1

A Tier 1 method for open burning consists of a single emission factor per unit area, area burned, and a speciation factor. The Tier 1 method is based on the following equation:

$$E_{BC} = A \times EF_{PM_{2.5}} \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC}	=	emissions of black carbon
A	=	area burned (e.g., acres, hectares)
$EF_{PM2.5}$	=	emission factor for $PM_{2.5}$ per area (e.g., acres, hectares)
$SF_{BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon

Tier 2

A Tier 2 method for open burning uses specific biome-based emission factors and fuel characteristics in the following equation:

$$E_{BC,k} = (0.45 \times A_k \times B_k \times a_k \times b_k) \times EF_{k,PM_{2.5}} \times SF_{k,BC/PM_{2.5}}$$

Where,

$E_{BC,k}$	=	emissions of black carbon for biome “k”
0.45	=	fraction of carbon in fuel
A_k	=	area burned of biome “k”
B_k	=	fuel load (mass of fuel per area for biome “k”)
a_k	=	fraction of above-ground biomass for biome “k”
b_k	=	combustion efficiency (fraction of fuel burned for biome “k”)
$EF_{k,PM2.5}$	=	emission factor for $PM_{2.5}$ for biome “k” (i.e., emissions per mass of C in the fuel [kg/kg-C in fuel])
$SF_{k,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for biome “k”

Tier 3

A Tier 3 method would use the same equation as for Tier 2, with more-specific forest and biome-based emission factors, and would estimate emissions based on type of burning (i.e., smoldering versus flaming). Activity data for forest or biome fires would be area burned and fuel burned per unit area, by type of forest/biome and fuel to better fit the emission factors. Thus, they could be further disaggregated into major climate and soil categories and possibly management practice based on local understanding and measurements. Likewise, speciation for forest and other biome fires would consider both the type of biome being burned and variation by percent of smoldering and flaming burning (i.e., by prescribed burns and wild fires).

$$E_{BC,k} = (0.45 \times A_k \times B_k \times a_k \times b_k) \times (EF_{k,PM_{2.5,SM}} \times SF_{k,BC/PM_{2.5,SM}} \times Smf + EF_{k,PM_{2.5,F}} \times SF_{k,BC/PM_{2.5},F} \times FF)$$

Where,

$E_{BC,k}$	=	emissions of black carbon for biome “k”
0.45	=	fraction of carbon in fuel
A_k	=	area burned of biome “k”
B_k	=	fuel load (mass of fuel per area for biome “k”)
a_k	=	fraction of above-ground biomass for biome “k”
b_k	=	combustion efficiency (fraction of fuel burned for biome “k”)
$EF_{k,PM2.5,SM}$	=	emission factor for $PM_{2.5}$ for biome “k” for smoldering combustion

$EF_{k,PM2.5,F}$	=	emission factor for $PM_{2.5}$ for biome "k" for flaming combustion (i.e., emissions per mass of C in the fuel (kg/kg-C in fuel)
$SF_{k,BC/PM2.5,SM}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for biome "k" for smoldering combustion
$SF_{k,BC/PM2.5,F}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for biome "k" for flaming combustion
Smf	=	fraction of combustion that is smoldering
FF	=	fraction of combustion that is flaming

Potential Sources of Activity Data, Emission Factors, and Speciation Factors

Potential sources of activity data, emission factors, and speciation factors for the Tiers 1, 2, and 3 methods for estimating BC emissions from open biomass burning in North America are provided in Table 3.1-1. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.1-1. Potential Sources of Activity Data, Emission Factors, and Speciation Factors for Open Burning

Parameter	Canada	United States	Mexico
Tier 1			
Area burned	• Randerson 2012 (remote sensing)[a] • Other source(s), such as records kept by local agencies in Canada: Canadian Interagency Forest Fire Centre (CIFFC)		Monthly database, by vegetation type: National Forest Commission (*Comisión Nacional Forestal*—Conafor)
Emission factor ($PM_{2.5}$)	• Prescribed burning, excluding British Columbia: AP-42 (EPA 1995a) • Prescribed burning in British Columbia: 2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed (GVRD and FVRD 2003)	AP-42 (EPA 1995a)	AP-42 (EPA 1995a)
Speciation factor (BC)	Average BC fraction: SPECIATE (see Figure 2.1-1 above; use EC factor for BC); WRAP 2005		Average BC fraction: SPECIATE (see Figure 2.1-1 above; use EC factor for BC)
Tier 2			
For each Biome: • Area burned • Fuel load • Above-ground fraction of load • Combustion efficiency	• Area burned: Randerson 2012 (remote sensing)[a] or data as reported by local agencies • Fuel load and consumption by biome: van Leeuwen et al. 2014; Akagi et al. 2011; WRAP 2005		• Area burned: Conafor • Fuel load and consumption by biome: None available • Combustion efficiency: Akagi et al. 2011
Biome-specific emission factor ($PM_{2.5}$)	Akagi et al. 2011[b]; May et al. 2014		Akagi et al. 2011; Yokelson et al. 2011
Biome-specific speciation Factor (BC)	Akagi et al. 2011[b]; May et al. 2014		

Table 3.1-1. Potential Sources of Activity Data, Emission Factors, and Speciation Factors for Open Burning

Parameter	Canada	United States	Mexico
		Tier 3	
For each Biome: same as Tier 2, plus % by burning regime (% smoldering and/or % flaming)	• Area burned: Randerson 2012 (remote sensing)[a] supplemented by data reported by local agencies • Fuel load and consumption by biome: van Leeuwen et al. 2014; Akagi et al. 2011; or local expert judgment		• Area burned: Conafor • Combustion efficiency: Akagi et al. 2011 • Fuel load and consumption by biome: None available • % by burning regime (% smoldering and/or % flaming): None available
Biome- and burning regime–specific emission factor ($PM_{2.5}$)	Akagi et al. 2011[b,c]; May et al. 2014; or local expert judgment		Akagi et al. 2011[b,c]; Yokelson et al. 2011
Biome- and burning regime–specific speciation factor (BC)	Akagi et al. 2011[b,c]; May et al. 2014; or local expert judgment		

[a] Remotely sensed burn area data developed from MODIS satellite may be used, although this method may miss small fires and fires obscured by forest canopy.

[b] Emissions reported using the Single Particle Soot Photometer (SP2) technique may result in higher (by factor of 2) emission factors as compared to those developed using filter technique (May et al. 2014). Therefore, earlier emission factors developed using the filter method may need to increase if further research supports this claim.

[c] Akagi et al. 2011 only report overall average emission factors or speciation factors. Nevertheless, since the fraction of burning that is smoldering generally increases with time, the equation above includes a separate consideration of emission and speciation factors for future reference.

3.1.2 Agricultural Burning

Tier 1

A Tier 1 method for agricultural burning is the same as for open burning, and consists of a single emission factor per unit area, area burned, and a speciation factor. The Tier 1 method is based on the following equation:

$$E_{BC} = R \times EF_{PM_{2.5}} \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC} = emissions of black carbon
R = amount of residue burned:

$$R = A \times Y \times s \times d \times p \times Cf$$

Where,

A = area burned
Y = crop yield (per unit area burned)
s = ratio of crop residue to yield
d = dry matter content of yield
p = portion of residue burned
Cf = combustion factor or combustion efficiency
$EF_{PM2.5}$ = emission factor for $PM_{2.5}$ per mass of fuel
$SF_{BC/PM2.5}$ = speciation factor to convert $PM_{2.5}$ to BC

The use of average values for all variables except "A" is assumed. There should also be a mass accounting of any residue removed and used for other activities, which should be subtracted from the amount of residue ("R") calculated. Chapter 2.4 of the *2006 IPCC Guidelines* is used to estimate Y and Cf for wheat, maize, and rice (assumes d = 0.85) (IPCC 2006). Average BC speciation factors are used for agricultural fires (0.075) (WRAP 2005).

Tier 2

A Tier 2 method for agricultural burning uses crop-specific emission factors and fuel characteristics, using the same equation as that for Tier 1 (but breaking out each factor by specific crop data):

$$E_{BC,c} = R_c \times EF_{c,PM_{2.5}} \times SF_{c,BC/PM_{2.5}}$$

Where,

$E_{BC,c}$	=	emissions of black carbon for crop "c"
R_c	=	amount of residue burned for crop "c":

$$R_c = A_c \times Y_c \times s_c \times d_c \times p_c \times Cf_c$$

Where,

A_c	=	area burned for crop "c"
Y_c	=	crop yield for crop "c" (per unit area burned)
s_c	=	ratio of crop residue to yield for crop "c"
d_c	=	dry matter content of yield for crop "c"
p_c	=	portion of residue burned for crop "c"
Cf_c	=	combustion factor or combustion efficiency for crop "c"
$EF_{c,PM2.5}$	=	emission factor for $PM_{2.5}$ per mass of fuel for crop "c"
$SF_{c,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for crop "c"

Tier 3

A Tier 3 method uses the same equation as for Tier 2 and Tier 1, with region- or country-specific parameters based on local measurements data. Speciation data for agricultural burning in a Tier 3 approach would be based on crop type.

Potential Sources of Activity Data, Emission Factors, and Speciation Factors

Potential sources of activity data, emission factors, and speciation factors (wherever applicable) for the Tier 1 and Tier 2 methods for estimating BC emissions from agriculture burning in North America are provided in Table 3.1-2. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.1-2. Potential Sources of Activity Data, Emission Factors, and Speciation Factors for Agricultural Burning

<table>
<tr><th>Parameter</th><th>Canada</th><th>United States</th><th>Mexico</th></tr>
<tr><td colspan="4">Tier 1</td></tr>
<tr><td>Average values for:
• Area burned
• Yield (avg.)
• Residue: yield
• Dry matter content
• Portion of residue burned
• Combustion factor</td><td colspan="2">• Area burned (McCarty 2011, remote sensing) or local agency reports
• Residue loading by crop: EMEP/EEA 2013, Table 3-2; Schreuder and Mavko 2010; van Leeuwen et al. 2014; WRAP 2005
• Combustion factor data: Van Leeuwen et al. 2014; Akagi et al. 2011</td><td>• Area burned: National Union of Sugarcane Harvesters (Unión Nacional de Cañeros A.C.), Estadísticas de la Agroindustria Azucarera Nacional
• Crop Residues: Valdez-Vazquez et al. 2010
• Annual production per crop: Agriculture and Food Produce Information System (Siacon)(Sagarpa 2013)</td></tr>
<tr><td>Emission factor ($PM_{2.5}$)</td><td colspan="2">Akagi et al. 2011; WRAP 2005</td><td>Akagi et al. 2011; Yokelson et al. 2011; for sugarcane: Hall et al. 2012</td></tr>
<tr><td>Speciation factor (EC or BC)</td><td colspan="2">Average BC fraction: SPECIATE database (Figure 4-1, EPA 2013a; use EC factor for BC); WRAP 2005</td><td>Average BC fraction: SPECIATE database (Figure 4-1, EPA 2013a; use EC factor for BC); for sugarcane: Hall et al. 2012</td></tr>
<tr><td colspan="4">Tier 2</td></tr>
<tr><td>By crop type:
• Area burned
• Yield (avg.)
• Residue: yield
• Dry matter content
• Portion of residue burned
• Combustion factor</td><td colspan="2">• Area burned (McCarty 2011, using remote sensing) and local agency reports
• Residue loading by crop: Schreuder and Mavko 2010; van Leeuwen et al. 2014; 2002 Fire Emission Inventory for the WRAP Region–Phase II report 2005
• Combustion factor data: van Leeuwen et al. 2014; Akagi et al. 2011</td><td>• Area burned: National Union of Sugarcane Harvesters (Unión Nacional de Cañeros A.C.), Estadísticas de la Agroindustria Azucarera Nacional
• Annual production per crop: Agriculture and Food Produce Information System (SIACON) (Sagarpa 2013)
• Parameters for crop residues (Valdez-Vazquez et al. 2010)</td></tr>
<tr><td>Crop-specific emission factor ($PM_{2.5}$)</td><td colspan="2">Schreuder and Mavko 2010; van Leeuwen et al. 2014; Akagi et al. 2011; WRAP 2005</td><td>For sugarcane: Hall et al. 2012</td></tr>
<tr><td>Crop-specific speciation factor (EC or BC)</td><td colspan="3">See Tier 1</td></tr>
<tr><td colspan="4">Tier 3</td></tr>
<tr><td>By crop type:
• Area burned
• Yield (avg.)
• Residue: yield
• Dry matter content
• Portion of residue burned
• Combustion factor</td><td colspan="2">• Area burned (McCarty 2011, using remote sensing) and local agency reports
• Residue loading by crop: Schreuder and Mavko 2010; van Leeuwen et al. 2014; WRAP 2005
• Combustion factor data: van Leeuwen et al. 2014; Akagi et al. 2011</td><td>See Tier 2</td></tr>
<tr><td>Crop-, climate-, and soil-specific emission factor ($PM_{2.5}$)</td><td colspan="2">Schreuder et al. 2010; van Leeuwen et al. 2014; Akagi et al. 2011; WRAP 2005</td><td>For sugarcane: Hall et al. 2012</td></tr>
<tr><td>Crop-specific speciation factor (EC or BC)</td><td colspan="3">See Tier 1</td></tr>
</table>

3.2 Energy/Industry

The energy/industry sector includes fossil fuel combustion for purposes of: power generation; oil and natural gas production, processing and refining (including venting and flaring); manufacturing (including stationary diesel engines); and, industrial and institutional/commercial boilers. The manufacturing industries covered in this sector include, for example: mineral, chemical, metal and wood products manufacturing and production. Brick production in Mexico is also addressed in this sector.

Fine particulate ($PM_{2.5}$) and BC emissions are released into the atmosphere as a function of combustion of fossil fuels by energy/industrial sources. Different types of fossil fuels (e.g., coal, oil, natural gas, diesel, liquid petroleum gas, process gas) are used to generate electricity and power equipment used by industries. Emissions from the combustion of biomass fuels are addressed in Section 3.1 (Biomass Burning) and Section 3.4 (Residential Combustion) of these guidelines.

3.2.1 General Energy/Industry Sources

Tier 1

For the different industries within the energy/industry sector (excluding brick kilns), the Tier 1 method estimates BC emissions using fuel consumption and a default emission factor, by type of fuel combusted within the selected industry. The Tier 1 method is based on the following equation:

$$EBC = \sum_{i,I} \left(Q_{i,I} \times EF_{i,I,PM_{2.5}} \times SF_{i,I,BC/PM_{2.5}} \right)$$

Where,

E_{BC}	=	emissions of black carbon from fuel combustion (sum of emissions from all fuels)
i	=	type of fuel (e.g., natural gas, coal)
I	=	type of industry (e.g., power production, cement, iron and steel)
$Q_{i,I}$	=	quantity of fuel type “i” combusted in industry “I”
$EF_{i,I,PM2.5}$	=	$PM_{2.5}$ emission factor for fuel type “i” and industry “I”
$SF_{i,I,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbons for fuel type “i”

Tier 2

A Tier 2 method estimates emissions for each combination of fuel and technology type that is used (excluding brick kilns). Activity data for the Tier 2 method can be at the national, state, regional, or other required inventory area–level. The Tier 2 method is based on the following equation:

$$E_{BC} = \sum_{i,j} \left(Q_{i,j} \times EF_{i,j,PM_{2.5}} \times SF_{i,BC/PM_{2.5}} \right)$$

Where,

E_{BC}	=	emissions of black carbon
i	=	type of fuel
j	=	technology/equipment type (e.g., diesel engine, natural gas-fired boiler, fuel-oil furnace)
$Q_{i,j}$	=	amount of fuel “i” combusted in technology/equipment type “j”
$EF_{i,j,PM2.5}$	=	$PM_{2.5}$ emission factor for fuel type “i” and technology/equipment type “j”
$SF_{i,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for fuel type “i”

Tier 3

A Tier 3 method is based on device-specific measurements data. Unlike for $PM_{2.5}$, methods to measure BC emissions from instruments (i.e., stack probes) are not available. However, BC-to-$PM_{2.5}$ ratios (BC:$PM_{2.5}$) have been developed from recent studies, and application of these ratios can be considered a pseudo–Tier 3 approach. For example, $PM_{2.5}$ emissions from utility natural gas–fired boilers can be estimated by using a stack sampling probe (Tier 3 approach), which measures amount of mass collected by the $PM_{2.5}$ filter and stack parameters (e.g., flowrate). Once measured, a BC-to-$PM_{2.5}$ ratio can be applied.[1]

To the extent these Tier 3 data are available for the desired inventory domain, they can be used to estimate emissions using the following equation:

$$E_{BC} = \sum_i \left(E_{i,PM_{2.5}} \times SF_{i,BC/PM_{2.5}}\right)$$

Where:

E_{BC}	=	emissions of black carbon from fuel combustion (sum of emissions from all fuels);
$E_{i,PM2.5}$	=	$PM_{2.5}$ emissions estimated from direct measurements (e.g., probe sampling) for fuel type "i"
$SF_{i,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for fuel type "i"

Note that even though measurements data may be available, they may be of questionable quality or there may be concern that the data are not representative of average production or fuel consumption for a given industry, facility, or emissions unit. In these cases of questionable quality, a feasible approach to estimating emissions may be to apply the tiers as follows: step 1) implement Tier 3 (obtain measurements data); step 2) compare measured emissions to emissions calculated based on emission factors, or those measured or estimated for other similar facilities; step 3) if measurements data are questionable (i.e., not comparable to emissions determined through other methods), use expert judgment as to whether to employ Tier 3 or Tier 2.

Potential Sources of Activity Data, Emission Factors, and Speciation Factors

Potential sources of activity data, emission factors, and speciation factors (wherever applicable) for the Tier 1 and Tier 2 methods for estimating BC emissions from industrial and energy sources in North America are shown in Table 3.2-1 below. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

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[1] To calculate the mass amount of $PM_{2.5}$ based on a source test, apply the following equation:

$$Emissions_{PM2.5} = \left(\frac{Cf}{Vm}\right) \times Qf$$

Where:

$Emissions_{PM2.5}$	= $PM_{2.5}$ emissions (grams/minute)
Cf	= amount of $PM_{2.5}$ collected on the filter during the source test (grams)
Vm	= volume of gas sampled at standard temperature and pressure (standard cubic feet [scf])
Qf	= flow rate during source test (standard cubic feet per minute)

Table 3.2-1. Potential Sources of Activity Data, Emission Factors, and Speciation Factors for the Energy/Industry Sector

Parameter	Canada	United States	Mexico
Tier 1			
Quantity of fuel, by fuel type	*Report on Energy Supply and Demand in Canada* (RESD) (Statistics Canada 2015a)	• *Annual Energy Outlook* (AEO) (EIA 2015a) • Industry associations	International Energy Agency (IEA); Secretariat of Energy (*Secretaría de Energía*—Sener); National Institute of Statistics and Geography (*Instituto Nacional de Estadística y Geografía* – INEGI); INECC; Semarnat; industry associations
Emission factor ($PM_{2.5}$)	WebFIRE (EPA 2015b)		
Speciation factor (EC or BC)	SPECIATE database (EPA 2011b); use EC factor for BC		
Tier 2			
Quantity of fuel, by fuel type and technology/equipment type	RESD (Statistics Canada 2015a); industry associations; specialized models (e.g., for Upstream Oil and Gas)	AEO (EIA 2015a); Industry associations	See Tier 1
Emission factor ($PM_{2.5}$)	WebFIRE (EPA 2015b)		
Speciation factor (EC or BC)	SPECIATE database (EPA 2011b); use EC factor for BC		
Tier 3			
$PM_{2.5}$ Emissions	Direct emission measurements		
Speciation factor (EC or BC)	• SPECIATE database (EPA 2011b); use EC factor for BC • Flaring: McEwen and Johnson 2012	• SPECIATE database (EPA 2011b); use EC factor for BC	SPECIATE database (EPA 2011b); use EC factor for BC

3.2.2 Brick Kilns in Mexico

In Mexico, bricks are the primary construction material. They are manufactured using different techniques, depending on their type: solid bricks are mostly manufactured in traditional kilns; hollow or perforated bricks are manufactured using mechanized processes. Industrial manufacturing, whereby up to 1 million bricks can be produced per day in large, highly efficient facilities, accounts for roughly 9 percent of total brick production. The rest is produced in 17,052 traditional kilns, located mostly in the states of Puebla, Jalisco, Guanajuato, San Luis Potosí, Michoacán, Durango, Chihuahua, Querétaro, and Estado de México, which use mainly wood but also other fuels. These states comprise roughly 76 percent of total artisanal brick production in Mexico (Kato et al. 2013).

There are many different types of kilns and fuels used in traditional brick manufacturing in Mexico. Depending on their output, size can be small (up to 5,000 bricks/batch), medium (up to 10,000–15,000 bricks/batch) or large (up to 30,000–35,000 bricks/batch). Total output varies seasonally: during the dry season, highly productive kilns can render from 1 to 3 batches per month, compared to during the rainy season, when the most they can achieve is one batch per month (Cárdenas 2012). On average, kilns can produce 12 to 14 batches per year. Kilns can also be fixed or temporary, which is one of the reasons why it is difficult to determine exactly how many kilns are in operation each year. Fuels are also variable: artisans use mainly scrap wood and sawdust, but plastic, tires, manure, coconut husks, cardboard, battery cases and used motor oil can also be burned in these kilns (Stratus 2012). Although some efforts are being made to introduce improved brick kilns like the "MK2" and better wood and air supply systems, to reduce emissions and health impacts, most artisanal production is performed in traditional, highly inefficient kilns.

A typical brick-making process starts with clay extraction, sifting, mixing (with salt and water), brick forming (using a mold), drying (outside, in the sun), and firing (in the kiln). It is this latter step that involves combustion and produces most of the particulate emissions. At the start of the kiln operation, the kiln is left uncovered while it produces considerable amounts of smoke and soot. Afterwards, it is covered to allow it to stabilize (i.e., to reach and maintain a temperature of at least 600°C for at least one hour). Temperature control is based on artisans' experience and knowledge, since most kilns lack temperature monitors. The entire process takes between 14 and 24 hours, during which time fuel is continuously fed to the kiln to maintain its temperature (Stratus 2012).

There have been several research studies on the health and climate impacts of brick kilns in different parts of the world. BC emissions depend largely on the fuel used, but also on kiln efficiency, technology, operating practices, the type of clay used, and many other factors that vary considerably among regions.

Tier 1

The Tier 1 method estimates emissions from Mexican brick kilns based on total brick production across the inventory area, average size of batches, and average emission factor per batch. The Tier 1 method is based on the following equation:

$$E_{BC} = \frac{Production}{Batch\ Size} \times EF_{PM2.5,batch} \times SF_{BC/PM2.5}$$

Where,

E_{BC} = emissions of black carbon
Production = total brick production in the inventory area (kg)
Batch Size = average size of brick batch (bricks/batch)
$EF_{PM2.5,batch}$ = $PM_{2.5}$ emission factor (per batch)
$SF_{BC/PM2.5}$ = speciation factor to convert $PM_{2.5}$ to black carbon

Tier 2

The Tier 2 method is based on improved activity data and emission factors as compared to Tier 1. Also, Tier 2 considers average oven efficiency and average use of wood, and estimates BC emissions using average brick production and a single emission factor, assuming all brick kilns burn wood, exclusively. The Tier 2 method is based on the following equation:

$$E_{BC} = Production \times \frac{Eff_{kiln}}{HV_{wood}} \times EF_{BC}$$

Where,

E_{BC} = emissions of black carbon
Production = total brick production in the inventory area (kg)
Eff_{kiln} = average kiln efficiency (megajoules per kg of bricks—MJ/kg brick)
HV_{wood} = heat content of wood (MJ/kg dry wood)
EF_{BC} = black carbon emission factor (grams/kg dry wood)

Tier 3

The Tier 3 method estimates emissions for each combination of fuel type and kiln type. Major fuel types are wood and fuel oil, which account for roughly 80 percent of fuel used in brick kilns. Activity data for the Tier 3 method would depend on kiln type or region. The Tier 3 method is based on the following equation:

$$EBC = \sum_{i,j}\left(Q_{i,j} \times \frac{Eff_{kiln_j}}{HV_i} \times EF_{BC_{i,j}}\right)$$

Where,

E_{BC}	=	emissions of black carbon
i	=	type of fuel (wood or fuel oil)
j	=	technology or equipment type (e.g., fixed, campaign, MK2)
$Q_{i,j}$	=	quantity of bricks produced (kg) in kiln type “j,” using fuel type “i”
$Eff_{kiln,j}$	=	average kiln efficiency (MJ/kg bricks) of kiln type “j”
HV_i	=	heat content of fuel (MJ/kg dry wood)
$EF_{BC,i,j}$	=	black carbon emission factor for fuel type “i” and kiln type “j”

Potential Sources of Activity Data, Emission Factors, and Speciation Factors

Potential sources of activity data, emission factors, and speciation factors (wherever applicable) for the Tiered methods for estimating BC emissions from Mexican brick kilns are shown in Table 3.2-2 below. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.2-2. Potential Sources of Activity Data, Emission Factors, and Speciation Factors for Mexican Brick Kilns

Parameter	Mexico
Tier 1	
Brick production	Kato et al. 2013
Average size of brick batch	Cárdenas 2012
$PM_{2.5}$ emission factor	TCEQ 2002, CARB 2014
Speciation factor	Christian et al. 2010, Stratus 2012
Tier 2	
Brick production	Kato et al. 2013
Average kiln efficiency	Cárdenas 2012
Heat content of wood	INECC 2013
BC emission factor, wood	Christian et al. 2010

Table 3.2-2. Potential Sources of Activity Data, Emission Factors, and Speciation Factors for Mexican Brick Kilns

Parameter	Mexico
Tier 3	
Amount of bricks produced, per kiln type	Kato et al. 2013[a]
Average kiln efficiency, per kiln type	Cárdenas 2012[a]
Heat content, per fuel type	None identified
BC emission factor, wood[b]	Christian et al. 2010

[a] Current studies only contain data for Guanajuato. Similar studies would be needed to estimate emissions for remainder of the country.

[b] There are several studies underway to quantify emission factors for fuel oil by major kiln type, but currently there are no BC emission factors for fuel oil combusted in brick kilns in Mexico.

[c]Studies on production per type of dosification, amount of mechanization or clay type can also improve emission estimates in the future.

3.3 Mobile Sources

The mobile sources sector is divided into five broad subsectors: onroad, including cars, trucks, buses, etc.; nonroad, including equipment used for construction, agriculture and industry; marine vessels; aircraft; and locomotives**.** Because of the prevalence of diesel engines, the mobile sources sector is one of the largest sources of BC emissions**.** PM emission inventory methods and data are established in the United States and are the basis of the tier recommendations within each subsector**.** Computer models developed in the United States for onroad (MOVES) and nonroad sectors (NONROAD) provide a template for Tier 3 recommendations**.** An advantage for estimating accurate BC emissions for the mobile sources sector is that total fuel consumption is tracked across each subsector, which provides the basis for Tier 1 recommendations**.** Mobile source BC emissions should be a top priority for emission inventory developers, and the guidelines provided below for each sector enable estimation of these emissions for each country.

3.3.1 Onroad Sources

Onroad mobile sources include motor vehicles used for personal and passenger transportation, municipal services, goods movement, and commercial endeavors. Subsectors of onroad mobile sources include cars, light trucks, heavy-duty trucks, buses and motorcycles. A variety of fuels are used in onroad sources, including gasoline (petrol), diesel, compressed natural gas (CNG), liquid petroleum gas (LPG) and ethanol blends. The most significant contributors to BC emissions from onroad mobile sources by far are diesel vehicles, primarily heavy trucks. Incomplete combustion of long-chain hydrocarbons found in diesel fuel produces the soot commonly seen emitting from diesel vehicles. For older-technology diesel trucks (i.e., those without diesel particulate filters), BC can make up the majority of total $PM_{2.5}$ emissions, on a mass basis. The advent of diesel particulate filters on new-technology trucks and for retrofit on older-technology trucks is one of the more effective means of reducing BC emissions.

Detailed $PM_{2.5}$ emission inventories have long been developed in Canada, Mexico, and the United States for onroad vehicles. To produce these inventories, emission factor models developed in the United States have typically been adapted to Canada and Mexico, including the PART5 (EPA 1995b) and MOBILE6 (EPA 2014a) models produced by EPA. These models estimate the amount of $PM_{2.5}$ emitted per mile driven by different vehicle classes, based on measured emissions data. In 2010, the United States began using the MOVES (emissions simulator model) framework, which is a significant development for BC emissions estimation because:

- it incorporates a significant amount of new $PM_{2.5}$ emissions data from cars, light trucks and heavy-duty trucks, that are more realistic than previous estimates, leading to higher estimates of total $PM_{2.5}$ from onroad sources; and
- it estimates EC emissions directly, using a detailed speciation approach accounting for such factors as diesel aftertreatment and vehicle load. This provides a finer estimate of BC emissions than post-hoc speciation, as EC is a close surrogate for BC.

Elemental carbon–to–total $PM_{2.5}$ ratios vary greatly by fuel type, and by vehicle type (with or without exhaust after-treatment devices); and thus a more detailed estimate of EC emissions in MOVES was warranted. In the US *Report to Congress on Black Carbon,* the onroad mobile source sector was the only one to rely on direct estimates of BC rather than post-hoc speciation (EPA 2013a).

Because MOVES incorporates up-to-date emission factors and produces direct estimates of elemental carbon, use of MOVES is recommended; EPA recently released MOVES2014, which further refined elemental carbon estimates, so MOVES2014 is specifically recommended. This is the primary means to promote consistency in onroad BC emissions estimates across the three North American countries. As designed, MOVES supports a detailed inventory that would be considered Tier 3. Initial efforts to adapt MOVES to other countries have been supported by EPA (known as MOVES International; Glover et al. 2012), which established an approach to adjusting emission rates within the MOVES model to reflect differences in emissions standards between the target country and the United States. While local emissions data are preferable to adjusting US-based rates, it was recognized that most countries do not have the detailed data necessary to completely replace the US emission rates in MOVES. Tier 1 and 2 levels would be based on MOVES emission factors aggregated externally to the model, based on simple model runs, applied to the activity data specified for each tier.

Tier 1

Tier 1 is an aggregate fuel-based approach, based on a single national estimate of fuel consumption, by fuel type (e.g., gasoline, diesel, CNG) and by calendar year. (CNG only applies to transit buses in MOVES, and PM emissions from CNG are low, so this would be considered a lower-priority fuel type.) This requires an off-model calculation using emission rates aggregated from simple MOVES runs. Emission factors would be from MOVES aggregated to a single fuel-based BC emission factor (i.e., assumed to be same as the EC emission factor), by calendar year. For Canada and Mexico, it is necessary to adjust for differences in vehicle emission standards using the EPA MOVES International approach. If not possible, a simple national/annual run for the US version of the model will suffice to produce the needed emission factor, expressed as EC per total energy consumed for each fuel type. Total energy consumed can be converted to fuel consumption using the energy content of each fuel by country. Activity data would be total fuel consumed, by fuel type only. Speciation factors are not needed if a MOVES EC emission factor is used.

The Tier 1 method is based on the following equation:

$$E_{BC} = \sum_i \left(Q_i \times EF_{i,EC} \times 1/En_i \right)$$

Where,

E_{BC}	=	emissions of black carbon from onroad fuels (gasoline/petrol and diesel)
Q_i	=	quantity of fuel type "i"
$EF_{i,EC}$	=	fuel-based EC emission factor for fuel type "i," (grams EC/kJ energy, from MOVES)
En_i	=	energy content of fuel type "i" (kJ/gallon)

Tier 2

Tier 2 is a more detailed, fuel-based approach, based on estimates of fuel consumption by fuel type and vehicle class (i.e., car, light truck, bus, heavy truck). This would require an off-model calculation using fuel-based emission rates derived from simple MOVES runs. Emission factors would be from MOVES, aggregated to a single fuel-based BC (i.e., EC) emission factor, by calendar year, fuel type and vehicle class. For Canada and Mexico, it is necessary to adjust for differences in vehicle emission standards using the MOVES International approach. If not possible, a simple national/annual run for the US version of the model will suffice to produce the needed emission factor, expressed as EC per total energy consumed. Total energy consumed can be converted to fuel consumption using the energy content of each fuel by country. Activity data would be fuel consumed by vehicle class, fuel type, and calendar year. Speciation factors are not needed if a MOVES EC emission factor is used.

The Tier 2 method is based on the following equation:

$$E_{BC} = \sum_{i,j} \left(Q_{i,j} \times EF_{i,j,EC} \times 1/En_i \right)$$

Where,

E_{BC}	=	emissions of black carbon from onroad vehicles (gasoline/petrol, and diesel)
$Q_{i,j}$	=	quantity of fuel type “i” for vehicle class “j”
$EF_{i,j,EC}$	=	fuel-based EC emission factor for fuel type “i” and vehicle class “j” (grams EC/kJ energy, from MOVES)
En_i	=	energy content of fuel type “i” (kJ/gallon)

Tier 3

Tier 3 is a detailed activity-based approach, using MOVES customized to individual country emission standards and using country-specific data on vehicle activity, and so on, with MOVES directly estimating EC emissions. For Canada and Mexico, the model can be customized with country-specific inputs for vehicle kilometers traveled (VKT), average speeds, fuel parameters, vehicle age, and meteorological data. The MOVES Country Data Manager (CDM) and Custom Domain features allow direct input of these country-specific data in a user-friendly manner. Of these, VKT is the most critical. If VKT data are not available, a lower-tier approach should be used. US defaults for the other inputs can be used, but are not recommended for other countries. For Mexico, if possible, the use of MOVES International to account for differences in vehicle emission standards is recommended. Speciation factors are not needed if MOVES EC output is used. Canada and the United States have harmonized emission standards, so the default emission rates can apply in both countries.

No Tier 3 equation is provided because calculations are performed internally to MOVES, based on the broad activity inputs provided by the user.

Potential Sources of Activity Data, Emission Factors, and Speciation Factors

Potential sources of activity data, emission factors, and speciation factors (wherever applicable) for the tiered methods applicable to estimating BC emissions from onroad mobile sources in North America are shown in Table 3.3-1. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.3-1. Potential Sources of Activity Data, Emission Factors, and Speciation Factors for Onroad Sources

Parameter	Canada	United States	Mexico
Tier 1			
Amount of fuel consumed (by gas and diesel total)	RESD (Statistics Canada 2015a)	AEO (EIA 2015a)	*Petróleos Mexicanos* (Pemex)
Emission factor (EC/total energy [kJ])	Same as United States; MOVES2014 run with Canada-specific inputs where available (vehicle population, age etc); emission rates do not need to be updated since Canadian and US standards are in alignment	Post-process of MOVES2014 run in national/annual mode, dividing EC by total energy (separately for gas and diesel)	Same as United States; MOVES2014 adjusted for differences in Mexico and US emissions standards, if possible, and run with Mexico-specific inputs (vehicle population, age etc.)
Energy content (kJ/gallon)	From the GREET model (ANL 2015): Gasoline E0: 122,481 Gasoline E10: 118,287 Lowsulfur diesel: 135,562		
Tier 2			
Amount of fuel consumed by vehicle class	Modified from RESD (Statistics Canada 2015a) fuel data, if fleet data are available	Federal Highway Administration highway statistics (FHWA 2015)	Pemex
Emission factor, EC/total energy (kJ)	Same as United States; MOVES2014 run with Canada-specific inputs where available (vehicle population, age etc). Emission rates do not need to be updated since Canadian and US standards are in alignment.	Post-process of MOVES2014 run in national/annual mode, dividing EC by total energy for each fuel and vehicle class	Same as United States; MOVES2014 adjusted for differences in Mexico and US emissions standards, if possible, and run with Mexico-specific inputs (vehicle population, age etc.)
Energy content (kJ/gallon)	See Tier 1		

Table 3.3-1. Potential Sources of Activity Data, Emission Factors, and Speciation Factors for Onroad Sources

Parameter	Canada	United States	Mexico
Tier 3			
Minimum: vehicle distance traveled (also possible: average speed, roadway distribution, others)	VKT: Transport Canada[a]	MOVES2014 national defaults (no input required)	VKT: INECC, Semarnat (i.e., General Directorate of Management of Air Quality and Registry of Emissions and Transfer of Contaminants [*Dirección General de Gestión de la Calidad del Aire y Registro de Emisiones y Trasferencia de Contaminantes*—DGGCARETC])
Emission factor ($PM_{2.5}$)	MOVES2014 run with Canada-specific inputs where available (vehicle population, age etc). Emission rates do not need to be updated since Canadian and US standards are in alignment	Internal to MOVES	MOVES2014, adjusted for differences in Mexico and US emissions standards, if possible, and run with Mexico-specific inputs (vehicle population, age etc.)

[a]For a complete description of activity data sources, refer to Canada's National Greenhouse Gas Inventory (Environment Canada 2015b)

3.3.2 Nonroad Sources

BC emissions from nonroad sources are primarily derived from the combustion of diesel fuel, with lesser contributions from gasoline and gaseous fuels such as LPG and natural gas. The nonroad sources addressed in this section are self-propelled or otherwise portable (e.g., handheld equipment), and include recreational, construction, industrial, lawn and garden (commercial and residential), agricultural, commercial, logging, airport ground support equipment, underground mining, oilfield support equipment, recreational marine, and railroad support equipment. (Emission estimation methods for locomotives, marine and aviation sources are addressed below in Sections 3.3.4 through 3.3.6). The smaller engines in certain types of equipment commonly use gasoline and come in two and four-stroke configurations. Larger engines typically use diesel fuel, due to the power output and durability advantages. Each of these engine types has unique PM and BC emission characteristics.

The Tier 1 approach relies on simplified, aggregated-source category descriptions—for example, with sources grouped by fuel type and equipment-use category (e.g., diesel construction and agricultural equipment, gasoline-powered lawn and garden equipment, and industrial equipment such as forklifts commonly powered by gaseous fuels)—for use when more-detailed, disaggregated equipment activity data are not available. Tier 2 approaches assume equipment population and activity levels can be evaluated at a more detailed level, such as by general engine technology. The Tier 3 approaches are the most data-intensive, but also the most precise, using equipment data at a granular level to estimate emissions on a bottom-up basis. The appropriateness of a given approach will vary depending upon the data source availability for each equipment category. For example, detailed hours of use estimates may be available for certain equipment use categories such as diesel agricultural equipment, allowing for a Tier 3 evaluation. On the other hand, lawn and garden equipment use may only be quantifiable based on top-down fuel use estimates, requiring a Tier 1 level of analysis.

Tier 1

The Tier 1 method estimates BC emissions using total annual fuel consumption for a given equipment use category and a default fuel-specific emission factor. Activity data for the Tier 1 method can be at the national, state, regional, or other required inventory area–level. The Tier 1 method is based on the following equation:

$$E_{BC} = \sum_{i} \left(Q_i \times EF_{i,PM_{2.5}} \times SF_{i,BC/PM_{2.5}}\right)$$

Where:

E_{BC}	=	emissions of black carbon for a given equipment category
i	=	type of fuel
Q_i	=	annual fuel consumption for each fuel type “i” (e.g., in tonnes or liters)
$EF_{i,PM2.5}$	=	emission factor for fuel type “i” (e.g., in g/tonne or g/liter of fuel)
$SF_{i,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for fuel type “i”

Tier 2

The Tier 2 method accounts for different engine technologies. Activity data for the Tier 2 method can be at the national, state, regional, or other required inventory area–level. The Tier 2 method is based on the following equation:

$$E_{BC} = \sum_{c,i,t} \left(Q_{c,i,t} \times EF_{c,i,t,PM_{2.5}} \times SF_{i,t,BC/PM_{2.5}}\right)$$

Where:

E_{BC}	=	emissions of black carbon
c	=	equipment use category
i	=	fuel type
t	=	technology level (e.g., <1981, 1981 to 1990, 1991 to Stage I, Stage I, Stage II, Stage IIIA)
$Q_{c,i,t}$	=	fuel consumption (e.g., in tonnes) for a given equipment use category “c,” fuel type “i,” and technology level “t”
$EF_{c,i,t,PM2.5}$	=	$PM_{2.5}$ emission factor for a given equipment use category “c,” fuel type “i,” and technology level “t”
$SF_{i,t,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for fuel type “i,” and possibly by technology level “t” (if available)

Tier 3

The Tier 3 method relies on detailed equipment characteristics and activity estimates in order to calculate emissions on a horsepower-hour (or kWh) basis. This method is most applicable for inventories where detailed, disaggregated equipment count and activity data are available. The Tier 3 method is based on the following equation:

$$E_{BC} = N \times HRS \times HP \times LF \times EF_i \times SF_{i,t,BC/PM_{2.5}}$$

Where:

E_{BC}	=	emissions of black carbon
N	=	source population (number of units)
HRS	=	hours of use
HP	=	average rated horsepower
LF	=	typical engine load factor (0–1.0)
EF_i	=	$PM_{2.5}$ average emission factor per unit of use (e.g., grams/kWh)
$SF_{i,t,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon (by fuel type “i” and possibly technology level “t,” if available)

Where data are available, calculations can also be stratified further as follows:

- N: engine counts can be split by age and power level
- HRS: annual hours for each equipment category can vary by engine age
- HP: average engine horsepower can vary by equipment type and horsepower range
- EF: different deterioration factors can be applied to the emission factor, accounting for variations with cumulative hours of use

Potential Sources of Activity Data, Emission Factors, and Speciation Factors

Potential sources of emission factors, activity data, and speciation factors (wherever applicable) for the tiered methods applicable to estimating BC emissions from nonroad sources in North America are shown in Table 3.3-2. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.3-2. Potential Sources of Emission Factors, Activity Data, and Speciation Factors for Nonroad Sources

Parameter	Canada	United States	Mexico
Tier 1			
Fuel usage data by fuel type	RESD (Statistics Canada 2015a)) for total fuel use; apply ratios of nonroad to total fuel use by fuel type for US from Annual Energy Outlook (EIA 2015a) and NONROAD2008 model (EPA 2014b)	NONROAD2008 model (EPA 2014b); USDA Census of Agriculture (for agricultural equipment)	Secretariat of Energy (Sener) for total fuel use; apply ratios of nonroad to total fuel use by fuel type for US from Annual Energy Outlook (EIA 2015a) and NONROAD2008 model (EPA 2014b)
Emission factor ($PM_{2.5}$)	NONROAD2008 model (EPA 2014b)	NONROAD2008 model (EPA 2014b)	NONROAD-Mexico
Speciation factor (EC or BC)	SPECIATE database (EPA 2011b); use EC factor for BC MOVES2014 Speciation Report (EPA 2014c)		

Table 3.3-2. Potential Sources of Emission Factors, Activity Data, and Speciation Factors for Nonroad Sources

Parameter	Canada	United States	Mexico
Tier 2			
Fuel usage data by engine technology and equipment use category	RESD (Statistics Canada 2015a); Annual Energy Outlook (EIA 2015a); NONROAD 2008, (EPA 2014b); surveys, private-sector sources	NONROAD2008 model (EPA 2014b)	Sener; Annual Energy Outlook (EIA 2015a); NONROAD 2008, (EPA 2014b); surveys, private-sector sources
Emission factor ($PM_{10/2.5}$)	NONROAD2008 model (EPA 2014b), adjusted for differences from US standards	NONROAD2008 model (EPA 2014b)	NONROAD-Mexico
Speciation factor (EC or BC)	SPECIATE database (EPA 2011b); use EC factor for BC MOVES2014 Speciation Report (EPA 2014c)		
Tier 3			
Annual hours of engine use by category, engine size, and technology	Population: Commercial databases of equipment sales Activity: Surveys, NONROAD2008	NONROAD2008 model (EPA 2014b)	NONROAD-Mexico
Emission factor ($PM_{10/2.5}$)	NONROAD2008 model (EPA 2014b), adjusted for differences from US standards	NONROAD2008 model (EPA 2014b)	NONROAD-Mexico
Speciation factor (EC or BC)	SPECIATE database (EPA 2011b); use EC factor for BC MOVES2014 Speciation Report (EPA 2014c)		

3.3.3 Locomotives

BC emissions from locomotives are derived from the combustion of diesel fuel associated with railroad movement of passengers and freight. This includes line-haul trains that transit long distances, short-haul trains, passenger trains, as well as switch engines that operate at railroad yards. BC emissions from electric-powered trains are not addressed in this section, as the primary emission source in that case is the generation of the electricity (see Section 3.2.1). Also note that yard truck operations and rail cargo handling equipment are not included in this section, but are discussed in the onroad section (3.3.1) and nonroad section (3.3.2), respectively.

The Tier 1 approach relies on aggregate fuel data; the Tier 2 approach estimates emissions for three different locomotive activity types (i.e., line-haul, yard, and passenger trains); and, the Tier 3 approach is based on detailed, locomotive model–specific testing data.

Tier 1

The Tier 1 method estimates BC emissions using total annual fuel consumption and a default locomotive emission factor. Activity data for the Tier 1 method can be at the national, state, regional, or other required inventory area–level. The Tier 1 method is based on the following equation:

$$E_{BC} = Q \times EF_{PM_{2.5}} \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC}	=	emissions of black carbon
Q	=	quantity of locomotive fuel used
$EF_{PM2.5}$	=	$PM_{2.5}$ emission factor for locomotive fuel
$SF_{BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to BC, for locomotives

Tier 2

The Tier 2 method accounts for different locomotive types. Activity data for the Tier 2 method can be at the national, state, regional, or other required inventory area–level. To use this approach it may be necessary to work with railroad companies and trade associations to get the required activity data. The Tier 2 method is based on the following equation:

$$E_{BC} = \sum_i (Q_i \times EF_{i,PM_{2.5}}) \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC}	=	emissions of black carbon
i	=	rail operation type (i.e., line haul, yard, and passenger)
Q_i	=	amount of locomotive fuel combusted, by rail operation type “i”
$EF_{i,PM2.5}$	=	$PM_{2.5}$ emission factor for rail operation type “i”
$SF_{BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to BC for locomotives

Tier 3

The Tier 3 method relies on detailed locomotive characteristics (i.e., locomotive make and engine combination, such as: GE ES40DC locomotive equipped with GEVO-12 engine) and activity, and is most applicable for local inventories when detailed train movement data are available. To get the required detailed activity and engine test data to use this approach, it will be necessary to work with the rail companies and engine manufacturers. The Tier 3 method is based on the following equation:

$$E_{BC} = \sum_c (H_c \times EF_{c,PM_{2.5}}) \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC}	=	emissions of black carbon
c	=	locomotive make/engine combination
H_c	=	hours of operation for rail locomotive/engine combination “c”
$EF_{c,PM2.5}$	=	emission factor for locomotive/engine combination “c.” If detailed data are available, emission factors should be weighted for different engine power settings (notches), based on typical amount of time spent in each notch setting. This would provide an aggregated emission factor that can be applied to total hours of operation.
$SF_{BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for locomotives

Potential Sources of Activity Data, Emission Factors, and Speciation Factors

Potential sources of emission factors, activity data, and speciation factors (wherever applicable) for the tiered methods applicable to estimating BC emissions from locomotives in North America are shown in

Table 3.3-3. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.3-3. Potential Sources of Emission Factors, Activity Data, and Speciation Factors for Locomotives

Parameter	Canada	United States	Mexico
Tier 1			
Fuel usage data	RESD (Statistics Canada 2015a)	Energy Information Administration (EIA 2015b)	Pemex
Emission factor ($PM_{2.5}$)	US EPA locomotive emission factor study (EPA 2009b)		
Speciation factor (EC or BC)	MOVES model (EPA 2014a)		
Tier 2			
Fuel usage by locomotive type	Railroad operators; Railway Association of Canada	Railroad operators; Association of American Railroads; American Short Line and Regional Railroad Association; US Surface Transportation Board R-1 Data (STB 2015)	Railroad operators; Secretariat of Communications and Transport of Mexico (*Secretaría de Comunicaciones y Transportes*—SCT)
Emission factor ($PM_{2.5}$)	US EPA locomotive emission factor study (EPA 2009b)		
Speciation factor (EC or BC)	MOVES model (EPA 2014a)		
Tier 3			
Locomotive specific activity data	Railroad operators		
Emission factor ($PM_{2.5}$)	Locomotive manufacturers; US EPA guidance (Appendix 6-6, EPA 1992)		
Speciation factor (EC or BC)	MOVES model (EPA 2014a)		

3.3.4 Marine

BC emissions from commercial marine vessels are derived from the combustion of diesel or residual fuel blends associated with the movement of marine freight and the provision of marine services such as fishing, offshore oil and gas support, research, and military operations. This includes large ships that transit international waters, as well as smaller vessels used for domestic coastal and inland waterway operations.

This section does not include emissions from shore powering of dockside vessels, as the primary emission source in that case is the generation of the electricity (see Section 3.2.1). Also note that drayage truck operations and dockside cargo-handling equipment are not included in this section, but are discussed in the onroad section (3.3.1) and nonroad section (3.3.2), respectively.

The Tier 1 approach relies on aggregate fuel data; the Tier 2 approach is based on activity in terms of kilowatt-hours (kWh), by vessel type; and the Tier 3 approach also uses kWh, but relies on vessel-specific data to quantify ship power, which provides a more accurate estimate of emissions as compared to lower tiers. Note that a mixture of tier approaches may be the most appropriate for a particular inventory (for example, larger vessels can be tracked using Automatic Identification System [AIS] data, allowing use of Tier 3, while smaller vessels may require a Tier 1 fuel-based approach).

Tier 1

The Tier 1 method estimates BC emissions using total annual fuel consumption and a default marine vessel emission factor. To obtain appropriate fuel usage data it may be necessary to contact energy agencies within the country of interest that track marine fuel consumption. The Tier 1 method is based on the following equation:

$$E_{BC} = \sum_{i} \left(Q_i \times EF_{i,PM_{2.5}} \times SF_{i,BC/PM_{2.5}} \right)$$

Where,

E_{BC}	=	emissions of black carbon from total marine fuel combustion
i	=	type of fuel (i.e., diesel or residual blend)
Q_i	=	quantity of marine fuel used, by fuel type "i"
$EF_{i,PM2.5}$	=	$PM_{2.5}$ emission factor for marine fuel type "i"
$SF_{i,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for fuel type "i"

Tier 2

The Tier 2 method requires activity data, in terms of annual hours of operation by the type of marine vessel and operation. Activity data for the Tier 2 method can be at the national, state, regional, or other required inventory area–level. To obtain appropriate vessel activity data it may be necessary to contact transportation agencies within the country of interest that track vessel movements. The Tier 2 method is based on the following equation:

$$E_{BC} = \sum_{i,j,k} \left(H_{i,j,k} \times VP_i \times LF_j \times EF_{k,PM_{2.5}} \times SF_{k,BC/PM_{2.5}} \right)$$

Where,

E_{BC}	=	emissions of black carbon
$H_{i,j,k}$	=	hours of operation for vessel type "i" in operating mode "j" using fuel type "k"
i	=	marine vessel type (e.g., fishing, ferry, container ship, tanker)
j	=	marine operating mode (i.e., cruising, reduce speed, maneuvering, and hotelling)
k	=	marine fuel type (diesel or residual blend)
VP_i	=	vessel power for typical vessel "i"
LF_j	=	typical operating load factors for mode "j"
$EF_{k,PM2.5}$	=	$PM_{2.5}$ emission factor for fuel type "k"
$SF_{k,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for fuel type "k"

Tier 3

The Tier 3 method relies on detailed vessel characteristics and activity data for individual vessels that operate in the inventory area. To obtain appropriate vessel activity data it may be necessary to contact transportation agencies or ports that track vessel movements, or use satellite tracking data (e.g., AIS data) for the individual movement of vessels. The Tier 3 method uses the Tier 2 equation, but the activity data and emission factors are based on vessel-specific operations.

Potential Sources of Activity Data, Emission Factors, and Speciation Factors

Potential sources of emission factors, activity data, and speciation factors for the tiered methods applicable to estimating BC emissions from marine sources in North America are shown in Table 3.3-4.

For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.3-4. Potential Sources of Emission Factors, Activity Data, and Speciation Factors for Marine Sources

Parameter	Canada	United States	Mexico
Tier 1			
Fuel usage data	RESD (Statistics Canada, 2015a)	Energy Information Administration (EIA 2015b)	Pemex
Emission factor ($PM_{2.5}$)	US EPA Regulatory Impact Analysis (Category 1 and 2, EPA 2007; Category 3, EPA 2009c) and IMO *Reduction of GHG Emission From Ships* (IMO 2014)		
Speciation factor (EC or BC)	EPA *Report to Congress on Black Carbon* (EPA 2013a, pages 276 to 278		
Tier 2			
Activity (kWh) by vessel type	Coastwise Shipping Survey (Domestic Shipping Report—S.1; and S.4 Shipping Report—Towboat and Ferry Operators) (Statistics Canada 2012)	Entrance and clearance data: US Army Corps of Engineers (USACE 2015a), and Waterborne Commerce Statistics Center (USACE 2015b)	• SCT • Entrance and clearance data: Secretariat of the Navy (*Secretaría de Marina*)
Emission factor ($PM_{2.5}$)	US EPA Regulatory Impact Analysis (Category 1 and 2, EPA 2007; Category 3, EPA 2009c) and IMO *Reduction of GHG Emission From Ships* (IMO 2014)		
Speciation factor (EC or BC)	EPA *Report to Congress on Black Carbon* (EPA 2013a, pages 276 to 278)		
Tier 3			
Vessel-specific operations	Port-provided data; Transport Canada; Canadian Coast Guard AIS data (CCG 2015)	Entrance and clearance data: US Army Corps of Engineers (USACE 2015a), and US Coast Guard AIS data	Entrance and clearance data: Secretariat of the Navy (*Secretaría de Marina*) and vendor-provided AIS data
Vessel characteristics	IHS Registry of Ships (IHS 2015)		
Emission factor ($PM_{2.5}$)	US EPA Regulatory Impact Analysis (Category 1 and 2, EPA 2007; Category 3, EPA 2009c) and IMO *Reduction of GHG Emission From Ships* (IMO 2014)		
Speciation factor (EC or BC)	EPA *Report to Congress on Black Carbon* (EPA 2013a, pages 276 to 278)		

3.3.5 Aviation

BC emissions from aviation are derived from the combustion of aviation gasoline and jet fuel associated with the movement of passengers and freight and other aviation activities such as traffic monitoring, firefighting, and military operations. These activities are conducted by small, piston-powered, fixed-wing aircraft and helicopters that use aviation gasoline, as well as medium-to-large helicopters and aircraft equipped with turboprops, turbofans, and jet engines that combust jet fuel.

The Tier 1 approach relies on aggregate fuel data; the Tier 2 approach provides airport-level estimates, by general aircraft type (e.g., commercial, air taxi, general aviation, and military); and, the Tier 3 approach requires detailed information about aircraft movements for specific aircraft model and engine combinations, for specific routes. Multiple-tier approaches may be required to provide an appropriate and comprehensive inventory. For example, detailed data may be available for larger commercial air carriers that use international airports, while only landing and take-off (LTO) count, by aircraft types, is available for regional municipal airports, thus requiring a hybrid approach that uses both the Tier 2 and 3 methods.

Note that airport vehicle and ground support equipment are addressed in Section 3.3.1 (Onroad) and Section 3.3.2 (Nonroad), respectively. To estimate emissions from other stationary sources that operate at an airport, such as boilers, electricity generators, and incinerators, it is recommended that methods presented in Section 3.2 be used. Emissions from rockets are not included in this guidance.

Tier 1

The Tier 1 method estimates BC emissions using total annual fuel consumption and a default aviation emission factor. To obtain appropriate fuel usage data it may be necessary to contact energy agencies within the country of interest that track fuel aviation consumption. The Tier 1 method is based on the following equation:

$$E_{BC} = \sum_{i} \left(Q_i \times EF_{i,PM_{2.5}} \times SF_{i,BC/PM_{2.5}} \right)$$

Where,

E_{BC}	=	emissions of black carbon from total aviation fuel combustion
i	=	type of fuel (i.e., aviation gasoline or jet fuel). Note that piston engines associated with smaller aircraft and helicopters use aviation gasoline while jet fuel is used by larger helicopters and aircraft equipped with turboprops, turbofans and jets
Q_i	=	quantity of aviation fuel used, by fuel type “i”
$EF_{i,PM2.5}$	=	$PM_{2.5}$ emission factor for aviation fuel type “i”
$SF_{i,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for fuel type “i”

Tier 2

The Tier 2 method requires activity data in terms of airport annual landing and takeoff cycles (LTOs) by general aircraft type (commercial air carriers, air taxis, general aviation, and military operations). This approach requires contacting transportation agencies that monitor aircraft movements. In order to include BC emissions from “cruising,” it is necessary to implement the Tier 1 total fuel approach; the difference between the Tier 1 and Tier 2 estimates provides an aggregated approximation of cruising emissions. The Tier 2 method is based on the following equation:

$$E_{BC} = \sum_{i,j} \left(LTO_{i,j} \times EF_{i,j,PM_{2.5}} \times SF_{i,j,BC/PM_{2.5}} \right)$$

Where,

E_{BC}	=	emissions of black carbon
$LTO_{i,j}$	=	activity annual airport LTOs for aircraft type “i” using fuel type “j”
i	=	aircraft type (i.e., commercial air carriers, air taxis, general aviation, and military)
j	=	aircraft fuel type (i.e., aviation gasoline, or jet fuel)
$EF_{i,j,PM2.5}$	=	$PM_{2.5}$ emission factor for aircraft type “i” and fuel type “j”
$SF_{i,j,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon for fuel type “j”

Tier 3

When detailed aircraft data are available, a Tier 3 approach would be recommended, involving the use of the US Federal Aviation Administration's (FAA's) latest emission estimating model, Aviation Environmental Design Tool (AEDT) (FAA 2015a). Environment Canada has developed its own in-house model, known as AGEM,[2] used for both the National Inventory Report (NIR) and the APEI. These models can be used to estimate emissions at the airport level for individual aircraft LTO cycles. It should be noted that the new version of the AEDT model does not include a component to estimate cruising emissions. It is anticipated that a future version of AEDT may include the FAA's System for Assessing Aviation's Global Emissions (SAGE) which would include cruising emissions (FAA 2015b). Until the two models are integrated it is necessary to separately run both models. Data needed to run the models may be available from agencies or airports that monitor aircraft traffic. Alternatively, it may be necessary to contact the airlines directly to obtain detailed data about their fleet and level of activity.

Potential Sources of Activity Data, Emission Factors, and Speciation Factors

Potential sources of emission factors, activity data, and speciation factors for the tiered methods applicable to estimating BC emissions from aviation sources in North America are shown in Table 3.3-5. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.3-5. Potential Sources of Emission Factors, Activity Data, and Speciation Factors for Aviation Sources

Parameter	Canada	United States	Mexico
		Tier 1	
Aggregated fuel usage	RESD (Statistics Canada 2015a)	Department of Transportation/Bureau of Transportation Statistics (BTS 2015a)	Pemex
Emission factor ($PM_{2.5}$)	APEI (Environment Canada 2014)	US National Emissions Inventory (EPA 2013a)	
Speciation factor (BC)	EPA *Report to Congress on Black Carbon* (EPA 2013a, pages 278 to 279)		
		Tier 2	
LTO data, by aircraft type	Aircraft movement statistics (Transport Canada 2015)	FAA Terminal Area Forecast data (FAA 2015c)	SCT
Emission factor ($PM_{2.5}$)	APEI (Environment Canada 2014)	US National Emissions Inventory (EPA 2011a)	
Speciation factor (BC)	EPA *Report to Congress on Black Carbon* (EPA 2013a, pages 278 to 279)		

[2] Aviation Greenhouse Gas Emission Model (AGEM), <http://www.ledevoir.com/documents/pdf/bilan_ONU.pdf>.

Table 3.3-5. Potential Sources of Emission Factors, Activity Data, and Speciation Factors for Aviation Sources

Parameter	Canada	United States	Mexico
Tier 3			
Aircraft specific activity data	NAV Canada	Airlines or airports; Department of Transportation/Bureau of Transportation Statistics T-100 data (BTS 2015b)	Airlines or airports
Emission factor ($PM_{2.5}$)	Aviation Environmental Design Tool (AEDT) (FAA 2015a); System for Assessing Aviation's Global Emissions (SAGE) (FAA 2015b)		
Aircraft cruising fuel usage	For aircraft not included in SAGE, Eurocontrol Base of Aircraft Data (BADA) or aircraft manufacturers data may be required		
Speciation factor (BC)	EPA *Report to Congress on Black Carbon* (EPA 2013a, pages 278 to 279)		

3.4 Residential Combustion

Residential combustion includes any combustion that would occur in an "in-home" setting for cooking, heating, or other domestic purposes. Fuels that are combusted for residential purposes include oil, coal, LPG, kerosene, natural gas, and wood. Typical combustion devices used in a residential setting include: small-capacity boilers; furnaces; cookstoves; fireplaces; fireplace inserts; wood-fueled heating stoves; and pellet stoves. Wood stoves may be further disaggregated based on type of technology; for example: conventional, certified, advanced, and energy efficient.

For Mexico alone, it is estimated that 22 to 25 million people use wood for cooking or heating, mainly in rural areas of the states of Chiapas, Guanajuato, Guerrero, Hidalgo, Michoacán, Oaxaca, Puebla, Quintana Roo, Tabasco, Veracruz and Yucatán. Recent estimates show that fuelwood supplied 34 percent of the country's residential energy use in 2009, and that proportion has remained relatively constant in later years. Although adoption of cleaner, more efficient cookstoves is slowly increasing, traditional, less efficient open fires are still predominant (GIRA 2012). According to recent studies, it is particularly difficult to find information on fuelwood use in Mexico because most of the wood is acquired and used outside the formal market. Also, there is considerable variability of use in different regions in the country (i.e., vegetation diversity, which determines fuelwood availability, changes with geographical situation and meteorological conditions) and an increasing amount of rural households are using a mixture of fuels (i.e., LPG and wood), as LPG is made available in more regions. Moreover, it is currently impossible to differentiate between different fuel uses (i.e., heating and cooking) (GIRA 2012, p. 10). However, there is increasing literature on emission factors, particularly to estimate the climate and health benefits of introducing efficient cookstoves in rural households, where traditional, open fire cooking and heating is predominant. Also, activity data (i.e., number and types of cooking devices) is improving with time, particularly in areas where public policies are aimed at replacing open fire cooking with closed, more efficient cookstoves. These studies have rendered data on emission factors and activity that are relevant in estimating BC emissions.

Tier 1

A Tier 1 method estimates BC emissions using national level fuel consumption data for all fuel types. The Tier 1 method is based on the following equation, which is the same method as used for the energy/industry sector sources:

$$E_{BC} = \sum_{i} (Q_i \times EF_{i,PM_{2.5}} \times SF_{i,BC/PM_{2.5}})$$

Where,

E_{BC}	=	emissions of black carbon from fuel combustion (sum of emissions from all fuels)
i	=	type of fuel
Q_i	=	Quantity of fuel "i"
$EF_{i,PM2.5}$	=	$PM_{2.5}$ emission factor for fuel type "i"
$SF_{i,BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to BC, for fuel type "i"

Tier 2

A Tier 2 method differentiates emission factors by device (or technology) and fuel type. Activity data for the Tier 2 method can be at the national, state, regional, or other required inventory area-level. The Tier 2 method is based on the following equation:

$$E_{BC} = \sum_{i,j} (Q_{i,j} \times EF_{i,j,PM_{2.5}}) \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC}	=	emissions of black carbon
i	=	type of fuel
j	=	device/technology type
$Q_{i,j}$	=	amount of fuel "i" combusted in device/technology type "j"
$EF_{i,j,PM2.5j}$	=	$PM_{2.5}$ emission factor for fuel type "i" and device/technology type "j"
$SF_{BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to BC

For residential wood combustion in the United States, the Tier 2 method can be employed for estimating the amount of wood burned and emissions, using the "Residential Wood Combustion (RWC) Emission Estimation Tool" (EPA 2013b). This tool provides appliance profiles (i.e., fraction of homes in a county that use each type of device) and burn rates (i.e., amount of wood burned in each device annually). Because it contains data from surveys to develop the appliance profiles and burn rates at the county level, the tool is only appropriate for estimating residential wood combustion emissions in the United States. To employ the Tier 2 approach for other fuels, local sources of data would be needed to determine the amount of fuel burned in specific devices, which may not be a feasible approach to implement for many inventory efforts.

In Mexico, the Tier 2 method can be employed for estimating residential heating and cooking emissions by using household level data for either wood only, or combined wood and LPG combustion.

Tier 3

The most feasible approach to estimating emissions from residential combustion is based on data for a wide area, such as a city, county/municipality, state/province, or country. Therefore, either a Tier 1 or Tier 2 method is most appropriate for this sector. No Tier 3 approach has been determined at this time.

Potential Sources of Activity Data, Emission Factors, and Speciation Factors

Potential sources of activity data, emission factors, and speciation factors (wherever applicable) for the Tier 1 and Tier 2 methods for estimating BC emissions from residential fuel combustion are shown in Table 3.4-1. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.4-1. Potential Sources of Emission Factors, Activity Data, and Speciation Factors for Residential Combustion

Parameter	Canada	United States	Mexico
Tier 1			
Quantity of fuel	RESD (Statistics Canada, 2015a)	AEO (EIA 2015a)	GIRA 2012
Emission factor	WebFIRE (EPA 2015b); 2011 NEI (EPA 2013b); CARB 2014	$PM_{2.5}$: WebFIRE (EPA 2015b); 2011 NEI (EPA 2013b); CARB 2014	BC for cooking fires and cook stoves: Christian et. al. 2010
Speciation factor (EC or BC)	SPECIATE (EPA 2011b); use EC factor for BC	SPECIATE (EPA 2011b); use EC factor for BC	Not applicable
Tier 2			

Quantity of fuel (by technology or device)	• RESD (Statistics Canada 2015a)
	• Information from the fuel suppliers and individual companies
	• Energy conservation/ climate change mitigation studies for relevant sectors
	• Residential, commercial/ institutional and agriculture sector surveys
	• Energy demand modeling
		• *For wood:* EPA's RWC Emission Estimation Tool (EPA 2013b)
		• For other fuels:
		  ○ Information from the fuel suppliers and individual companies
		  ○ Energy conservation/climate change mitigation studies for relevant sectors
		  ○ Residential, commercial/ institutional and agriculture sector surveys
		  ○ Energy demand modeling
			• Total number of households; percent of total households burning wood: INEGI
			• Percent of households using wood exclusively, and other fuels (municipality level): GIRA 2012
			• Average occupancy per household (national average): GIRA 2012
			• Average occupancy per household: Conapo
			• Per capita use of wood, by type of wood, according to macroecological region (municipality level): (municipal level): GIRA 2012
			• Fuel consumption and fuel efficiency, by type of technology

Emission factor ($PM_{2.5}$) (by fuel, device)	$PM_{2.5}$: EMEP/EEA 2013 (Chapter 1.A.4)	$PM_{2.5}$ for wood: EPA's RWC Emission Estimation Tool (EPA 2013b)	BC for cooking fires and cook stoves: Christian et al. 2010
Speciation factor (EC or BC) (by fuel, device)	SPECIATE (EPA 2011b); use EC factor for BC	SPECIATE (EPA 2011b); use EC factor for BC	Zhang 2012; SPECIATE (EPA 2011b); in SPECIATE, use EC factor for BC

3.5 Other Sources

The Other Sources sector includes various sources of combustion that are not part of the specific sectors covered by these guidelines. The Other Sources sector currently includes: charbroiling/commercial cooking; cremation; structure and vehicle fires; and open burning of municipal solid waste (MSW).

Additional sources that were investigated as part of the Other Sources sector included paved and unpaved road dust, and industrial and dairy soil. During the literature review phase, no studies were identified for the industrial and dairy soil category. Particulate matter estimation methods are available for paved and unpaved road dust from AP-42 (EPA 1995a). BC emissions from paved and unpaved road dust are primarily from motor vehicles and are covered under the Mobile Sources sector. Additionally, due to the uncertainty associated with estimation methods for paved and unpaved road dust and its relatively low contribution to BC emissions, methods for this category were not included in these guidelines.

3.5.1 Charbroiling (Commercial Cooking)

BC and $PM_{2.5}$ emissions result from incomplete combustion during charbroiling activities. Commercial charbroiling operations are a significant source of PM_{10} and $PM_{2.5}$ emissions within the overall nonpoint source emission inventories. The magnitude of PM emissions largely depends on the type of cooking equipment and the type of meat cooked. Under-fired charbroiling cooking operations are a major source of PM emissions compared to other charbroiling equipment operations. Under-fired charbroilers consist of three main components: a heating source, a high-temperature radiant surface, and a slotted grill. The grill holds the meat while exposing it to the radiant heat surface below. When grease from the meat falls onto the high-temperature radiant surface, PM emissions occur. The most common fuel type used for under-fired charbroilers is natural gas; however, other fuel types (i.e., solid fuels) are sometimes used. This category, which includes broilers, grill charbroilers, flame broilers, and direct-fired barbecues, contributes to the majority of emissions for the commercial cooking sector.

Tier 1

The Tier 1 method for estimating emissions from charbroiling is based on the type of equipment used for charbroiling. This method relies on per capita emission factors and the population of the inventory area. The per capita emission factors are dependent on the type of equipment used for charbroiling/commercial cooking activities (i.e., conveyorized, under-fired, flat-griddle, clamshell griddle, and deep-fat frying). Activity data for the Tier 1 method can be at the national, state, regional, or other required inventory area–level. The Tier 1 method for this source category is independent of fuel consumption and fuel type. The Tier 1 method is based on the following equation, for each type of cooking equipment:

$$E_{BC} = \sum_{j} \left(POP_j \times EF_{j,PM_{2.5}} \right) \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC}	=	emissions of black carbon
j	=	type of equipment (i.e., conveyorized, under-fired, flat-griddle, clamshell griddle, and deep-fat frying)
POP	=	population of devices of equipment type “j” in inventory area
$EF_{j,PM2.5}$	=	per capita $PM_{2.5}$ emission factor for equipment type “j”
$SF_{BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon

Tier 2 and Tier 3

The most feasible approach to estimating emissions from charbroiling is based on data for a wide area, such as a city, county/municipality, state/province, or country, and is based on type of equipment, as shown in the Tier 1 methods. Therefore, more-refined activity data, measured data, and facility-specific data that would be indicative of a Tier 2 or Tier 3 method are not appropriate for this sector.

Potential Sources of Emission Factors, Activity Data, and Speciation Factors

Potential sources of activity data, emission factors, and speciation factors (wherever applicable) for the Tier 1 method for estimating BC emissions from charbroiling (commercial cooking) are shown in Table 3.5-1. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.5-1. Potential Sources of Activity Data, Emission Factors, and Speciation Factors for Charbroiling (Commercial Cooking)

Parameter	Canada	United States	Mexico
Tier 1			
Population	Canada population and demography (Statistics Canada 2015b)	US Census Bureau (US Census Bureau 2015)	National Institute of Statistics and Geography (INEGI 2015)
Emission factor ($PM_{2.5}$)	2011 NEI (EPA 2013b)		
Speciation factor (EC or BC)	SPECIATE database (EPA 2011b); use EC factor for BC		

3.5.2 Human Cremation

Cremation includes combustion of fuel, incineration of the container (i.e., casket), human body, and other container contents. The most common types of fuels used in crematoriums are natural gas, fuel oil, and electricity.

Particulate matter in the form of dust, soot, ash and other unburned particles are released from the combustion of the cremation container and the contents of the container (including human remains). Particulate matter emission rates depend on the design of the crematory, combustion temperature, gas retention time, duct design, duct temperature and any control devices.

Tier 1

The Tier 1 method estimates fine particulate matter ($PM_{2.5}$) emissions using national statistics on the number of human cremations, and applies a BC speciation factor. Detailed data can be used in place of default factors, wherever available. The Tier 1 method is based on the following equation:

$$E_{BC} = Mortality_{Rate} \times \%_{Cremation} \times Weight_{Avg} \times EF_{PM_{2.5}} \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC}	=	emissions of black carbon
$Mortality_{Rate}$	=	estimated number of deaths in the Inventory area
$\%_{Cremation}$	=	percent of bodies cremated
$Weight_{Avg}$	=	Average body weight
$EF_{PM2.5}$	=	$PM_{2.5}$ emission factor
$SF_{BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon

Tier 2 and Tier 3

The most feasible approach to estimating emissions from cremation is based on data for a wide area, such as a city, county/municipality, state/province, or country. Therefore, more-refined activity data, measured data, and facility-specific data that would be indicative of a Tier 2 or Tier 3 method are not appropriate for this sector.

Potential Sources of Emission Factors, Activity Data, and Speciation Factors

Potential sources of activity data, emission factors, and speciation factors (wherever applicable) for estimating emissions from cremation activities are shown in Table 3.5-2. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.5-2. Activity Data, Emission Factors, and Speciation Factors for Cremation

Parameter	Canada	United States	Mexico
	Tier 1		
Number of deaths	Cremation Association of North America (CANA); crematorium associations; direct contact with crematorium operators	Direct contact with crematorium operators	Crematorium associations; direct contact with crematorium operators
$\%_{Cremation}$	Cremation Association of North America (CMNA 2015)		
$Weight_{Avg}$	EPA study on crematories (EPA 1999)		
Emission factor ($PM_{2.5}$)	2011 NEI (EPA 2013b)		
Speciation factor (EC or BC)	SPECIATE (EPA 2011b); use EC factor for BC		

3.5.3 Structure and Vehicle Fires

Structure fires include the accidental burning of structures and their contents. Structural materials such as insulation and wood, and the contents of structures such as furniture, carpets, clothing, paper and plastics, can burn in fires, resulting in emissions of $PM_{2.5}$. Emissions from structure fires depend on the type of structure, the type of combustible materials, and amount of material combusted. Because differences in mixtures and quantities of combustible materials occur in commercial structures as compared to residential structures, commercial structures are not included in this category.

Air emissions from accidental vehicle fires are also covered in this category. Similarly to structure fires, emissions from vehicle fires depend on the fuel-loading (i.e., vehicle components and vehicle contents). Typically, non-metallic vehicle components are combustible (e.g., tires, upholstery, wooden trim, belts, hoses, and plastic parts).

Tier 1

The Tier 1 method estimates $PM_{2.5}$ emissions by using national statistics on the number of structure fires or vehicle fires. The Tier 1 method is based on the following equation:

$$E_{BC} = AR_{Fires} \times EF_{PM_{2.5}} \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC} = emissions of black carbon
AR_{Fires} = activity rate for either structure fires or vehicle fires (i.e., number of structure or vehicle fires in the inventory area)
$EF_{PM2.5}$ = $PM_{2.5}$ emission factor for structure fires or vehicle fires
$SF_{BC/PM2.5}$ = speciation factor to convert $PM_{2.5}$ to black carbon for either structure fires or vehicle fires

Tier 2

The Tier 2 method is similar to the Tier 1 method, but accounts for local data on fuel loading. For structure fires, the fuel-loading data take into account the combustible structural material, structure contents, area of structure burned, and loss rate. For vehicle fires, the fuel-loading data take into account the combustible vehicle components, vehicle contents, and mass of vehicle(s) burned. Default fuel-loading factors can be used if local data are not available. The Tier 2 method is based on the following equation:

$$E_{BC} = AR_{Fires} \times FL \times EF_{PM_{2.5}} \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC}	=	emissions of black carbon
AR_{Fires}	=	activity rate for structure or vehicle fires (i.e., number of structure or vehicle fires in the inventory area);
FL	=	fuel loading (i.e., tons burned/fire)
$EF_{PM2.5}$	=	$PM_{2.5}$ emission factor
$SF_{BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon

Tier 3

A Tier 3 method generally involves modeling or facility-level data and estimates, and is not currently available for this source category.

Potential Sources of Emission Factors, Activity Data, and Speciation Factors

Potential sources of activity data, emission factors, and speciation factors (wherever applicable) for estimating emissions from both structure fires and vehicle fires are shown in Table 3.5-3. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.5-3. Activity Data, Emission Factors, and Speciation Factors for Structure and Vehicle Fires

Parameter	Canada	United States	Mexico
Tier 1			
Number of structure/vehicle fires	Local fire departments and volunteer fire departments; Council of Canadian Fire Marshals and Fire Commissioners	US Fire Administration (USFA 2015); National Fire Protection Association (NFPA 2015); local fire departments and volunteer fire departments; direct contact with Fire Marshall's office; US EPA	Local fire departments and volunteer fire departments; direct contact with Fire Marshall's office
Emission factor ($PM_{2.5}$)	Norwegian Emission Inventory (Aasestad 2007)		
Speciation factor (EC or BC)	SPECIATE (EPA 2011b); use EC factor for BC		
Tier 2			
Fuel loading (structure and vehicle fires)	GVRD and FVRD 2003	California Air Resources Board (CARB 1994); expert judgment from local and regional fire departments	
Emission factor ($PM_{2.5}$)	GVRD and FVRD 2003	California Air Resources Board (CARB 1994); US EPA Emission Inventory Improvement Program (EPA 2000)	
Speciation factor (EC or BC)	SPECIATE database (EPA 2011b); use EC factor for BC		

3.5.4 Open Burning of MSW

This source category covers air emissions from burning of municipal solid waste (MSW) in open areas. Open burning of residential MSW typically occurs in rural areas where there is no garbage pick-up and where burning is seen as an easier or cheaper alternative to landfilling. Some regions have laws that prohibit on-site burning of MSW. In Mexico, open burning also occurs in some landfills and open waste dumps, to increase capacity. The air emissions depend on the quantity of waste burned and the composition of the waste. MSW includes paper, plastics, metals, wood, glass, rubber, leather, textiles, and food wastes. (Non-combustible portions of the waste, such as glass and metals, are considered not to be burned). Fine particulate emissions are caused by incomplete combustion of fuel (i.e., combustible portions of MSW).

Refer to Section 3.1 for more details on open burning of biomass. MSW that is picked up by local solid-waste agencies is typically incinerated or landfilled and is not included in this source category. Also, land-clearing debris and yard wastes are not included in this source category.

Tier 1

The Tier 1 method estimates $PM_{2.5}$ emissions using quantity of waste generated within the inventory area, composition of the waste, and a default emission factor. The Tier 1 method relies on per-capita waste generation rates and combustibles content (%). The following Tier 1 equation is based on the assumption that 100% of the population practices open burning. Inventory compilers should collect local data on burning practices to modify the equation as necessary (e.g., multiply by 0.4 if only 40% of the population in the Inventory area practices open burning). The Tier 1 method is based on the following equation:

$$E_{BC} = Population \times Q_{WasteGen} \times Comb_{Waste} \times EF_{PM_{2.5}} \times SF_{BC/PM_{2.5}}$$

Where,

E_{BC}	=	emissions of black carbon
Population	=	population in the inventory area that practices open burning
$Q_{WasteGen}$	=	per capita waste generation rate
$Comb_{Waste}$	=	combustible content of waste (i.e., percentage of the total waste that is actually burned)
$EF_{PM2.5}$	=	$PM_{2.5}$ emission factor (lb/ton)
$SF_{BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon

Tier 2

The Tier 2 method uses locality-specific activity data (e.g., waste generation rate, waste composition) to estimate $PM_{2.5}$. This method relies on a fuel-loading factor and a $PM_{2.5}$ emission factor to estimate fine particulate emissions.

The fuel-loading factor can be estimated for the inventory area using detailed data on waste generation; waste that is picked up, recycled, composted, or landfilled; and composition of waste, as follows:

$$Fuel_{Loading} = \left[MSW_{Gen} - \left(MSW_{Landfilled} + MSW_{Recycled} + MSW_{Other\ Disposed}\right)\right] \times Comb_{Waste}$$

Where,

$Fuel_{Loading}$	=	fuel loading factor (i.e., quantity of waste burned, in tons)
MSW_{Gen}	=	total quantity of MSW generated in inventory area
$MSW_{Land\ Filled}$	=	quantity of MSW that is landfilled
$MSW_{Recycled}$	=	quantity of MSW that is recycled
$MSW_{Other\ Disposed}$	=	quantity of MSW that is disposed of using other methods
$Comb_{Waste}$	=	combustible content of waste

Using the fuel-loading factor, the emissions are estimated as follows:

$$E_{BC} = Fuel_{Loading} \times EF_{PM_{2.5}} \times SF_{BC/\mathrm{PM}_{2.5}}$$

Where,

E_{BC}	=	emissions of black carbon
$EF_{PM2.5}$	=	$PM_{2.5}$ emission factor (lb/ton)
$SF_{BC/PM2.5}$	=	speciation factor to convert $PM_{2.5}$ to black carbon

Tier 3

The most feasible approach to estimating emissions from MSW combustion is based on data for a wide area, such as a city, county or municipality, a state, or country. Therefore, either a Tier 1 or Tier 2 method is most appropriate for this sector. No Tier 3 approach has been determined at this time.

Potential Sources of Emission Factors, Activity Data, and Speciation Factors

Potential sources of activity data, emission factors, and speciation factors (wherever applicable) for estimating emissions from open burning of MSW are shown in Table 3.5-4. For Tier 1, the specific recommended emission factors and speciation factors will be found in the tables in Appendix B.

Table 3.5-4. Activity Data, Emission Factors, and Speciation Factors for Municipal Solid Waste Combustion

Parameter	Canada	United States	Mexico
Tier 1			
Population	Statistics Canada (Statistics Canada 2015b)	US Census Bureau (US Census Bureau 2015)	National Institute of Statistics and Geography (INEGI 2015)
Per-capita waste generation rate	• Amount of residential waste generated per capita per year, by province/territory (Statistics Canada 2004) • Percentage of rural population by province/territory that performed the activity of open burning; percentage of the rural population that used a particular type of burning method; percentage of waste burned when conducting open burning (Gartner Lee 2003)	US EPA (EPA 2015c); solid waste management companies	National Institute of Statistics and Geography (INEGI 2013); solid waste management companies
Combustible content of waste	US EPA (EPA 1994, 1996); Minnesota (MPCA 2010); solid waste management companies		National Institute of Statistics and Geography (INEGI 2013); solid waste management companies

Table 3.5-4. Activity Data, Emission Factors, and Speciation Factors for Municipal Solid Waste Combustion

Parameter	Canada	United States	Mexico
Emission factor ($PM_{2.5}$)	2011 NEI (EPA 2013b)		National Institute of Ecology and Climate Change (INECC 2013); BC: Christian et al. 2010; 2011 NEI (EPA 2013b)
Speciation factor (EC or BC)	SPECIATE database (EPA 2011b); use EC factor for BC		National Institute of Ecology and Climate Change (INECC 2013); Christian et al. 2010; SPECIATE database (EPA 2011b); use EC factor for BC
Tier 2			
Fuel loading	Local public health departments, local sanitation departments, landfill operators; solid waste management companies		National Institute of Statistics and Geography (INEGI 2013); Christian et al. 2010; local public health/sanitation departments; landfill operators; solid waste management companies
Emission factor ($PM_{2.5}$)	2011 NEI (EPA 2013b)		National Institute of Ecology and Climate Change (INECC 2013); Christian et al. 2010; 2011 NEI (EPA 2013b)
Speciation factor (EC or BC)	SPECIATE database (EPA 2011b); use EC factor for BC		SPECIATE database (EPA 2011b); National Institute of Ecology and Climate Change (INECC 2013); Christian et al. 2010

4 Recommendations for Further Research

The EPA's *Report to Congress* identifies as high-priority research needs for BC, "[i]mproving global, regional, and domestic BC emission inventories with more laboratory and field data on activity levels, operating conditions, and technological configurations, coupled with better estimation techniques for current and future emissions" (EPA 2013a). Based on the research conducted to develop the present guidelines, these needs continue to be relevant.

Perhaps the most important area for further research is the improvement of speciation factors for BC, both in terms of accounting for light-absorbing properties, and aligning these factors with the level of detail found in underlying PM emission factors. A long-term goal would be speciation factors based on a consistent definition and measurement protocol relative to light-absorbing carbon, and complete alignment between the level of detail in speciation factors and underlying PM emission factors. Research programs focused on these goals are required to reduce the significant uncertainty currently associated with using speciation factors to produce BC inventories.

Other recommendations have been compiled by the ERG team and focus on improvements for specific sectors, as follows:

- Biomass Burning:
    - For determining area burned and amount of fuel burned using remote sensing data, obtain better satellite instruments (which may not be able to see the

understory, but could see smaller fires more accurately). Otherwise, each country needs to inventory these variables for each fire.

- For fuel load, obtain spatially accurate data developed from field experiments.
- For emission factors/speciation, understand and inventory the moisture in the fuel and wind speeds at the time of burning, and relate these, along with fuel load, to the amount of smoldering and flaming. This will improve the accuracy of emission factors/speciation and how the amount of flaming and smoldering is accounted for.

- Onroad Sources:
  - Improve vehicle activity data (i.e., distance traveled, speed distributions, vehicle age distributions) in Mexico and Canada for inputs to MOVES.
  - Improve emission rate data for Canada and Mexico. A starting point could be to adapt US emission rates and then replace these with local data collected over time.
- Nonroad Sources:
  - Develop standardized sources of equipment population and activity.
  - Collect and use more-precise data on equipment type so that generic aircraft or ship profiles can be replaced with aircraft-specific or vessel-specific data to estimate emissions.
  - Improve the representativeness of load factors for marine vessels and by accounting for variances in terrain for locomotives.
  - Examine and account for changes in operating load (i.e., loaded versus unloaded) that may not be accurately accounted for in the PM emission factors.
  - Examine and account for the impact that engine age has on PM emissions.
  - Conduct more-comprehensive BC testing of in-use aircraft, marine vessels, and locomotives, to provide more-representative speciation profiles, or direct BC emission factors.
  - Conduct additional studies of the impacts that different control options have on PM/BC emissions, to provide a better assessment of the level of PM controls currently in place, which could be reflected in the inventory.
- Industry/Energy Sector/Brick Kilns in Mexico:
  - Develop brick production estimates and efficiency, per major kiln type, based on representative samples from all major brick-producing regions (current data are only from tests performed in one state in Mexico).
  - Develop BC emission factors per major kiln type, for both wood and fuel oil, in place of current emission factors (which are based on burning only wood in a very limited number of kilns).
- Residential Sources/Cookstoves in Mexico:
  - Conduct surveys to determine per capita use of wood, by municipality, in place of current statistics (which were estimated with a model, by ecological region).

    - Develop BC emission factors from a representative sample of open fires and cookstoves, in place of the current emission factors (which were obtained from a small sample of open fires and cookstoves in one locality).

- Other Sources/ Burning of Municipal Solid Waste in Mexico:
    - Develop estimates of fuel loading per region, and BC emission factors from a representative sample, in place of current statistics and emission factors (which were developed from data at only one site).

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Appendix A: Emissions Data Management

When considering multiple emission sectors with myriad sources of data, the development of an emission inventory is a significant effort. From the beginning, inventory development requires thorough tracking and documentation of the methods and data used. This allows users of the inventory to understand the data and the assumptions and uncertainties underlying emissions estimates. It also provides a tracking of the evolution of inventory estimates as new data become available for updates. A system for cataloguing and managing the inputs used for an emission inventory is therefore considered good practice. A general discussion of inventory data management is provided, so that users may consider how to approach data management for black carbon inventories.

Emissions data management systems house the necessary activity data; emission factors; temporal, spatial, and speciation data; and other required data used to develop emission inventories. In addition to managing the emissions and activity data, these management systems can produce custom reports, facilitate reporting emissions data to agencies or other users, provide emissions data in air quality modeling formats, and be used for emissions data tracking and analyses. Most emissions data management systems are equipped to handle various pollutants (criteria pollutants, hazardous air pollutants, GHGs, BC, etc.) for various source types (i.e., point; area; onroad and nonroad mobile sources; biogenic; fires; and windblown dust).

Emissions data management systems can also be designed to store emission inventory protocol and guidance documents. Most systems are capable of housing multiple emission inventories, regardless of inventory domain. These systems can also be used to establish baseline emissions, track emissions over time, support strategy and regulatory developments, help with compliance programs, maintain bibliographical data references, and facilitate thorough quality assurance/quality control of inventories. Some emissions data management systems may provide a geographical information system (GIS) component to view results and create visual reports.

The scope of any emissions data management system depends on the scope of the inventory or inventories it is serving, the complexity and volume of data to be managed, and the end-use of the emission inventory/inventories. Emissions data management systems range from simple spreadsheets and databases, to complex environmental management information systems. Emissions data management systems can also be Web-based and provide access to the public via the Internet.

Some of the key components of an emissions data management system include the following:

- Secure user login, and user roles
- Data management procedures
- Data collection and reporting guidelines
- Data documentation procedures
- Emissions estimation techniques (measurements and estimates)
- Emissions testing plans (e.g., annual performance tests, concentration monitoring, emission factor development tests)
- Regulatory reporting guidelines
- Data collection tools and data entry forms
- Tier(s) used
- Emission factors
- Activity data

- Speciation factors
- Temporal and spatial allocation factors
- Importing facility-specific data (e.g., CEMS data)
- Bibliographical data references
- User-specified reports and data analyses
- Data import formats (e.g., data model)
- Data export formats (e.g., SMOKE, IDA, and NIF)

These components may be housed in a relational database using subsectors as a key field, at the level where choices of Tier, emission factor, activity data or speciation factor would vary.

In addition to collecting, managing, storing, and assuring quality of emission inventory data, these data management systems can be used to share emissions data for regional and international inventory development and air quality analyses. In particular, for purposes of BC emission inventory development, using effective data management tools will facilitate updating and improving inventories, over time.

The US EPA uses the Emission Inventory System (EIS) to collect and disseminate data from its National Emissions Inventory (NEI). The EIS was developed to provide authorized EPA, state, local, and tribal users with access to emission inventory data, and to provide transparency to the emission inventory process. Authorized users can access facility-level inventory and emissions data, run and extract custom reports, and request support from the EPA through a central message center. More information on US EPA's EIS is available online at: <www.epa.gov/ttnchie1/eis/gateway/>.

In Mexico, the Datgen (database system) is used to compile emissions data for point (energy and industry) sources. Semarnat uses the SINEA website to make its inventories available to the public (Semarnat 2015).

The Commission for Environmental Cooperation (CEC) is currently in the process of developing a Web portal for emissions data management, called the North American Portal on Climate Pollutants (see <http://climateportal.cec.org/>). This Web platform is designed to make the data from air pollutant emission inventories for Canada, Mexico, and the United States comparable and easy for researchers and policy experts to use. The CEC portal does not currently include an inventory development tool, but includes emission inventories for GHGs, BC, and short-lived climate forcers, published with the cooperation of the governments of Canada, Mexico, and the United States. CEC is expecting to include other inventories in the future. The Portal currently involves three key components:

- a **menu of search tools** for accessing trinational emission inventory data;
- a **data dictionary** that defines a common framework aimed at enhancing the comparability of different inventories, through the use of semantic tags; and
- a **publicly accessible application programming interface (API)** that distributes trinational emission inventory data to advanced users, front-end developers and researchers.

Using the cited systems as a starting point, inventory developers are encouraged to develop an emissions data management system, or plan to use or adapt an existing one, at the outset of an emission inventory effort. This will encourage a disciplined approach to inventory development, and provide documentation needed for inventory users and future inventory iterations. A data management approach need not be overly complex; the best system is one that will be kept up-to-date and provides the needed level of detail for inventory users and developers.

Appendix B: Validation and Uncertainty

Improving and verifying BC emission inventories are essential elements of inventory development. In the effort toward continual improvement, routine validation to identify gaps in inventory performance is good practice. Analysis of inventory uncertainties can help inventory developers and decision-makers understand the limitations of an emission inventory. Uncertainty analysis coupled with sensitivity analysis are methods to focus on areas that are the most critical to improve.

Identifying and Quantifying Sources of Uncertainty

Estimating the uncertainty of BC emission inventories is important for developers and decision-makers, in order to put inventory estimates in context. It is also important to highlight where resources can be best dedicated toward gathering more data and improving the quality of the overall inventory. The current ability to quantify uncertainty for North American BC emission inventories is a challenge, as evidenced by the lack of quantitative uncertainty estimates in BC inventories estimated in the EPA and Arctic Council Task Force BC reports (the Mexico SNAP report does provide a method for calculating uncertainty, and a case study for one sector). This challenge stems from the fact that BC emission estimates are based on PM emission estimates and there is no quantification of BC emissions in official PM emission inventories, such as the US National Emission inventory. To develop uncertainty estimates for BC inventories will require developing bottom-up uncertainty estimates for underlying PM inventories first. Studies that have quantified uncertainty have estimated very large ranges; for example, for a global BC inventory, Bond et al. (2004) estimated an uncertainty range of about -50 percent to +275 percent, relative to the estimated inventory total.

A related challenge in quantifying uncertainty of bottom-up emission inventories is that the inventories are the product of a string of components—emission factors, activity factors, and for BC inventories, speciation factors—with independent factors contributing uncertainty in each. The overall uncertainty of BC inventories is compounded across each of these individual uncertainties. Given the need to first quantify uncertainty in underlying PM inventories, which lack uncertainty estimates, BC inventory developers are faced with a major challenge in estimating uncertainty. However, methods published as part of IPCC guidelines for GHG inventories can be extended to BC, providing a pathway for inventory developers to quantify BC uncertainty as well (IPCC 1996). These guidelines provide details on methods to quantify uncertainty based either on statistical analysis, where data permit, or “expert elicitation” (i.e., an alternative approach of polling experts for subjective judgment on uncertainties), where data do not allow direct quantification. A detailed discussion of expert elicitation is provided in the IPCC guidelines, including considerations in choosing experts, polling their opinions and synthesizing into quantifiable probability the distributions for use in propagation calculations.

Sources of Uncertainty

Quantifying uncertainty requires accounting for several sources of variability and error in the inventory methods and underlying data. These sources contribute to the uncertainty of emission factors, activity data and speciation factors to different degrees. The ability to quantify each depends on the availability of detailed data, as noted; in some cases, the expert elicitation method summarized later in this section is required for quantification.

- **Variability.** Variability in emission factors and activity is unavoidable. Source sectors consist of multiple individual sources (e.g., vehicles, power plants, cookstoves). These individual sources have natural variability that cannot be reduced even if every single source is sampled extensively. This natural variation can be quantified through population statistics, and reflected as error bars (e.g., 95 percent confidence intervals) in the reporting of emission factors. Variability can be quantified based on the distribution of the measurements around a central tendency (i.e., mean or median), using standard statistical analysis techniques.

- **Measurement.** Measurement error is the result of lack of precision in the devices used to measure emissions or activity, or in the test procedures under which data are collected (e.g., reproducibility of the experiments). For example, emission monitors require frequent calibration; even if calibrated well, the monitors will have an uncertainty tolerance due to detection limits of the instrument, which is quantifiable based on the specifications of the instrument. If not calibrated well, the measurement may be prone to bias, and difficult to quantify unless the instrument is checked by an independent source. Further, inconsistencies in how BC is defined (EC vs. LAC, as discussed in Section 2.2) adds to measurement uncertainty.
- **Sample Bias.** Emission factors are typically derived from samples of the entire population in a particular sector, and/or a subset of the source operation. In many sectors a relatively small number of high-emitting sources contribute to a higher share of emissions, which needs to be reflected in the emission factor. To accomplish this, ideally the sample is representative of the entire population—either with a large sample size that ensures a representative spread of sources, or through stratified sampling that targets higher-emitting sources. If this is not accomplished, or if the sample is simply too small to cover the range of emissions, the sample will be biased and add error to the overall emission inventory calculation. Sample bias is difficult to quantify without an independent estimate of representative emissions.
- **Model Formulation.** The calculation of bottom-up emission inventories relies on models built on simplifying assumptions. The process of simplifying the complexity of real emissions into a model framework introduces errors. Emission factors may be based on more-typical operating patterns and neglect more-extreme events. Differences in emission sources (e.g., vegetation, industrial source, vehicle type) may be lost by grouping into a single emissions subcategory. Factors which have complex results on emissions, such as meteorology, equipment age, and fuel diversity and quality, may be lost in favor of more-aggregate, linear assumptions.

  A model formulation issue of particular relevance for the BC inventory guidance is the recognition that aggregated emission factors and activity data, as generally recommended for Tier 1 and Tier 2 approaches, will introduce error into the emission inventory calculation. Aggregating emission factors and activity data requires inherent assumptions about the mix of more-detailed source categories, which are not provided by the user. This aggregation may also serve to dampen nonlinearities that exist within an individual source sector, such as seasonal impacts. However, though the process of aggregation introduces error, the point of more aggregation is to allow an estimate to be produced where there would otherwise be none. On balance, the use of an aggregated Tier 1 approach is judged better than no estimate for a particular sector, but should really only be used in such a case.

  Errors introduced by model formulation are not easily quantified from underlying data; expert judgment may be required to quantify uncertainty.
- **Speciation.** Speciation to derive BC emission inventories introduces additional error which is also related to model formulation. Speciation factors bring with them errors from the same sources as the underlying PM emission factors: variability, measurement, sample bias, and model formulation. An additional measurement issue is that instruments are measuring elemental carbon rather than optical BC. Speciation factors are often derived from emission sampling programs separate from the underlying emission factors to which they are applied. This means that the factors themselves will reflect variability, measurement error, and sample bias. When applied to underlying PM emission factors, error is introduced from a model formulation perspective because the measurement and sample conditions are not aligned. Use of speciation is a necessity

at this stage of BC emission inventory development; over time, however, the hope is that BC can be directly measured as part of broader emission factor characterization, eliminating the need for this additional step and the errors introduced by it.

- **Incomplete Data.** The preceding error sources are based on the quantification of sectors included in the emission inventory. An additional source of error is an inventory that is incomplete because a particular source sector is left out. The goal of this guidelines document is to reduce this error by providing at least Tier 1 methods for sectors making up the vast majority of BC sources. Not every single potential source of BC can be accounted for, and some very small subsectors are not included. This gap may be quantified by comparison of top-down emissions with bottom-up estimates.

Quantifying Uncertainty

To estimate uncertainty requires knowing the probability distribution and variability for each element of the inventory calculation (i.e., emission factors, activity data, and speciation factors). As discussed above, these will ideally be quantified directly from underlying data, using statistical techniques or “bootstrapping,” an analysis technique that uses underlying variability in the data to construct a distribution and variance for a specific component. In the absence of data to pursue these methods, an alternative approach of polling experts, for subjective judgment on uncertainties, is presented as well. In practice, quantifying every element of uncertainty may not be a realistic endeavor for an emission inventory developer. A reasonable attempt can therefore be made if the uncertainties in emission factors, activity data and speciation factors are estimated and combined through established methods, while documenting that certain elements of uncertainty (e.g., model formulation, incomplete data) are not included in the quantified estimate. The following sections discuss how a more targeted effort can be undertaken to quantify an uncertainty estimate.

Emission factors

Uncertainty in PM emission factors arises primarily from variability, measurement, sample bias and model formulation (aggregation). The major sources of PM emission factors quoted in the guidelines (see, e.g., mobile source emission models in Section 3.3, Mobile Sources) generally do not include uncertainty estimates with the emission factors, though underlying data are often available. In these cases, the uncertainty of variability and measurement would need to be quantified directly, using the probability distribution and standard deviation of underlying sample data, or through bootstrapping. Quantifying sample bias requires comparison to independent sources, or expert elicitation.

Activity data

The activity data sources recommended in these guidelines tend to come from estimates compiled by government agencies (e.g., energy consumption, burn area, and vehicle distance traveled). The quantification of uncertainty depends on the agency compiling the data, and the inventory developer should inquire with the reporting agency if uncertainty estimates are provided in the reported data. It may be possible to obtain underlying data from which to establish the probability statistics, or to use for bootstrapping. Barring this, expert elicitation is required.

Speciation factors

The SPECIATE database includes information on uncertainty (EPA 2011b). However, this metric would only cover variability and measurement error. Sample bias and model formulation will also contribute significant uncertainty to the application of speciation factors in BC inventories (e.g., due to the mismatch between the number of source categories in PM inventories and the number of available speciation profiles).

Combining Uncertainty

Once the distribution and standard deviation have been estimated for emission factors, activity and speciation factors, IPCC guidance details two approaches to quantifying inventory uncertainty: 1) mathematical quantification (deemed more simple), and 2) Monte Carlo simulation, which iterates many computer simulations of the inventory calculation, using random selection of inventory components (emission factors, activity data, speciation factors), based on their probability distribution.

For approach 1, the IPCC guidelines provide mathematical equations for combining uncertainties for inventories derived through additive (Rule A) and multiplicative (Rule B) approaches. BC inventories developed across multiple sectors will use both. Individual sectors use a multiplicative approach (Rule B), based on uncertainty as a percentage of the target variable, and total inventories are then summed across sectors (Rule A). The equations for each approach are shown in the following excerpt from the IPCC guidelines (IPCC 1996[3]):

- *Rule A*: Where uncertain quantities are to be combined by addition, the standard deviation of the sum will be the square root of the sum of the squares of the standard deviations of the quantities that are added with the standard deviations all expressed in absolute terms (this rule is exact for uncorrelated variables).

  Using this interpretation, a simple equation can be derived for the uncertainty of the sum, that when expressed in percentage terms becomes:

  EQUATION 6.3

  $$U_{total} = \frac{\sqrt{(U_1 \bullet x_1)^2 + (U_2 \bullet x_2)^2 + \ldots + (U_n \bullet x_n)^2}}{x_1 + x_2 + \ldots + x_n}$$

  Where:

  U_{total} is the percentage uncertainty in the sum of the quantities (half the 95% confidence interval divided by the total (i.e. mean) and expressed as a percentage);

  x_i and U_i are the uncertain quantities and the percentage uncertainties associated with them, respectively.

- *Rule B*: Where uncertain quantities are to be combined by multiplication, the same rule applies except that the standard deviations must all be expressed as fractions of the appropriate mean values (this rule is approximate for all random variables).

  A simple equation can also be derived for the uncertainty of the product, expressed in percentage terms:

  EQUATION 6.4

  $$U_{total} = \sqrt{U_1^2 + U_2^2 + \ldots + U_n^2}$$

  Where:

  U_{total} is the percentage uncertainty in the product of the quantities (half the 95% confidence interval divided by the total and expressed as a percentage);

  U_i are the percentage uncertainties associated with each of the quantities.

Source: IPCC 1996.

The IPCC guidelines provide templates for estimating uncertainty using these approaches, as well as methods to project trends in uncertainty based on the change in emissions over time. In short, for a given subsector, the uncertainties established for emission factor, activity data, and speciation factor (through analysis of underlying data or expert elicitation) would be inputs to Equation 6.3, above. The resulting uncertainty of this subsector would then be input along with other subsectors into Equation 6.4, above, to estimate total uncertainty across the inventory.

The Monte Carlo approach (approach 2) is generally implemented using software packages specifically designed for this. Add-on programs for Microsoft Excel (e.g., @Risk®, Oracle Crystal Ball) are relatively easy to set up and iterate, and require defining probability distributions for each emission factor, activity

[3] IPCC guidelines were updated in 2006, but the fundamental approach for calculating uncertainty remains consistent with what is presented here.

data element, and speciation factor used in the inventory. The Monte Carlo approach is appropriate for BC inventories, calculating individual sector inventories many times (generally in the thousands) using randomly selected inputs for emission factor, activity data element, and speciation factor. Results for each iteration would be summed across all sectors and a distribution of total emissions would be constructed from the results of each iteration; from this, an uncertainty estimate on the total BC inventory could be estimated.

Validation Methods

Validation compares an emission inventory and underlying factors with independent data sources, as a check on inputs and inventory results, and to understand where significant gaps may exist in individual sectors. Validation is important for verifying the quality of the inventory, and for highlighting areas for future research. As with emission inventories for other pollutants, there is not an estimate of absolute truth for BC emissions. Several different sources can be used to assess different aspects of the inventory, and monitoring can provide a limited check on a relative basis. Different approaches to validation are summarized below.

Independent Datasets

The most direct way to evaluate emission and speciation factors is through datasets not included in the development of the emission factors. Because the same sources of uncertainty exist in these independent datasets, care must be taken in making this comparison. Independent datasets are particularly useful for evaluating sample bias in emission factors, and for this reason an ideal independent dataset reflects a large sample size, or a stratified sampling approach. The availability of independent datasets will depend on the source sector and variety of measurement methods available. As an example, for onroad mobile sources, emission factors based on laboratory test measurements have been validated using independent data from roadside remote sensing devices, portable emissions measurement systems, or ambient measurements taken in roadway tunnels. For this source sector, having several different methods to measure emissions provides a more ready supply of independent data for validation. For other sectors, with more limited data, independent studies from the literature (e.g., from another country) can support validation.

Comparison across Tiers

For many of the sectors, Tier 1 methods use aggregate “top down” activity sources (e.g., energy consumption, fuel consumption). These activity sources have traditionally been used to check bottom-up inventories, which use other, more detailed activity elements. For example, for mobile sources, total fuel consumption (recommended for Tier 1) is often used to check bottom-up inventories based on vehicle distance traveled. The structure of the guidelines into tiers is convenient for validation, because for many sectors it means the Tier 1 approach can be used as a check on Tier 2 or 3 approaches, if different activity data are used. This approach allows validation of combined emission factor and activity data elements, the foundation of the bottom-up emission inventory.

Monitoring

Satellite and monitoring data are an objective source of PM and BC estimates, though not on an absolute mass basis. This limits how these sources can be applied to evaluate emission inventories. These data sources are helpful for evaluating trends over time, or seasonal changes. Ambient air monitors can be used to measure relative changes in emissions from isolated events (e.g., fires), or to compare ratios of different pollutants from those estimated by bottom-up inventories. Monitoring data for PM also include secondary PM formed in the atmosphere (e.g., nitrate, sulfate, secondary organic aerosols, etc.), which needs to be accounted for in validating directly-emitted PM species like elemental carbon. For validation purposes, monitors are usually compared to air quality modeling results that account for secondary PM, rather than to mass emission inventories that include only direct PM.

Recommended Emission Factors and Speciation Factors for TIER 1 Black Carbon Emission Estimations

Notes: Each table provides Emission Factors (EFs) and Speciation Factors (SFs) to support calculations of Black Carbon emissions, by sector, for Tier 1 methods presented in Section 3. For Biomass, Energy & Industry, Residential and Other sectors, EFs and SFs apply to all calendar years. For Onroad Mobile and Nonroad Mobile, EFs and SFs apply only to a base year, Calendar Year 2013. Documentation of each EF and SF is provided in each table in the form of references, and additional notes on derivation where needed.

SECTION 3.1 BIOMASS

Tier 1 Emission Factors (EF)

Fuels	Emission Source	Factor	Pollutant	Units	Reference(s)	WebFIRE Factor ID #	Notes
Biomass	**Open Fires**, Mexico	324	$PM_{2.5}$	kg/hectare	AP-42, table 13.1-2 (EPA 1994)	NA	Average particulate for forest wildfires (averaged over 9 US regions) reported in Table 13.1-2 of AP-42
Biomass	**Open Fires**, Canada and US	324	$PM_{2.5}$	kg/hectare	AP-42, table 13.1-2 (EPA 1994); GVRD and FVRD 2003	NA	
Biomass	**Prescribed Burning**, Canada (outside British Columbia), Mexico and US	632	$PM_{2.5}$	kg/hectare	AP-42, table 13.1-4 (EPA 1994)	NA	Average particulate for prescribed burn (averaged over 6 US regions) reported in Table 13.1-4 of AP-42
Biomass	**Prescribed Burning**, Canada (British Columbia)	752	$PM_{2.5}$	kg/hectare	GVRD and FVRD 2003	NA	
Biomass	**Agricultural Burning**, Mexico (sugar cane)	2.49	$PM_{2.5}$	g/kg	Hall et al. 2012	NA	Average recommended emission factor from combustion chamber study by Hall et al. 2012
Biomass	**Agricultural Burning**, Mexico	6.26	$PM_{2.5}$	g/kg	Agaki et al. 2011; Yokelson et al. 2011	NA	Value reported in Table 1 (Agaki et al. 2011) and Table 2 (Yokelson et al. 2011)
Biomass	**Agricultural Burning**, Canada and US	5.25	$PM_{2.5}$	g/kg	WRAP 2005; Akagi et al. 2011	NA	Average of the value from CARB in Table 24 in WRAP2005 and the value from Agaki et al. 2011

Notes: NA = not applicable

Tier 1 Speciation Factors (SF)

Source / Fuel Type	EC (weight %)*	Reference(s)	SPECIATE Profile# (if applicable)	SPECIATE Uncertainty (if applicable)
Open Fires & Prescribed Burning	9.5	SPECIATE (EPA 2011b)	92102	NA
Agricultural Burning, Mexico (sugar cane)	28.5	Hall et al. 2012	NA	NA
Agricultural Burning	10.9	SPECIATE (EPA 2011b)	92103	NA

*Notes: *Speciation factor is for percentage of $PM_{2.5}$ that is elemental carbon (EC). EC has been acknowledged as a proxy for BC until improved measurement methods and data become available.*
NA = not applicable.

SECTION 3.2 ENERGY AND INDUSTRY (EF)

Fuels	Emission Source	Tier 1 Emission Factors (EF)					Notes
		Factor	Pollutant	Units	Reference	WebFIRE Factor ID #	
Anthracite Coal	Electric Generation	(2.500E0)+(8E-2*A)	$PM_{2.5}$	LB/ton	WebFIRE (EPA 2015b)	45	Typical ash content for anthracite coal is 7.0-16.0%, by weight (EPA 1985)
Bituminous/ Subbituminous Coal	Electric Generation	5.64	$PM_{2.5}$	LB/ton	WebFIRE (EPA 2015b)	502	
Distillate Oil	Electric Generation	1.55	$PM_{2.5}$	LB/1000 gallons	WebFIRE (EPA 2015b)	2256	
Kerosene/Naphtha (Jet Fuel)	Electric Generation	0.01107	$PM_{2.5}$	LB/million BTUs	WebFIRE (EPA 2015b)	11510	
Lignite Coal	Electric Generation	0.79*[6.6E-1 * (A)]	$PM_{2.5}$	LB/ton	WebFIRE (EPA 2015b)	1584	Pulverized coal, dry bottom, wall fired. Typical ash content for lignite coal is 6.2%, by weight (EPA 1985).
Liquified Petroleum Gas (LPG)	Electric Generation	0.848	$PM_{2.5}$	LB/1000 gallons	WebFIRE (EPA 2015b)	3778	Propane EF
Natural Gas	Electric Generation	7.6	$PM_{2.5}$	LB/million Cubic Feet	WebFIRE (EPA 2015b)	2496	
Process Gas	Electric Generation	7.41	$PM_{2.5}$	LB/million Cubic Feet	WebFIRE (EPA 2015b)	2596	
Residual Oil	Electric Generation	4.3A	$PM_{2.5}$	LB/1000 gallons	WebFIRE (EPA 2015b)	2004	Typical ash content for residual oil is 0.05-0.1%, by weight (EPA 1985).
Solid Waste	Electric Generation	0.04063	$PM_{2.5}$	LB/million BTUs	WebFIRE (EPA 2015b)	3823	
Wood/Bark Waste	Electric Generation	10	$PM_{2.5}$	LB/ton	WebFIRE (EPA 2015b)	2860	
Anthracite Coal	Industrial	(2.500E0)+(8E-2*A)	$PM_{2.5}$	LB/ton	WebFIRE (EPA 2015b)	3896	Typical ash content for anthracite coal is 7.0-16.0%, by weight (EPA 1985)
Bituminous/Subbituminous Coal	Industrial	5.64	$PM_{2.5}$	LB/ton	WebFIRE (EPA 2015b)	4329	
Distillate Oil	Industrial	1.55	$PM_{2.5}$	LB/1000 gallons	WebFIRE (EPA 2015b)	5690	
Kerosene/ Naphtha (Jet Fuel)	Industrial	0.01107	$PM_{2.5}$	LB/million BTUs	WebFIRE (EPA 2015b)	12248	
Lignite Coal	Industrial	(5.600E-1*A) + 6.400E-1	$PM_{2.5}$	LB/ton	WebFIRE (EPA 2015b)	5461	Typical ash content for lignite coal is 6.2%, by weight (EPA 1985).
Liquified Petroleum Gas (LPG)	Industrial	1.106	$PM_{2.5}$	LB/1000 gallons	WebFIRE (EPA 2015b)	8006	Propane EF
Natural Gas	Industrial	7.6	$PM_{2.5}$	LB/million Cubic Feet	WebFIRE (EPA 2015b)	5945	
Process Gas - Petroleum Refinery Gas	Industrial	8.7	$PM_{2.5}$	LB/million Cubic Feet	WebFIRE (EPA 2015b)	5995	
Process Gas - BFG	Industrial	8.6	$PM_{2.5}$	LB/million Cubic Feet	WebFIRE (EPA 2015b)	6006	
Process Gas - Coke Oven Gas	Industrial	8.919	$PM_{2.5}$	LB/million Cubic Feet	WebFIRE (EPA 2015b)	6015	
Residual Oil	Industrial	(4.67E0*A)+(1.50E0)	$PM_{2.5}$	LB/1000 gallons	WebFIRE (EPA 2015b)	5526	Typical ash content for residual oil is 0.05-0.1%, by weight (EPA 1985).
Wood/Bark Waste	Industrial	10	$PM_{2.5}$	LB/ton	WebFIRE (EPA 2015b)	6360	
Various	Brick Kilns (Mexico)	40.39	$PM_{2.5}$	kg/burn	TCEQ 2002, CARB 2014	NA	Original TSP EF (TCEQ 2002) multiplied by 0.9001 size fraction for PM2.5 (CARB 2014)

Notes: NA = not applicable. A = Ash content of fuel, weight %.

SECTION 3.2 ENERGY AND INDUSTRY (SF)

Tier 1 Speciation Factors (SF)

Source / Fuel Type	EC (weight %)*	Reference(s)	SPECIATE Profile # (if applicable)	SPECIATE Uncertainty (if applicable)	Notes
Bituminous Coal Combustion	1.696	SPECIATE (EPA 2011b)	92104	NA	
Distillate Oil Combustion	10	SPECIATE (EPA 2011b)	92115	NA	
Lignite Combustion	1.428729379	SPECIATE (EPA 2011b)	92125	NA	
Natural Gas Combustion	38.4	SPECIATE (EPA 2011b)	92112	NA	
Liquified Petroleum Gas (LPG)	38.4	SPECIATE (EPA 2011b)	92112	NA	No available profile for LPG. Profile is for Natural Gas. Alternatively, inventory compilers can use other surrogate profiles available in SPECIATE
Process Gas Combustion	14.57143457	SPECIATE (EPA 2011b)	92136	NA	
Residual Oil Combustion	1	SPECIATE (EPA 2011b)	92117	NA	
Solid Waste Combustion	1.52188727	SPECIATE (EPA 2011b)	92126	NA	
Subbituminous Coal Combustion	4.2763	SPECIATE (EPA 2011b)	92110	NA	
Wood/Bark Waste	3.3	EMEP/EEA 2013	NA	NA	
Brick Kilns (Mexico)	0.865	Stratus 2012	NA	NA	

*Notes: *Speciation factor is for percentage of $PM_{2.5}$ that is elemental carbon (EC). EC has been acknowledged as a proxy for BC until improved measurement methods and data become available.*
NA = not applicable.

SECTION 3.3.1 MOBILE ONROAD

Tier 1 Emission Factors (EF)

Fuels	Emission Source	Factor	Pollutant	Units	Reference(s)	WebFIRE Factor ID #	Notes
Diesel	**All diesel-fueled vehicles** (Canada & US)	1.481	EC	grams/gallon consumed	EPA 2014a	NA	For Canada & US, MOVES2014 run for 2013 Calendar Year; Energy Content 135,562 kJ/gallon
Gasoline	**All gasoline-fueled vehicles** (Canada & US)	0.050	EC	grams/gallon consumed	EPA 2014a	NA	2013; Energy Content 118,287 kJ/gallon (E10)
CNG	**All CNG-fueled vehicles** (Canada & US)	0.024	EC	grams/100 SCF consumed	EPA 2014a	NA	2013; Energy Content 103,706 kJ/gallon
Diesel	**All diesel-fueled vehicles** (Mexico)	3.185	EC	grams/gallon consumed	EPA 2014a	NA	For Mexico, 2013 approximated with US MOVES run for 2004; Energy Content 135,562 kJ/gallon
Gasoline	**All gasoline-fueled vehicles** (Mexico)	0.073	EC	grams/gallon consumed	EPA 2014a	NA	2013 approximated with 2004; Energy Content 122,481 kJ/gallon (E0)
CNG	**All CNG-fueled vehicles** (Mexico)	0.036	EC	grams/100 SCF consumed	EPA 2014a	NA	2013 approximated with 2004; Energy Content 103,706 kJ/gallon

Notes: NA = not applicable; SCF = standard cubic feet; EC is a proxy for BC.
MOVES2014 was run to produce US totals of EC and Total Energy, and energy content used to convert Total Energy to gallons or SCF.

Tier 1 Speciation Factors (SF)	**Notes** Speciation Factors not needed for on-road; emission factors are provided in EC already.

SECTION 3.3.2 MOBILE NONROAD (EF)

Tier 1 Emission Factors (EF)

Fuels	Emission Source	Factor	Pollutant	Units	Reference(s)	WebFIRE Factor ID #	Notes
2-stroke gasoline	nonroad - US/Canada	472.759	$PM_{2.5}$	grams/gallon consumed	NONROAD (EPA 2014b)	NA	NONROAD 2008 run for US total, 2013 calendar year; 30 ppm sulfur diesel and gas. Total grams $PM_{2.5}$ divided by total liters of fuel for all SCCs
4-stroke gasoline	nonroad - US/Canada	27.993	$PM_{2.5}$	grams/gallon consumed	NONROAD (EPA 2014b)	NA	
LPG	nonroad - US/Canada	20.490	$PM_{2.5}$	grams/gallon consumed	NONROAD (EPA 2014b)	NA	
CNG	nonroad - US/Canada	0.223	$PM_{2.5}$	grams/gallon consumed	NONROAD (EPA 2014b)	NA	
Diesel	nonroad - US/Canada	86.337	$PM_{2.5}$	grams/gallon consumed	NONROAD (EPA 2014b)	NA	
2-stroke gasoline	nonroad - Mexico	440.132	$PM_{2.5}$	grams/gallon consumed	NONROAD-Mexico	NA	NONROAD 2008 (EPA 2014b) run for 1990 model year to simulate an uncontrolled fleet; 5,000 ppm sulfur diesel and 30 ppm sulfur gas. Total grams $PM_{2.5}$ divided by total liters of fuel for all SCCs. Methodology equivalent to NONROAD-Mexico.
4-stroke gasoline	nonroad - Mexico	398.712	$PM_{2.5}$	grams/gallon consumed	NONROAD-Mexico	NA	
LPG	nonroad - Mexico	111.787	$PM_{2.5}$	grams/gallon consumed	NONROAD-Mexico	NA	
CNG	nonroad - Mexico	2.127	$PM_{2.5}$	grams/gallon consumed	NONROAD-Mexico	NA	
Diesel	nonroad - Mexico	362.373	$PM_{2.5}$	grams/gallon consumed	NONROAD-Mexico	NA	

Notes: NA = not applicable

SECTION 3.3.2 MOBILE NONROAD (SF)

Tier 1 Speciation Factors (SF)

Source / Fuel Type	EC (weight %)*	Reference(s)	SPECIATE Profile # (if applicable)	SPECIATE Uncertainty (if applicable)	Notes
Nonroad/2-stroke gasoline	12.19	SPECIATE (EPA 2011b)	91113	NA	
Nonroad/4-stroke gasoline	38.4	SPECIATE (EPA 2011b)	92112	NA	
Nonroad/LPG	44.39	SPECIATE (EPA 2011b)	3858, 3859	9.5%	Assume same as gasoline; no LPG-specific SF found for nonroad engines
Nonroad/CNG	34.9	MOVES2014 (EPA 2014a); SPECIATE (EPA 2011b); NONROAD (EPA 2014b)	NA	NA	
Nonroad/Diesel - uncontrolled[1]	28.5	Hall et al. 2012	NA	NA	Applicable for Mexican fleet
Nonroad/Diesel - weighted average[2]	10.9	SPECIATE (EPA 2011b)	92103	NA	Applicable for US and Canadian fleets

*Notes: *Speciation factor is for percentage of $PM_{2.5}$ that is elemental carbon (EC). EC has been acknowledged as a proxy for BC until improved measurement methods and data become available.*
NA = not applicable.

1. EC speciation factor listed is for percentage of PM_{10} emissions.
2. Weighted average for controlled (i.e., with exhaust after-treatment) and uncontrolled (no after-treatment) engines.

SECTION 3.3.3-5 MOBILE L-M-A

Tier 1 Emission Factors (EF)

Fuels	Emission Source	Factor	Pollutant	Units	Reference(s)	WebFIRE Factor ID #	Notes
Locomotive Diesel	Mobile - locomotive	4.55900	$PM_{2.5}$	grams/gallon consumed	EPA Locomotive Emission Fators (EPA 2009b)	NA	2013 Calendar Year
ECA-compliant Diesel	Mobile - marine vessel	7.56300	$PM_{2.5}$	grams/gallon consumed	US EPA Regulatory Impact Analysis (Category 1 and 2, EPA 2007; Category 3, EPA 2009c)	NA	
Global Residual Blend	Mobile - marine vessel	23.73500	$PM_{2.5}$	grams/gallon consumed	IMO 2014. Reduction of GHG Emission From Ships (July 2014)	NA	
Jet Fuel	Mobile - aircraft	0.62000	$PM_{2.5}$	grams/gallon consumed	EMEP/EEA 2013	NA	

Notes: NA = not applicable

Tier 1 Speciation Factors (SF)

Source / Fuel Type	EC (weight %)*	Reference(s)	SPECIATE Profile # (if applicable)	SPECIATE Uncertainty (if applicable)
Mobile - locomotive 2013 diesel	67.67	MOVES2014 HDDT (EPA 2014a)	NA	NA
Mobile - marine vessel ECA-compliant diesel	77	EPA 2013a	NA	NA
Mobile - marine vessel global residual blend	6	EPA 2013a	NA	NA
Mobile - aircraft jet fuel	13	EPA 2013a	NA	NA

*Notes: *Speciation factor is for percentage of $PM_{2.5}$ that is elemental carbon (EC). EC has been acknowledged as a proxy for BC until improved measurement methods and data become available. NA = not applicable.*

SECTION 3.4 RESIDENTIAL

Tier 1 Emission Factors (EF)

Fuels	Emission Source	Factor	Pollutant	Units	Reference(s)	WebFIRE Factor ID #	Notes
Hard Coal and Brown Coal	Residential	398	$PM_{2.5}$	g/GJ	EMEP/EEA 2013	NA	
Distillate Oil	Residential	0.4	PM-filterable	LB/1000 gallons	WebFIRE (EPA 2015b)	25362	No $PM_{2.5}$ EFs for residential combustion of distillate oil. Inventory compilers can use PM-size fractions from ARB (CARB 2014).
Kerosene	Residential	0.4	PM-filterable	LB/1000 gallons	WebFIRE (EPA 2015b)	25591	No $PM_{2.5}$ EFs for residential combustion of kerosene. Inventory compilers can use PM-size fractions from ARB (CARB 2014).
Natural Gas	Residential	7.6	$PM_{2.5}$	LB/million cubic feet	WebFIRE (EPA 2015b)	25420	EF listed is for PM-Primary (Total PM). As per WebFIRE, all PM (total, condensable and filterable) is assumed to be less than 1.0 micrometer in diameter. Therefore, the PM emission factor can be used to estimate $PM_{2.5}$ emissions.
Wood	Residential	34.6	PM_{10}	LB/tons	WebFIRE (EPA 2015b)	25434	No $PM_{2.5}$ EFs for residential wood combustion. Inventory compilers can use PM-size fractions from ARB (CARB 2014).

Notes: NA = not applicable

Tier 1 Speciation Factors (SF)

Source / Fuel Type	EC (weight %)*	Reference(s)	SPECIATE Profile# (if applicable)	SPECIATE Uncertainty (if applicable)
Hard Coal and Brown Coal	6.4	EMEP/EEA 2013	NA	NA
Natural Gas Combustion	6.7	SPECIATE (EPA 2011b)	92156	NA
Oil Combustion	3.897896252	SPECIATE (EPA 2011b)	5644	1.35%
Wood Combustion	5.579138067	SPECIATE (EPA 2011b)	92105	NA

*Notes: *Speciation factor is for percentage of $PM_{2.5}$ that is elemental carbon (EC). EC has been acknowledged as a proxy for BC until improved measurement methods and data become available.*
NA = not applicable.

SECTION 3.5 OTHER (EF)

Fuels	Emission Source	Tier 1 Emission Factors (EF)					Notes
		Factor	Pollutant	Units	Reference(s)	WebFIRE Factor ID #	
Conveyorized Charbroiling	Charbroiling	0.049790839	$PM_{2.5}$	LB/person	2011 US NEI (EPA 2013b)	NA	
Under-fired Charbroiling	Charbroiling	0.4	$PM_{2.5}$	LB/person	2011 US NEI (EPA 2013b)	NA	
Deep Fat Frying	Charbroiling	0	$PM_{2.5}$	LB/person	2011 US NEI (EPA 2013b)	NA	
Flat Griddle Frying	Charbroiling	0.103	$PM_{2.5}$	LB/person	2011 US NEI (EPA 2013b)	NA	
Clamshell Griddle Frying	Charbroiling	0.006991186	$PM_{2.5}$	LB/person	2011 US NEI (EPA 2013b)	NA	
None specified	Human cremation	1.569047619	$PM_{2.5}$	LB/ton cremated	2011 US NEI (EPA 2013b)	NA	
None specified	Open burning - MSW	34.8	$PM_{2.5}$	LB/ton burned	2011 US NEI (EPA 2013b)	NA	
None specified	Open burning - MSW	10.5	$PM_{2.5}$	g/kg	SNAP Report (INECC 2013); Christian et al. 2010	NA	Mexico-specific factor
None specified	Open burning - MSW	0.646	BC	g/kg	SNAP Report (INECC 2013); Christian et al. 2010	NA	Mexico-specific factor
Detached Structure Fire	Structure fires	143.82	$PM_{2.5}$	kg/fire	Norwegian Emission Inventory (Aasestad 2007)	NA	
Undetached Structure Fire	Structure fires	61.62	$PM_{2.5}$	kg/fire	Norwegian Emission Inventory (Aasestad 2007)	NA	
Apartment Structure Fire	Structure fires	43.78	$PM_{2.5}$	kg/fire	Norwegian Emission Inventory (Aasestad 2007)	NA	
Industrial Structure Fire	Structure fires	27.23	$PM_{2.5}$	kg/fire	Norwegian Emission Inventory (Aasestad 2007)	NA	
Vehicle Fires	Vehicle fires	2.3	$PM_{2.5}$	kg/fire	Norwegian Emission Inventory (Aasestad 2007)	NA	

Notes: NA = not applicable

SECTION 3.5 OTHER (SF)

Tier 1 Speciation Factors (SF)

Source / Fuel Type	EC (weight %)*	Reference(s)	SPECIATE Profile# (if applicable)	SPECIATE Uncertainty (if applicable)	Notes
Charbroiling	4.056324426	SPECIATE (EPA 2011b)	92116		
Vehicle Fires	2.83	SPECIATE (EPA 2011b)	3283	2.05	No available profile for Vehicle Fires. Profile is for Tire Burning. Alternatively, Inventory compilers can choose other surrogate profiles available in SPECIATE.
Structure Fires	5.579138067	SPECIATE (EPA 2011b)	91105	NA	No available profile for Structure Fires. Profile is for Residential Wood Combustion. Alternatively, Inventory compilers can choose other surrogate profiles available in SPECIATE.
Open Burning - MSW	1.52188727	SPECIATE (EPA 2011b)	92126	NA	No available profile for Open Burning of MSW. Profile is for Solid Waste Combustion. Alternatively, Inventory compilers can choose other surrogate profiles available in SPECIATE.
Human Cremation	2.42	SPECIATE (EPA 2011b)	3288	2.12	No available profile for Human Cremation. Profile is for Incinerator. Alternatively, Inventory compilers can choose other surrogate profiles available in SPECIATE.

*Notes: *Speciation factor is for percentage of $PM_{2.5}$ that is elemental carbon (EC). EC has been acknowledged as a proxy for BC until improved measurement methods and data become available.*