ACRP

REPORT 11

AIRPORT
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Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

AIRPORT COOPERATIVE RESEARCH PROGRAM

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Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

The ACRP was authorized in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), and the Air Transport Association (ATA) as vital links to the airport community; (2) the TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academies formally initiating the program.

The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for the ACRP are solicited periodically but may be submitted to the TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel, appointed by the TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

Primary emphasis is placed on disseminating ACRP results to the intended end-users of the research: airport operating agencies, service providers, and suppliers. The ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties, and industry associations may arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by airport-industry practitioners.

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FOREWORD

By Lawrence D. Goldstein
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ACRP Report 11: Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories provides a framework for identifying and quantifying specific components of airport contributions to greenhouse gas emissions (GHG). This guidebook can be used by airport operators and others to prepare an airport-specific inventory of greenhouse gas emissions. It identifies calculation methods that can be applied consistently, improving comparability among airports and enhancing understanding of relative contributions of greenhouse gases to local environments. The inventory methods presented focus on the six primary greenhouse gases: carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons. As part of the methodology, the guidebook provides instructions on how to calculate emissions from specific sources and how to create carbon dioxide (CO_2) equivalencies.

Concerns continue to increase with respect to the potential effects of human activities on the earth's climate; and scientific studies suggest that these activities, including aviation, contribute to increasing atmospheric concentrations of GHG emissions associated with global warming. While approaches for computing noise and local air quality at the airport level are generally well established, specific guidance or generally applied practice for computing airport-level GHG emission inventories has not previously been available. In general, under international treaties, GHGs are addressed at a national or state level. However, responding to growing local political and community concerns, cities and counties across the country are beginning to attempt to quantify the contribution of sources within their boundaries to local and regional GHG emissions. Previously, these efforts have occurred without a common approach or structure. Based on that need, it is evident that airport operators could benefit from a guidebook providing uniform methods of developing airport GHG emissions inventories.

Given the level of interest regarding aviation's contribution to GHG emissions and ultimately to climate change, it is important that airports have information necessary to address potential concerns. On a sub-regional level, many localities have begun to develop aviation-related GHG inventories using various methods and accounting approaches. This guidebook provides a concise set of step-by-step instructions on how to generate airport GHG inventories—what sources should be included, how to calculate emissions, and how to account for the ownership and control as well as geographic boundaries. The guidebook provides different options that allow users to define an effective inventory approach within the limits of available resources. Industry-wide adoption of the guidance materials could ultimately lead to consistent inventory methods by different airports to facilitate comparisons and sharing of knowledge.

Application of the inventory procedures provided within the guidebook could also help airports track GHG emissions over time, recognizing contributions from specific sources within defined activity boundaries. As a result, broad use of the proposed inventory procedures could help clarify ownership and control issues and assist in quantifying and comparing potential reductions in GHG emissions using alternative actions and programs within the airport environment.

Potential users of this guidebook are first and foremost airport operators and managers, and their consultants. City and state officials could also use the guidebook to help integrate airport GHG inventories into their larger regional inventories, clarifying the specific makeup and percentage of airport-generated contributions. The broader scientific community should also be interested in the process to enhance understanding of the sources of GHG, the emissions calculation methods and how to create CO_2 equivalencies. Ultimately, the information gathered should be useful for studying the impacts of airport-generated GHG emissions on climate change.

CONTENTS

CHAPTER 1

Introduction and Background

This *Guidebook* is intended to provide concise instructions primarily to airport operators on how to develop an airport-specific greenhouse gas (GHG) emissions inventory. Instructions are provided to guide the user in developing appropriate and consistent inventories. Rather than burden the body of the *Guidebook* with too much detail, much of the detailed background information supporting the suggestions in the *Guidebook* is provided in the appendices that serve as a companion to the *Guidebook*. Every attempt has been made to keep the *Guidebook* simple to use and, thus, the *Guidebook* relies on the appendices for greater elaboration and support for the methods. Many airport operators prepare an air quality protocol before embarking on the development of an inventory (protocols refer to documents that identify data sources and methodologies to be deployed in an analysis.). This *Guidebook* is not intended to replace such protocols, but rather serve as a reference point for various methods.

With clarity and conciseness in mind, the *Guidebook* is organized to provide first a brief introduction and limited background information in this chapter (Chapter 1). The chapter reviews issues associated with airport GHG inventories which the user should consider before embarking on preparing an inventory. Then Chapter 2 provides directions for developing inventories, covering the protocols necessary for properly setting up an inventory. This is followed by instructions in Chapter 3 on how to calculate emissions from each source and how to create carbon dioxide (CO_2) equivalencies.

> Chapter 2 represents the heart of the inventory development process as it provides key considerations for the inventory makeup.

Chapter 2 represents the heart of this *Guidebook* since it ties together the background information in Chapter 1 and the calculation methods in Chapter 3. The overall procedure for developing an inventory is shown in Figure 1-1.

First-time users of this *Guidebook* should follow each of the steps shown in Figure 1-1 to become accustomed to the theories and materials in each chapter. After that, Step 2 (Chapter 2) could essentially be the starting point.

> First-time users of this *Guidebook* should follow each of the steps shown in Figure 1-1 to become accustomed to the theories and materials in each chapter.

1.1 Purpose of the *Guidebook*

Currently, the United States has no national or state legislative mandates for an airport operator to prepare GHG emissions inventories. Generally, the few inventories that have been generated by or for airports have been done voluntarily, even though they may be based on requests from municipalities. Such voluntary actions have been conducted in response to state and local climate action initiatives or, in the case of two inventories (for airport improvements at Sacramento International Airport and San Diego International Airport), were prepared in response to the California Environmental Quality Act (CEQA) analysis of proposed airport improvements. With no national legislative mandates, there is also no clear guidance on developing airport-specific inventories. As is shown in Appendix F of this report, airport GHG inventories differ in their approaches.

To fill this need, TRB initiated Project 02-06 under the Airport Cooperative Research Program (ACRP) to develop this *Guidebook* for airports. **The purpose of the *Guidebook* is to provide consistent guidance on developing airport GHG emissions inventories for those airports that wish to prepare such inventories.** The *Guidebook* includes methodical instructions and diagrams to clearly specify the procedures

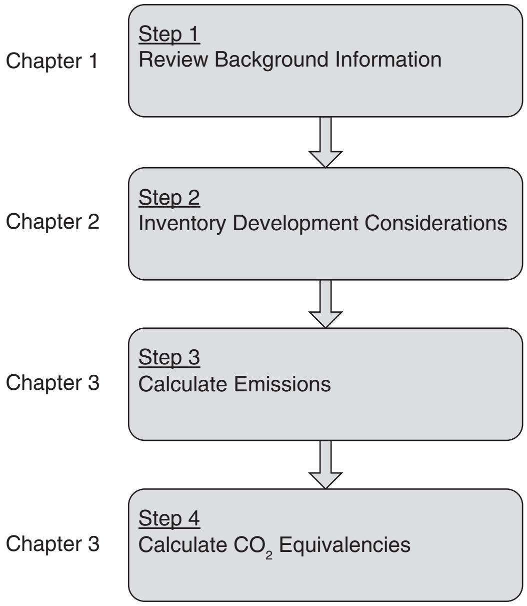

Figure 1-1. Overall procedure for developing an airport GHG emissions inventory.

to develop such inventories and explanations for the use of certain methods and metrics. In addition, the *Guidebook* is intended to provide background reasons for the development of these inventories, including the potential benefits thereof.

Both the scientific understanding and policies to address climate change are quickly evolving. Thus, certain parts of this *Guidebook* may need to be updated in the future to reflect changes in the understanding of the impacts of emissions on climate or as improved methods to calculate those emissions become available. Further, as future regulations and protocols are enacted, the *Guidebook* will need to be updated to account for these changes. Thus, the *Guidebook* represents a living document that is expected to be updated periodically.

1.2 Regulatory Considerations

On an international level, the driving force behind the control of GHG emissions has been the Kyoto Protocol (UN 1998) and local action. The protocol is a supplementary agreement to the United Nations Framework Convention on Climate Change (UNFCCC). Negotiated in Japan in 1997, the protocol came into full force on February 16, 2005, 90 days after the ratification of at least 55 countries that represented at least 55% of 1990 global CO_2 emission levels. As of February 4, 2008, 176 parties (175 countries and the European Economic Community [EEC]) had ratified the protocol. Countries that ratify the Kyoto Protocol commit to reduce their emissions of CO_2 and five other greenhouse gases, or engage in emissions trading if they maintain or increase emissions of these gases.

> The Kyoto Protocol is one of the underlying drivers for the development of airport GHG emissions inventories.

While the Kyoto target included domestic air travel-related emissions, emissions from international aviation were specifically excluded from the targets agreed upon under the Kyoto Protocol. Instead, countries were encouraged to control international aviation-related emissions through the activities of the International Civil Aviation Organization (ICAO). ICAO's Committee on Aviation Environmental Protection (CAEP) continues to consider the potential for using market-based mechanisms and has formed the Group on International Aviation and Climate Change (GIACC) to develop an aggressive program on international aviation and climate change.

The United States has not ratified the Kyoto Protocol and has yet to develop federal legislation to regulate GHG emissions. In lieu of federal legislative mandates, various U.S. corporations, nonprofits, and local governments have engaged in largely voluntary measures to quantify and reduce GHG emissions. This includes U.S. efforts such as the Mayors Climate Protection Agreement to promote the goals of the Kyoto Protocol, and the establishment of regional and national registries, such as The Climate Registry (TCR), to provide a formalized voluntary mechanism for developing, submitting, and tracking of corporate-based GHG emissions.

> In lieu of a national program to quantify and control emissions, regional and local initiatives have been developed.

In addition to these voluntary actions, some state and local legislative measures have been enacted requiring inventories and establishing emission reduction goals. The most significant of these legislative mandates is the California Global Warming Solutions Act, which is also known as Assembly Bill 32 (AB32). Passed in 2006, it charges the California Air Resources Board (CARB) with developing a comprehensive GHG emissions reduction plan for California through 2020. It is the first law in the United States to cap emission levels from major industries, as well as to require certain facilities to report their emissions, which, in this case, are reported to the California Climate Action Registry (CCAR).

To reinforce their climate action plans, several states have a state-based law similar to the National Environmental Policy Act (NEPA)—sometimes called mini-NEPAs—that now requires the preparation of GHG inventories. The

Massachusetts Environmental Policy Act (MEPA) requires preparation of a CO_2 emissions inventory, and in King County Washington, under Washington's State Environmental Policy Act (SEPA), county-based projects are required to prepare a GHG inventory.

There have been emerging discussions about federal GHG regulation following the recent U.S. Supreme Court case of *Massachusetts v. USEPA*. On April 2, 2007, the Supreme Court ruled on a 5-to-4 vote that USEPA has the authority to regulate GHG emissions and that USEPA must reevaluate its stance in not choosing to do so thus far. Other efforts include the 2008 lawsuit by California to regulate GHG emissions from mobile sources and California's petition of USEPA to regulate industrial GHG emissions. As such, the USEPA has been under increasing pressure to regulate GHG emissions under the Clean Air Act (CAA).

This *Guideline* has been prepared to aid airports that wish to voluntarily prepare airport-specific inventories, as well as those that may be required by existing and future mandates.

1.3 Overview of Greenhouse Gas Emissions

This *Guidebook* focuses on the development of inventories for the following GHGs:

1. Carbon dioxide (CO_2),
2. Methane (CH_4),
3. Nitrous oxide (N_2O),
4. Sulfur hexafluoride (SF_6),
5. Hydrofluorocarbons (HFC), and
6. Perfluorocarbons (PFC).

> Chapter 2 discusses different levels of evaluation based on the pollutants considered. This *Guidebook* recommends that airport GHG inventories consider the six Kyoto pollutants (Level 2). See Section 2.3.

This list mirrors the gases regulated under the Kyoto Protocol. These gases are typically covered in most GHG emissions reporting protocols including the guidelines from the Intergovernmental Panel on Climate Change (IPCC) and the recent protocol from TCR (IPCC 1999 and TCR 2008[a]). For U.S. economic sectors as a whole, these gases generally represent the most notable GHGs based on a combination of the quantity of pollutant emitted and potential for exerting climate change effects. For aviation, emissions of the fluorinated compounds (including HFC and PFC) are less significant because these compounds are generally emitted from industrial activities. They can be emitted from airport activities associated with the use of refrigeration and fire extinguishers, but these emissions are not well documented. Of the three remaining gases, emissions of CO_2 at an airport tend to be better understood than N_2O and CH_4.

In addition to the direct emissions, consideration can often be given to the other following pollutants that have the potential to exert climate change effects: water vapor (H_2O), particulate matter (PM), sulfur oxides (SO_x), oxides of nitrogen (NO_x), carbon monoxide (CO), and nonmethane volatile organic compounds (NMVOC). These pollutants can produce some direct effects, but their main contributions are as precursors for indirect effects.

The direct effects that H_2O exert tend to be dominated by the normal, natural hydrologic cycle (rainfall, evaporation, etc.). However, water vapor still may have an important effect, especially for direct emissions into the stratosphere as occur for some aircraft flights. Similarly, the effects produced by PM species (i.e., black carbon or soot and sulfate aerosols) can be important. SO_x adds to this effect since it can react in the atmosphere and form sulfate aerosols. Both H_2O and PM also have indirect effects through contrail formation. Ozone (O_3) also has a climate change effect but is not directly emitted. Rather, O_3 is produced in the troposphere through reactions involving NO_x or CO and NMVOCs. In the stratosphere, it is produced through a reaction involving oxygen molecules (O_2) and ultraviolet (UV) radiation. Since O_3 is not directly emitted, it cannot be included in an airport emissions inventory. However, its precursors, NO_x, CO, and NMVOC can be included. NO_x can also produce nitrate aerosols, thus further complicating the assessment of indirect effects.

Although the indirect effects are generally considered important, they also have the largest uncertainties associated with their climate impacts. Inclusion of these precursor emissions within a GHG inventory arguably helps to comprehensively capture all of the emissions related to climate change, consistent with the general guidelines specified by the IPCC in promoting the need to quantify even indirect emissions as part of the overall GHG inventory (IPCC 2006). However, since there are technical issues for these precursors, such as no well-established CO_2 equivalencies for these precursors, these emissions cannot be directly compared to each other at this time using simple multipliers. More complex climate models are required for this purpose.

1.4 Overview of Reasons for Preparing Greenhouse Gas Emissions Inventories

Each year, USEPA prepares a GHG inventory for the United States (USEPA[b] 2008). Even though the inventory is developed using a "bottom-up" approach (i.e., it reflects the assessment of individual sectors), the sectoral data are large-scale and not specific to local (e.g., airport) sources. To aid with the national inventory, USEPA has developed GHG guidance to the states for the preparation of inventories based on a "top-down" approach and commented that such inventories ". . . may not be appropriate for use at a scale other than the state level . . ." (USEPA[h] 2007) Simultaneously, local jurisdictions (counties, cities, and individual airport operators) are beginning to prepare GHG inventories, and without a standard protocol for use at these smaller scales, these inventories cannot be compared with one another.

When beginning to develop a GHG inventory, consideration must be given to the purpose for preparing the inventory. The purpose will likely dictate the sources to be evaluated and data that are available. Although there are numerous reasons why an airport operator might prepare an inventory, generally, these reasons can be grouped into the following four categories:

1. Climate change initiatives—GHG reduction goals (climate action plan),
2. Environmental management and sustainability programs (sustainability project plan),
3. Disclosure of project/action effects (regulatory-based project plan), and
4. Future regulations.

The few GHG airport inventories that have been developed to date appear to fall under these categories, which are presented in Appendix A. The general relationship among these different inventory purposes is shown by source coverage in Figure 1-2. It is important to note that these categories are intended to distinguish among possible types of inventories and the sources they might consider. Individual inventories prepared subject to these local programs may vary, and could overlap substantially.

As shown in Figure 1-2, an inventory developed for a climate action plan or climate change initiative comprehensively includes all sources while other inventories may be subsets of these same sources. The following sections provide a brief overview of these inventory reasons and their needs.

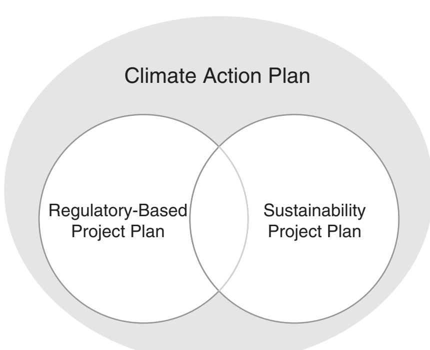

Figure 1-2. Relationship showing source coverage by different inventory purposes.

1.4.1 Climate Change Initiatives—Greenhouse Gas Reduction Goals

Most often, inventories developed as part of climate change initiatives are used to identify sources of emissions, recognize their contribution to regional, state, local, or national inventories, and then form the basis for examining ways to reduce emissions. Included in this category are inventories prepared for purposes of climate action registries, such as TCR, the California Climate Action Registry (CCAR), and the Eastern Climate Registry (ECR). The following general characteristics are typical of inventories performed in response to climate action initiatives:

- Currently voluntary—In future years it is expected that the USEPA will establish a required emissions reporting process that would fall into this category. Several city, county, regional, and state action plans are encouraging submission of the inventories to a climate action registry.
- Typically the most inclusive of sources and their emissions of all of the inventories—Generally, inventories are segregated by ownership and control of the source (see Section 2.2 regarding ownership and control inventory boundaries).
- Typically begin with an inventory for current-year emissions—for those whose plan includes a reduction goal, they often identify a backcast base-year's emissions (prior year such as 1990, 2000, or 2005) and emissions in a forecast year (the year associated with the goal). It should be noted that care must be taken when backcasting and/or forecasting since the data (e.g., source activities, emission factors, etc.) to support these processes may not be very accurate.

Table 1-1 provides a framework for the structure of a climate action plan inventory to enable a comparison to other inventories.

It is important to note that for **airport operators who are submitting their inventory to a climate action registry, registries have specific reporting requirements.** As noted in Appendix E, the registries typically ask for emissions sources to be reported as direct (Scope 1), indirect (Scope 2), and optional (Scope 3). The above format would translate emissions into the registry categories in the following way:

- Scope 1/direct emissions include airport operator emissions associated with (1.) fuel necessary to power airport-owned on- and off-road vehicles and (2.) direct energy necessary to power airport facilities (i.e., natural gas, fuel oil).
- Scope 2/indirect emissions include purchased electricity.

Table 1-1. Sample climate action plan emissions inventory.

User/Source Category	Scope	CO_2 (metric tons/year)	Percent of Source in User Category	Percent of Total
Airport Operator Owned/Controlled				
Stationary/facilities – purchased facility power	2	30,000	51.7%	1.2%
Stationary/facilities – natural gas	1	10,000	17.2%	0.4%
Ground support equipment/airport fleet	1	3,000	5.2%	0.1%
Ground access vehicles (public vehicles on airport roads)*	3	15,000	25.9%	0.6%
Total Airport Operator Owned/Controlled		**58,000**	**100%**	**2.3%**
Airline, Aircraft Operator, or Tenant Owned/Controlled				
Aircraft	3			
Ground	3	140,000	6.2%	5.5%
Ground to 3,000 ft	3	207,000	9.2%	8.1%
Above 3,000 ft (residual/cruise/APU)	3	1,890,000	84.1%	74.1%
Aircraft Total	**3**	**2,237,000**	**99.5%**	**87.7%**
Ground support equipment	3	6,540	0.3%	0.3%
Ground access vehicles	3	1,270	0.1%	0.1%
Stationary sources/facility power	3	3,000	0.1%	0.1%
Total Airline, Aircraft Operator, or Tenant Owned/Controlled		**2,247,810**	**100%**	**88.2%**
Public Owned/Controlled				
Public vehicles	3	175,000	71.72%	6.9%
Taxis	3	34,000	13.93%	1.3%
Vans/shuttles	3	23,000	9.43%	0.9%
Light rail	3	Unknown	na	na
Cargo trucks	3	12,000	4.92%	0.5%
Total Public Owned/Controlled		**244,000**	**100%**	**9.6%**
Total		**2,549,810**		**100%**
Waste recycling	3	(852)		
Grand Total Emissions		**2,548,958**		

*For purposes of this inventory reporting format, on-airport roadway vehicular travel-related emissions (both the emissions of/from the airport operator vehicles as well as public travel) are identified as airport operator controlled, as this infrastructure is owned and could be controlled by the airport operator. Thus, for the expanded reporting format, these sources are listed in the airport-controlled category, but are noted as Scope 3 to maintain consistency with TCR reporting formats.

- Scope 3/indirect and optional emissions include (1.) tenant emissions, (2.) public ground travel on- and off-airport, and (3.) airport employee commute emissions.

Table 1-2 provides a sample inventory format of an inventory created for climate registry purposes that might be prepared for an airport using the Scope 1, 2, and 3 categories.

Climate action registries also seek the reporting of the following three primary GHGs: carbon dioxide (CO_2), nitrous oxides (N_2O), and methane (CH_4). There are differing opinions as to how to create CO_2 equivalencies (CO_{2e} is a metric used to compare the emissions of different GHGs based upon their global warming potential, which is used to convert GHGs to CO_2 equivalents.) It is recommended that global warming potentials (GWPs) from the latest IPCC assessment report (at this time, the *Fourth Assessment Report*) be used to calculate CO_{2e} (IPCC 2007). However, to maintain consistency with previous inventories or to maintain consistency with other inventory development protocols such as those from the CCAR, TCR, and the International Council for Local Environmental Initiatives (ICLEI), whether or not mandated by government or other organizations, GWPs from previous IPCC assessment reports (e.g., Second Assessment Report and Third Assessment Report) can be used. **This *Guidebook* recommends that the documentation accompanying the inventory note which assessment is used and present the original mass emissions by pollutant prior to the application of the GWP, as well as the resultant CO_{2e} values.**

This *Guidebook* recommends use of GWPs from the latest IPCC assessment report (at this time, the *Fourth Assessment Report*), noting the source of the GWPs, presenting the original mass emissions by pollutant prior to the application of the GWPs, as well as the results after application.

Table 1-2. Sample climate action plan emissions inventory—registry reporting format.

Emission Source	2006 Emissions (CO_{2e} in metric tons)
Direct/Scope 1	
Stationary/facilities—natural gas	10,000
Ground support equipment/airport fleet	3,000
Subtotal, Direct/Scope 1	**13,000**
Indirect/Scope 2	
Purchased electricity (airport owned/controlled)	30,000
Subtotal, Indirect/Scope 2	**30,000**
Optional/Scope 3	
Aircraft/APU	2,237,000
Tenant ground support equipment	6,540
Tenant ground access vehicles	1,270
Tenant stationary sources/facility power	3,000
Public vehicles (off-airport travel)	175,000
Taxis (off-airport travel)	34,000
Vans/shuttles (off-airport travel)	23,000
Light rail (off-airport travel)	unknown
Cargo trucks (off-airport travel)	12,000
Ground access vehicles (public vehicles on airport roads)	15,000
Subtotal, Optional/Scope 3	**2,506,810**
Total	**2,549,810**
Waste Recycling	(852)
Grand Total	**2,548,958**

1.4.2 Environmental Management and Sustainability Programs

Airport operators that have adopted sustainability practices may wish to quantify GHG emission reduction benefits associated with their sustainability practices. For these inventories, the *Guidebook* strives to suggest the greatest flexibility in presenting data. A sustainability plan typically identifies individual actions that an airport operator is taking and/or plans to take to reduce its environmental footprint. In this case, the focus may be on the airport as a whole or it may be on individual projects. For the case where the desire is to inventory the airport in its entirety, the previously defined approach for climate change initiatives may be used. In the case of individual sustainability projects, only the sources that are affected by the action might be inventoried. For example, if an airport installed preconditioned air and 400-hz power at the gates, the emission reduction benefits associated with aircraft using these systems might be contrasted with the emissions associated with aircraft continuing to use their auxiliary power units (APUs). Table 1-3 provides an example of the results of a sustainability project.

> Projects in a sustainability program aim to reduce the environmental footprint of the airport, and the resulting inventory may be a subset of that which would be prepared for a Climate Action Inventory.

It is anticipated that as planning progresses at airports and more sustainability plans are developed and implemented, airport operators are likely to include the quantification of GHGs as part of their plans from the tactical perspective (the emission changes associated with actions) and also in a strategic sense (how future plans and policies may affect climate action goals as well as the effects of climate change on airports).

In quantifying emissions associated with a sustainability plan, the airport operator would have flexibility in how GHGs are presented. For those plans that include more than CO_2, this *Guidebook* recommends developing CO_2 equivalencies using the same approach as is used for climate action plans.

1.4.3 Disclosure of Project/Action Effects

> Inventories developed under the project disclosure umbrella are mainly related to the NEPA (or state NEPA-like) process where an agency approval is involved, and—as a result—the inventory reflects only the changes in emissions due to the project and is a subset of the Climate Action Inventory. Only a subset of the sources (i.e., those affected by the project) are included in a project disclosure inventory.

Inventories may also be required to support actions involving state and, possibly, federal approvals of airport improvements. In the United States, this project/action disclosure could occur in the form of documents prepared under NEPA

Table 1-3. Example emissions quantification of a sustainability project.

Source	Annual Metric Tons of CO_2		
	No Action	With Sustainability Action	Effect of the Sustainability Action
APU	15,000	7,000	(8,000)
Facility power emissions	30,000	35,000	5,000
Total	**45,000**	**42,000**	**(3,000) (Emissions Reduced)**

or based on state requirements that are similar to NEPA (called state NEPA-like laws or mini-NEPAs). As noted in Appendix A, there is currently no requirement to consider GHGs in NEPA, but several state NEPA-like processes are now requiring such evaluations.

A NEPA or state NEPA-like evaluation focuses on the project-related effects of an agency action. As has been the case of air quality assessments for criteria pollutants (CO, N_2O, etc.), consideration is limited to the air quality emission inventories associated with the sources that are affected by the action. For example, if the proposed action is a development project that would extend a runway, only the sources that would be affected by that action (the runway extension) would be inventoried. The primary analysis function of NEPA is to identify and disclose the effect of the project relative to what would happen if the project was not undertaken. In the runway extension example, the analysis might only focus on aircraft taxi movements and construction emissions. To support that analysis, documentation would be necessary to show how the project would affect existing and future aircraft operations levels (e.g., additional flights that may be induced). If additional flights would be induced, then additional support activity might occur, requiring the consideration of other sources.

Using this example, assuming that the runway extension would not induce activity relative to the no-action alternative, the project could affect energy use relative to sources owned and controlled by the airport operator, as well as its airport tenants. Each source and each owner should be considered. For instance, a slight increase in a subset of facilities/stationary sources could occur due to additional runway lights, and the construction process would consume energy and generate GHGs. Once the project is complete, it is likely that the runway extension would alter taxi-related aircraft emissions (reflected in the aircraft-ground category). Summing together the sources of emissions under various ownership and control would result in a net emission change and be reflected as a reduction, as shown in Table 1-4.

As noted in Appendix A, no specific guidance has been developed for NEPA-related GHGs. The inventories prepared to date for airports in California, subject to California's NEPA-like law (CEQA), have reflected three primary gases (CO_2, N_2O, and CH_4). In Massachusetts, the state NEPA-like law only requires the consideration of CO_2, except in specific circumstances where other pollutants are known to be substantial. For project disclosure airport inventories, the three primary GHG pollutants should be presented, and the GWPs as discussed for climate change initiatives/action plans should be used.

Table 1-4. Example inventory—disclosure of project effects.

	Annual CO_2 Emissions (metric tons)		
User/Source Category	**No Action**	**Runway Extension Preferred Alternative**	**Net Post Project-Related Emissions**
Airport Operator Owned/Controlled Sources Affected			
Facilities/stationary sources (airfield lighting for the runway)	40	41	1
Ground support equipment (vehicles needed to support construction of the runway)	0	220	220
Total Airport Operator Owned/Controlled Affected	40	261	221
Airline, Aircraft Operator, or Tenant Owned/Controlled			
Aircraft			
Ground	140,000	138,700	-1,300
Ground to 3,000 ft	NA	NA	0
Above 3,000 ft	NA	NA	0
Aircraft Total	**140,000**	**138,700**	**-1,300**
APU	NA	NA	0
Ground support equipment	NA	NA	0
Ground access vehicles	NA	NA	0
Stationary sources	NA	NA	0
Total Airline, Aircraft Operator, or Tenant Owned/Controlled	**140,000**	**138,700**	**-1,300**
Public Owned/Controlled			
Public vehicles	NA	NA	0
Shuttles and private vehicles	NA	NA	0
Total Public Owned/Controlled	**NA**	**NA**	**0**
Total Metric Tons Project Affected Sources	140,040	138,961	-1,079

Notes:
For some sources, only the sources of emissions that would be affected by the project are quantified.
NA = Project would not affect emissions from this source and thus emissions are not assessed.

1.4.4 Future Regulations

Appendix A notes a number of initiatives that are underway that could lead to regulation and/or the required reporting of GHGs. At this time, it is not possible to estimate the specific format and requirements of such regulation. It is possible that a unique reporting protocol might be necessary. However, it is also likely that one of the earlier formats would also serve those needs.

Perhaps the single most important regulation that could be enacted would come from USEPA. A national mandate to track and reduce GHG emissions could have far-reaching implications on all aspects of developing GHG inventories for airports. The recent lawsuits against USEPA by Massachusetts and California provide some indications of the pressures placed on USEPA to develop legislation.

> An inventory developed in anticipation of future regulations may be as comprehensive as one developed for a climate action plan or a subset, and it would help the airport be better prepared for the regulations.

An inventory developed in anticipation of future regulations would allow an airport operator to be better prepared to handle any actual regulations that are enacted. The inventory would allow better tracking of emissions over time, and better satisfaction of those regulations. Based on the specifics of each regulation and the needs of the airport operator, the inventories could be similar to those developed as part of a climate action plan or a subset corresponding to specific projects.

In addition to, or as part of, the GHG emissions tracking work, an airport could potentially position itself to generate revenues through carbon trading. As the carbon trading market becomes more established than it is currently, airports may be able to take advantage of the opportunities.

1.5 Airport Source Contributions to Greenhouse Gas Emissions

Aviation is just one mode of transportation that, in turn, is just one of many GHG emitting sectors. As shown in Figure 1-3, in the United States, the transportation sector is the second largest emitter of GHGs; the first is electricity generation (USEPA[a] 2007).

Within the transportation sector, ground vehicles (e.g., automobiles and trucks) comprise most of the GHG emissions, as indicated in Figure 1-4.

> Aviation accounts for 11% of transportation GHG emissions and is the only source that emits directly into the higher levels of the atmosphere.

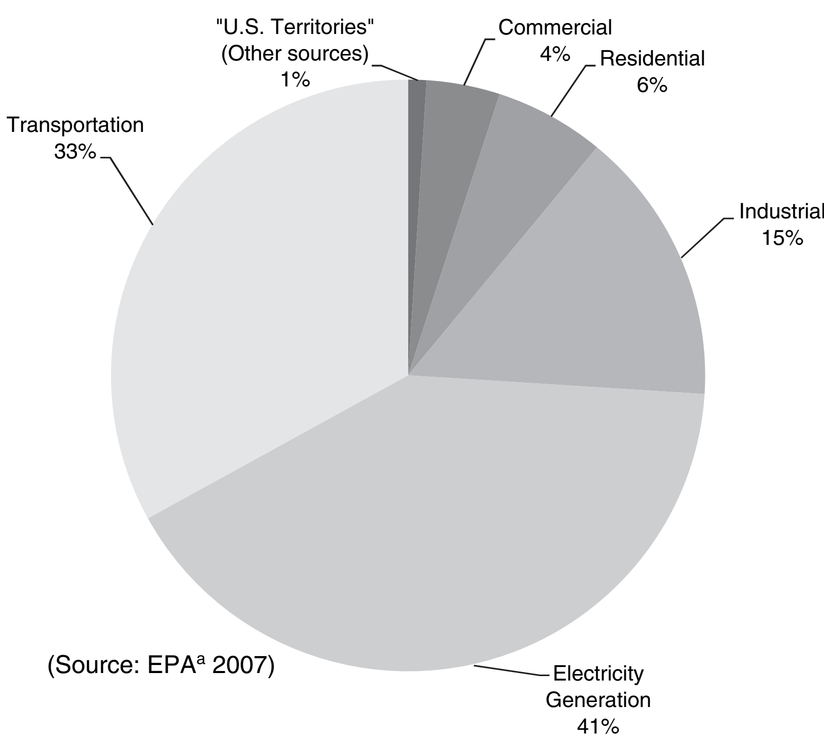

Figure 1-3. U.S. GHG emissions by sector.

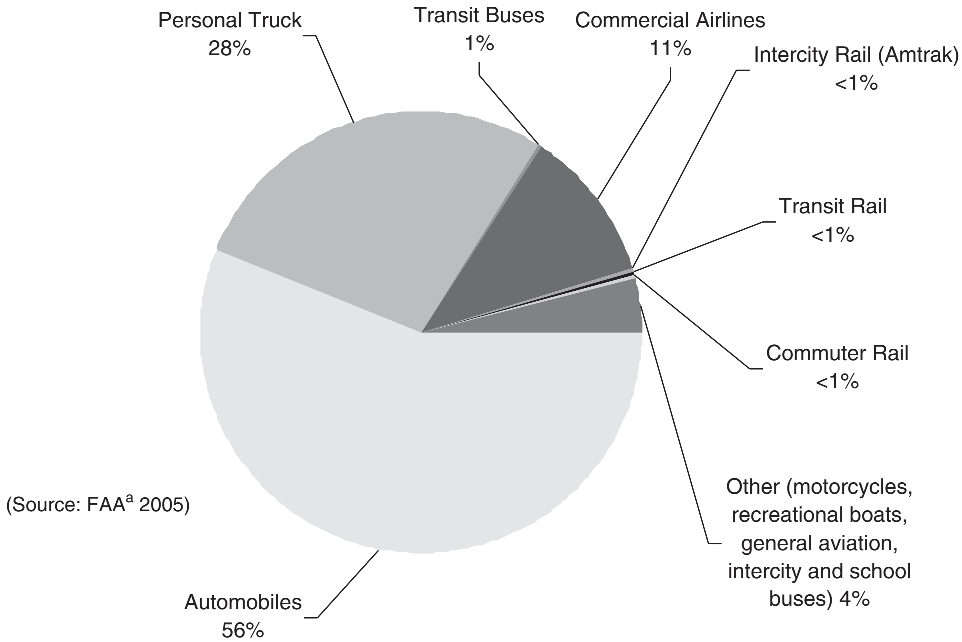

Figure 1-4. U.S. transportation sector GHG emissions by mode.

Commercial aviation accounts for about 11% of GHG emissions from transportation sources, or about 3% of total emissions, and represents the third largest source of transportation GHG emissions (behind automobiles and personal trucks).

For aircraft emissions, the FAA indicates on a mass basis, emissions are "composed of about 70% CO_2, a little less than 30% H_2O, and less than 1% each of NO_x, CO, SO_x, VOC, PM, and other trace components including HAPs." Most of the emissions are emitted during "cruise" (above 3,000 ft [914.4 m]) including about 90% of the CO_2 emitted and 70% of the CO emitted (FAA[a] 2005, p. 1). Globally, between 18% to 44% of aircraft emissions are emitted in the stratosphere (Gettelman & Baughcum 1999).

1.6 Introduction to the Use of Equivalency Methods

A significant dilemma in the evaluation of GHGs, particularly those associated with aviation, is how to account for the effects of the wide range of individual GHGs that are emitted. Different chemical species emitted from human and natural sources have different impacts on climate. For example, one ton of CO_2 has a different effect on the climate than one ton of methane (CH_4), and these effects occur over different periods of time. Further, some of these species have different impacts depending on where they are emitted (latitude, longitude, and altitude), when they are emitted (both time of day and time of year), what other chemicals are present in the atmosphere (from other natural and man-made sources), and on both local and long-term weather trends.

Scientists use complex computer simulations to approximate the physics and chemistry of these different effects. These simulations may take days or months to run. The most comprehensive reviews of the results of these complex simulations, of the measured data regarding climate change, and of the effects of different natural and human sources, are those provided by the IPCC, an international group of scientists brought together under the umbrella of the UN (see, for example, the most recent climate assessments in IPCC 2007).

Using results from these complex computer simulations, scientists have developed simplified methods for estimating the relative impacts on climate change of different chemical species and sources (e.g., different modes of transportation, home heating, cement making, etc.). These methods for relating impacts are called *equivalency methods.* They all require additional approximations and assumptions (beyond those in the more complex climate models), and may implicitly or explicitly incorporate economic and moral or value-based assumptions (e.g., the relative importance of effects that occur 20 years from now versus effects that occur 100 years from now). It is important to recognize that such scientific approximations, and economic and value-based assumptions, are required for analyzing trade-offs and relative contributions to climate impact. There is no way to avoid these issues. Further, the implicit assumptions are sometimes not obvious for various equivalency methods. Therefore, it is critical that the underlying assumptions be clearly understood and documented when using such equivalency methods.

Because of the high degree of uncertainty in estimating the impacts of some chemical species (especially those with complex indirect effects), and the different moral and value-based assumptions that may be implicit in these methods, there is a healthy scientific debate regarding the "best" equivalency methods. Scientists, economists, and others who study climate recognize that the usefulness of different equivalency methods often depends on the question one asks and the way in which the equivalent emissions are judged.

> An important point in developing an emissions inventory is to collect sufficient data to enable different equivalency methods and more advanced analyses to be conducted because there is currently no perfect equivalency metric.

Within Appendix D, several equivalency methods (radiative forcing index [RFI], GWP, global temperature potential [GTP], and others) are reviewed. The appendix describes the underlying assumptions, strengths and weaknesses, and estimation methods. Although there are differing opinions about the relative usefulness of these different equivalency methods, it is recommended that the latest data from the IPCC *Fourth Assessment Report* (IPCC 2007) be used. However, as was noted in prior sections, many of the publicly available protocols advocate the use of the IPCC *Second Assessment Report* or *Third Assessment Report*. Although the *Fourth Assessment Report* represents the state-of-the-art understanding, the international approach to local-level inventories has evolved using older data through the protocols developed by TCR, CCAR, and ICLEI. Therefore, for consistency with previous inventories, GWPs from the second and third reports could be used if the airport inventory is to be integrated into an inventory that uses these earlier assessments. The specific GWPs used should be specified as part of the overall inventory documentation.

Consistent with the IPCC *Fourth Assessment Report,* this *Guideline* recommends the GWP as the primary means of establishing equivalency for long-lived GHGs; however, in Appendix D, the *Guideline* notes the many shortcomings associated with the use of GWPs. Further, consistent with the IPCC, the GWP is not recommended for all climate change pollutants and impacts. For some short-lived climate change pollutants and impacts, the science is either too premature or too physically and chemically complex to support their inclusion in these simplified equivalency methods. This is especially true for some cruise-level effects of airplane emissions (indirect effects of NO_x emissions, contrails, and aviation-induced cirrus cloudiness) for which the scientific understanding is not sufficiently mature to enable equivalency metrics to be used with confidence. For these situations, more complex computer simulations, exercised over a range of scientific and economic scenarios are required to estimate the relative effects of the emissions. A simple multiplier is generally not appropriate.

As already noted, depending on the policy question, different equivalency methods may be more or less appropriate. Further, the scientific understanding of some effects is still relatively immature, and both the equivalency methods and the specific equivalency values are likely to change over time. Nonetheless, equivalency methods are useful for taking action based upon the compiled inventories or, in some cases, for summing up the overall magnitude of several different species (e.g., in a CO_{2e} unit).

For purposes of creating a CO_{2e}, it is recommended that the latest IPCC *Fourth Assessment Report* (IPCC 2007) be used and noted in the documentation of the emissions inventories. Separately accounting for each pollutant and reporting their emissions alongside the GWP values (while noting the source of the GWPs) would allow adjustments in the future as refined GWP values become available (e.g., from future IPCC assessment reports). Section 3.8 presents the specific process for calculating CO_{2e}. Although the GWPs from the *Fourth Assessment Report* are recommended, GWPs from prior reports can be used for consistency with previous inventories and other existing protocols. In general, it is recommended that a GHG inventory should always include both the original mass quantities of each pollutant as well as the CO_{2e} masses. This allows comparisons of the different pollutants as well as for potential changes to the CO_{2e} values if improved GWPs become available.

1.7 Allocating Emissions Reductions

A dilemma that airport operators are likely to have in the future quantification of emissions is **how to allocate emission reductions that the airport operator has implemented or funded through various funding sources (rates and charges, grants, bonds, etc.) that result in emission reductions associated with a source that is owned and controlled by another party** (i.e., tenants or public ground travel to/from the airport). For purposes of this section, those actions are referred to as actions where the airport operator has "influence," but does not own the source or control the emissions (see Section 2.2 for ownership and control inventory boundaries).

There are numerous instances where one party may have influenced the emissions of another party's sources. These influences represent actions that have the potential to shift emissions from one party to another. For instance, many airports are implementing preconditioned air (PCA) and 400-hz power at the gates. This type of project is designed to reduce the use of APUs on aircraft, by enabling the aircraft power needs when parked at the gate to be met with ground power. Although some 400-hz/PCA projects are funded and implemented by the tenants, others are undertaken by the airport operator. Further, in many airport settings, the electrical demands of the terminal (including the gates) are procured by the airport operator. For those locations where the ground power system is funded by the airport operator, or where the airport operator pays for the electrical power, the accounting for emissions associated with this need has been transferred from the tenant (due to the reduced reliance on the APU) to the airport operator (where the energy need is then electrical based). Other examples where similar accounting needs may arise include the following:

- Airport infrastructure projects—These projects, such as new runways or runway extensions are owned by the airport operator, may be funded through federal grant monies or locally backed revenue bonds, but result in emission reduction changes associated with airport tenants.
- National or regional airspace improvement—Delays in certain regions of the country often result in ground holds at cities with air service to those regions. Control of the national airspace and the aircraft that use it rests with the federal government.
- Surface traffic improvements—Improvements such as extending regional light rail systems to the airport or airport-sponsored busing programs (such as the Los Angeles' Van Nuys FlyAway) are designed to increase the use of higher-occupancy vehicles accessing airports versus reliance on single occupancy vehicles. Such programs decrease emissions from publicly owned vehicles.

There may be merit to developing a separate methodology to allocate recognition or "credit" for emission reductions. Such a methodology is currently outside the scope of this *Guidebook*.

> A separate methodology may need to allocate recognition for emissions reductions that cross over between a party that owns and controls the emissions and parties that influence the emissions.

We note that in the reporting protocol established by the Global Reporting Initiative (GRI), there is the recognition of emissions owned and controlled by one party where a substantial influence is exerted by another party on the emissions of those sources. Although GRI has not developed an accounting protocol for such influences, their sustainability plans recognize the influence that various parties may have over another party's activities (GRI 2008).

CHAPTER 2

Inventory Development Considerations

This chapter provides all of the protocol considerations to develop an airport GHG emissions inventory. Each section in this chapter serves to provide guidance on specific aspects of an inventory (e.g., source categorizations, geographic boundaries, etc.). They essentially provide instructions on how to set-up an inventory. In contrast, Chapter 3 provides all of the calculation methods to complete the inventory. An overview of the procedure is shown in Figure 2-1 and is reflected in the ensuing sections.

The steps in Figure 2-1 are shown serially in an attempt to methodically explain the process. However, it is expected that these steps may be followed in parallel under many cases to allow more efficient development of an inventory. As inventories are being prepared due to local influences, each airport operator should determine the best use of this guidance material based on their project needs and the data available.

> Although this *Guidebook* provides instructions on developing a GHG inventory, each airport operator should determine the most efficient use of the information based on their own needs and data.

In large part, this chapter is based on the background information provided in Appendix E. As such, that appendix should be reviewed for any additional information or clarifications on the guidance provided herein.

2.1 Purpose of the Inventory

The first step in the inventory development procedure is to determine the purpose of the inventory. This will aid in defining the breadth of sources to be considered. It is the responsibility of the inventory developers to make sure they understand the purpose for generating inventories such that they will know which sources to include in the inventory. As discussed in Section 1.4, the following four categories are reasons for developing an airport GHG inventory:

1. Climate change initiatives—GHG reduction goals,
2. Environmental management and sustainability programs,
3. Disclosure of project/action effects, and
4. Future regulations.

For the first category (climate change initiatives—GHG reduction goals), all sources that generate GHGs and are used or operated at the airport, including those owned by the airport operator (e.g., infrastructure items), as well as those that are influenced by the airport (e.g., aircraft) should be included in the inventory. This allows a comprehensive accounting of all sources, which is typically desired in a climate action plan. The inventory can be used to identify major sources and track the emissions of these sources over time. As a result, all of the sources listed later in Chapter 3 would ideally be included in an inventory developed for this reason.

The next two categories (environmental management and sustainability programs and disclosure of project/action effects) represent subsets of the climate action initiatives in terms of source coverage. In these two categories, only the affected sources are included in the inventory since the purpose is to monitor changes in GHG emissions associated with a project or action. For example, in a state NEPA-like inventory, such as the previous example of a runway extension, only the sources affected by the extension are included in the inventory. These could include construction equipment to build the extension, aircraft ground movement, and energy for runway lighting. For a sustainability project involving fuel conservation, just the airport infrastructure energy use (possibly electricity use) could be assessed depending on the specifics of the project. Often, the goals of such projects are to show differences in emissions caused by the projects. That is, the goals are to determine the differences between action (build) and no-action (no-build) cases to show the adverse or bene-

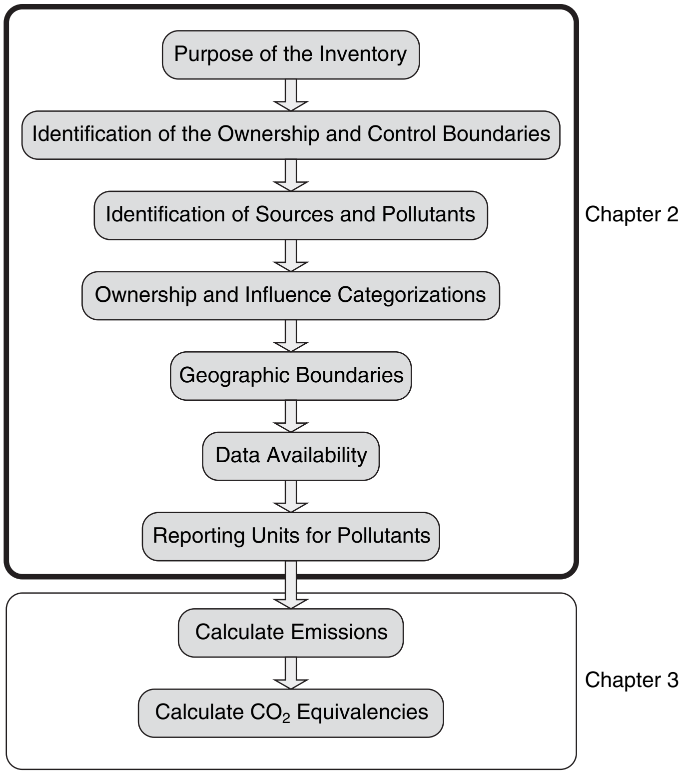

Figure 2-1. Overall inventory development procedure.

ficial environmental cost of the action. Therefore, only the affected sources in Chapter 3 would be considered when developing inventories under these two categories. It is up to the inventory developer to fully identify the affected sources for each project.

A GHG inventory developed in anticipation of future regulation could require coverage of all sources (as with a climate action initiative) or a subset (as with the environmental management and sustainability programs and disclosure of project/action effects). This depends on the future regulation(s) for which an inventory developer is preparing. Although the focus is mainly on regulations requiring mandatory reporting of GHG inventories, this *Guidebook* can also be helpful for other types of regulations that may not explicitly state the need for GHG inventories. The methods for quantifying GHG emissions that are presented in this *Guidebook* should be applicable to all of these regulations.

2.2 Identification of the Ownership and Control Boundaries

In preparing a GHG inventory, consideration must be given to boundaries of the inventory and the sources reflected in that inventory. Most often, the boundaries begin with issues of ownership and control.

2.2.1 Traditional Criteria Pollutant Inventory Boundaries

Most airport inventories that exclusively address criteria pollutants reflect emissions of sources within the airport fenceline (exceptions occur for inventories prepared under NEPA or state NEPA equivalents where a project affecting emissions outside the fenceline typically quantifies the emissions outside the fenceline), except for aircraft, which are limited to the operations in the landing and takeoff cycle (LTO, generally operations under 3,000 ft). Emissions are typically reported by pollutant and match the source categories listed in the FAA's Aviation Environmental Design Tool (AEDT)/Emissions and Dispersion Modeling System (EDMS) (FAA[a] 2007), as follows:

- Aircraft (in the landing and takeoff cycle) and APU,
- Ground support equipment (GSE),
- Stationary sources,
- Parking facilities and roadways (also called ground access vehicles or GAV)
- Training fires, and
- Construction activities.

In preparing traditional criteria pollutant inventories, little consideration is given to who owns the sources or controls these emissions.

2.2.2 Greenhouse Gas Inventory Boundaries

During the last decade, the consideration of GHG inventories has evolved to contain a step that requires a clear identification of the boundaries of the inventory. USEPA and World Resources Institute (WRI) along with World Business Council for Sustainable Development (WBCSD) guidance suggest that the following be considered when establishing the boundaries (USEPA[a] 2005 and WRI 2004):

> Whenever applicable, WRI protocols for source boundary and direct versus indirect emissions guidelines should be followed for consistency.

- Organizational structure—Is determined as reflected by control through ownership, legal agreements, joint ventures, etc. In the case of an airport, most airports are owned and operated by either: (1.) a city department, (2.) a county department, (3.) a state office, or (4.) an authority or port district. In preparing an inventory, the airport operator should consider how the inventory prepared for airport-related activities would be integrated into a broader organizational inventory (i.e., the airport division's inventory of a city-owned airport relative to other activities of a city).

- Operational boundary—Once an entity has determined its organizational boundaries in terms of the operations that it owns and controls, it then sets its operational boundaries. This involves identifying the emissions associated with its operations and categorizing them either as Scope 1 (direct), Scope 2 (indirect), or Scope 3 (indirect and optional) emissions.
  - Scope 1/direct emissions are from sources that are owned and controlled by the reporting entity (e.g., on-airport emissions from combustion in owned and controlled boilers, furnaces, vehicles, etc.). For an airport, the Scope 1 emissions would be those associated with fuel powering vehicles owned and operated by the airport entity, as well as stationary sources owned and operated by that entity. For instance, an airport owns snow removal equipment and ground vehicles that burn fuel to service the airport, as well as the airport heating system or generators that may burn heating oil.
  - Scope 2/indirect emissions are those from the generation of purchased electricity consumed by the entity. This would represent the electricity acquired to power airport facilities. Tenant-purchased electricity would not be Scope 2, but Scope 3.
  - Scope 3/indirect and optional emissions are a consequence of the activities of the entity, but occur at sources owned and controlled by another party. Scope 3 would be the largest quantity of emissions at an airport, because they would include aircraft-related emissions, emissions from all tenant-related activities (including aircraft operations and the associated ground support activities) as well as the public's ground travel to and from the airport.

Indirect and direct emissions as advocated by USEPA are similar to the Scope 1 and Scope 2 emissions noted by WRI, whereas WRI Scope 3 emissions are the emissions that USEPA considers optional. For the remainder of this document, the terms Scope 1, Scope 2, and Scope 3 are used to simplify the discussion.

ICLEI has prepared draft guidance to international local governments concerning the preparation of GHG inventories (ICLEI[b] 2008). Within the ICLEI guidance, in addition to organizational structure and operational boundary, there is a third element to be considered in inventories: geopolitical boundaries. The geopolitical boundaries ensure that the inventory reflects the accounting of emissions in a way that is "policy relevant," meaning that the inventory is structured to reflect sources that can be affected through policies of the local government. In this way, the ICLEI guidance differentiates between the following two types of inventories:

- Government operations analysis considers Scope 1, 2, and 3, where Scope 3 only includes emissions over which the government exerts significant control or influence. In this case, generally only the emissions from sources owned and controlled by the airport governmental entity would be reflected. Thus, aircraft sources would be omitted, unless the airport governmental entity owns and operates aircraft, as is sometimes the case of State Aviation Divisions.
- Community-scale analysis also considers Scope 1, 2, and 3 but seeks to reflect geopolitical boundaries. In the airport context, this inventory could reflect the inclusion of airport tenant activities that would include airline and aircraft operations. In the community context, ICLEI provides guidance for the inclusion of an airport's emissions if the airport is not physically located within the city boundaries, where many residents of the city use the airport.

The **preferred method for airports** recommended by this *Guidebook* is the preparation of inventories that **reflect the community-scale analysis** when preparing inventories for climate action plans. This is recommended to ensure consistency among airports, as the inventories for some airports are likely to be prepared by entities that participate in ICLEI or choose to register their emissions. Alternatively, if data are not available to enable the community-scale approach, the government operations analysis could be undertaken, with the inventory noting the deficiencies in available data. This *Guidebook* recommends that the traditional criteria pollutant format when applied to GHGs be recast using ownership and control reporting, where possible, for the NEPA-like evaluations and sustainability projects so as to enable GHG pollutants and criteria pollutants to be documented using a common format. Such a reformatting would not require additional analysis, and would enable a direct comparison between climate action plans and NEPA-like/sustainability project evaluations.

> If possible, an airport GHG inventory should follow ICLEI's community-scale analysis reflecting the emissions by both airport- and tenant-owned sources.

It should be noted that the adoption of the community-scale approach and the use of the Scope 1, 2, and 3 definitions reflect, in part, a desire to stay consistent with these protocols from ICLEI and WRI. Although the *Guidebook* has adopted these approaches, airport inventories could potentially be developed in other ways (e.g., focusing on just the airport-owned sources, no categorization of sources, etc.). The inventory developer should be cognizant of these other possibilities to properly address concerns that may be raised regarding the approaches recommended in this *Guidebook*.

2.3 Identification of Sources and Pollutants

As suggested previously, the sources to be included in an airport GHG inventory will depend on the purpose of the inventory. If the purpose is a climate action plan, then—typically—all sources under the ownership and control of the airport operator are identified, as well as those owned by tenants. This is in keeping with the community approach from ICLEI's boundary guidance. For NEPA-like project evaluations and sustainability projects, the airport operator typically has the flexibility to narrow the sources inventoried to those affected by the project.

The starting point for identifying the affected airport sources is to first list all six sources that have traditionally been cited for criteria gases and are consistent with the sources listed in the FAA's AEDT/EDMS (FAA[a] 2007): (1.) aircraft (in the LTO cycle) and APU, (2.) GSE, (3.) stationary sources, (4.) parking facilities and roadways (also represented by GAV), (5.) training fires, and (6.) construction activities.

Each of these sources should be considered relative to the party who owns/controls the source. For example, airport operators would be likely to focus on airport-owned GSE, stationary sources, fire training, and construction. Only if an airport operator owns and controls aircraft would aircraft and APU emissions be associated with the airport operator. Rather, aircraft emissions generally would be associated with tenants, along with APUs, GSE, tenant-based GAVs, etc.

Although this list is comprehensive overall, it is not specific to every source at an airport. For example, the stationary sources category covers a wide range of specific sources (e.g., boiler/heater, maintenance activities, engine tests, etc.) that could be listed individually depending on the needs of the airport operator or project. Further, for purposes of a GHG inventory, the stationary sources would also include accounting for electrical use (also called facility power). To provide consistency to both the criteria pollutant inventories and airport GHG inventories, the *Guidebook* recommends that the above six categories be preserved. Airports would have the flexibility to include more specific sources under those categories as exemplified in Table 2-1. Two additional categories—waste management (recycling) and other (a catch-all category for emissions unique to an airport)—are included in Table 2-1 that are not generally found in criteria pollutant inventories.

Table 2-1. Example of inventory categories showing specific sources.

Source Category	Specific Source
Aircraft and APU	Ground (reflecting taxi-idle, delay)
	Ground to 3,000 ft (reflecting takeoff, climbout, and approach)
	Above 3,000 ft
	Aircraft engine tests
GSE	Emissions may be reported in aggregate, but data collection requires knowledge of different types of GSE used by airport operators (snow removal, maintenance equipment, etc.) versus tenants (baggage tractors, belt loaders, cabin service trucks, etc.)
Parking Facilities and Roadways (GAV)	Vehicles transporting passengers (private autos, taxis, vans, shuttles, rental cars, etc.), and vehicles using airport parking
	Vehicles transporting airport and tenant employees, including vehicles in employee parking lots
	Vehicles transporting cargo
	Airport-owned vehicles
Stationary Sources/Facility Power	Airport facility boilers, heaters, and generators
	Fuels used by food concessions
	Maintenance activities
	Electrical consumption
Training Fires	Fuel usage for planned training activities
Construction	Vehicles consuming fuels during the construction process
Waste Management	Waste recycled, waste landfilled, etc.
Other	All other sources such as local on-airport companies with industrial processes, farming activities, etc.

Once the sources are identified, the availability of data and resources will need to be assessed to determine the pollutants to be accounted for in the inventory. Based on guidance provided by WRI and IPCC, as well as experience airport operators have gained from developing GHG inventories, it is recommended that the following levels of pollutant categories be used as a guide:

- Level 1 inventory that only considers CO_2;
- **Level 2 inventory (recommended) that considers six Kyoto pollutants (CO_2, CH_4, N_2O, SF_6, HFC, and PFC)—primary pollutants; and**
- Level 3 inventory that considers all pollutants including the six Kyoto pollutants, precursors and any others exerting a GHG effect.

At a minimum, CO_2 emissions (Level 1) must be quantified to form a GHG inventory. If resources and data allow, all attempts should be made to quantify the Kyoto pollutants (the primary pollutants) called out in Level 2. Although six pollutants are noted, it is likely that a Level 2 inventory would be dominated by CO_2 with lesser levels of CH_4 and N_2O. In part because of data availability and understanding of these emissions, the focus for Level 2 is usually on these three pollutants. This level is consistent with GHG inventory protocols identified by IPCC, WRI, ICLEI, and TCR. As such, **a Level 2 inventory is the recommended level for an airport inventory.** Level 3 is an alternate, and includes both precursors and any other pollutants (e.g., other halogenated compounds). Level 3 is geared toward satisfying scientific needs for a comprehensive accounting of all GHG effects while recognizing that Levels 1 and 2 generally capture the bulk of GHG emissions. Background information on all of these pollutants can be found in Appendices B through D.

> Level 1 (only CO_2 emissions) is the minimum for a GHG inventory, but Level 2 or higher is preferred.

Reporting at either Levels 2 or 3 would allow the highest assessment of an airport's carbon footprint and would be the most beneficial to the scientific community. Levels 1 and 2 are likely to be the most frequently prepared inventory levels. Inventory Level 3 would be the most detailed and also the most costly for the airport operator to prepare. Levels 2 and 3 serve as loose guidelines since it would also be beneficial to report a set of pollutants (in addition to CO_2) that partially cover these levels. For example, an airport may choose to report CO_2, CH_4, and N_2O but not have the data and/or resources to report the halogenated compounds (SF_6, HFC, and PFC) in Level 2. In this case, the reporting could be characterized as a partial Level 2. Similarly, partial reporting can be done for Level 3 or a combination of Level 2 and 3 (e.g., reporting CO_2, CH_4, and N_2O which are common to Levels 2 and 3, while also reporting NO_x from Level 3).

> To help efficiently use airport resources, a screening process could be employed to identify the major sources.

As part of the data collection and resource issues, a screening process could be employed to determine the significant sources. This would be useful for many airports that have limited resources and need guidance to determine which sources to exclude. The protocols from both IPCC and WRI promote the use of such approaches. Although WRI does not promote quantitative criteria at this time, IPCC suggests a 95% cutoff point such that sources accounting for 95% of emissions should be sufficient to report in an inventory (IPCC 2006). The 95% level can be determined from examining prior inventories. CCAR (2008) also employs the 95% criterion, referring to 5% as "de minimis." This is also supported by TCR (TCR[a] 2008). However, if data are available, and the effort to report the remaining 5% is reasonable, airport operators should consider including these de minimis sources in the inventory for completeness.

2.4 Ownership and Influence Categorizations

All airport GHG emissions inventories should have an ownership/control categorization layer. This should be done irrespective of the purpose of the inventory. For example, whether an inventory is developed for a registry or as part of a NEPA-like study, **the preferred approach should always include this ownership and control layer,** as it provides clarity in identifying the party/parties that can control those emissions. Table 2-2 shows an example of the categorization layer (i.e., "owning entity") in the first two columns (owning entity and source). A third column is provided for information purposes to relate these sources to the previously identified Scopes 1, 2, and 3. At an airport, the following three categories relate to ownership and control:

- Airport operator owned and controlled,
- Tenant owned and controlled (tenants include airlines, government, concessionaires, aircraft operators, fixed-based operators, etc.), and
- Public owned and controlled.

> An ownership and control categorization layer should be developed for all inventories, irrespective of the purpose of the inventory.

For those inventories that will be used to guide and measure the success of an emission reduction program, this layer provides sufficient transparency of the evolution of emissions over time to the public. As an option, additional layers could be added to point out the level of influence that non-owning entities have on certain sources. Such additions are at the discretion of the airport operator. As explained in Appendix E, entities that do not own but exert influence on sources can (and often should) be acknowledged for the emissions (or reductions of emissions) from these sources. As indicated previously, the allocation of emissions based on influence is outside the scope of this *Guidebook.* Therefore, although we note that the influence can be acknowledged, there is currently no guidance available to help quantify the allocations.

The underlying implication regarding this subject is that airports can have varying degrees of influence over sources they do not own. In general, all airport tenants are affected by the assets owned and controlled by the airport operator in some way, even if loosely through airport policies. As such, the airport operator may influence each source at the airport to varying degrees, and may also be able to claim recognition/credit for emissions reductions from those sources as well (again, to varying degrees).

In keeping with the guidance provided by WRI and as adopted by a variety of other organizations, as an option, categorization layers for the direct and indirect nature of emissions and their sources (classified as Scope 1, 2, or 3) also could be included. If the inventory is reported to TCR, this categorizing layer would provide consistency with the registry since it also uses these categories.

Table 2-2. Example of ownership categorization layer.

Owning/Controlling Entity	Source	Scope
Airport Operator	Aircraft (only aircraft owned by the airport operator; a few airport operators fly aircraft that they own)	Scope 1
	APU	Scope 1
	GSE	Scope 1
	GAV	Scope 1
	Stationary Sources	Scope 1 (electricity consumed in Scope 2)
	Fire Training	Scope 1
	Construction	Scope 1
	Waste Recycling	Scope 3
	Other	Scope 1/2/3
Tenant (includes airlines, government, concessionaires, aircraft operators, fixed-based operators, etc.)	Aircraft	Scope 3
	APU	Scope 3
	GSE	Scope 3
	GAV	Scope 3
	Stationary Sources	Scope 3
	Construction	Scope 3
	Waste Recycling	Scope 3
	Other	Scope 3
Public	GAV	Scope 3

As an option, the WRI scope categories could be specified to allow a better understanding of the direct and indirect nature of the emissions.

2.5 Geographic Boundaries

Since the effect of GHG emissions is global in nature, there are no "airport boundaries" in a true geographic sense as there are for criteria pollutants. The emissions from airport sources identified in Section 2.4 should be accounted for irrespective of *where* they occur. This means that in addition to accounting for emissions that occur on airport property (e.g., GSE, stationary sources, etc.), emissions from sources owned or influenced by the airport should also be included whether or not they occur on airport property or near the airport (e.g., as is the case for autos traveling to and from the airport). Judgment is required for some sources as to the extent of the airport's level of influence for purposes of achieving a policy-relevant inventory. All of the sources listed in Section 2.4, however, are considered to be either controlled or influenced by the airport. Designating sources by ownership and control is recommended to further assist with the inventory.

Unlike the health effects associated with criteria gases, GHG effects are global in nature and, hence, it does not matter where those emissions occur—ALL of the emissions must be accounted for.

For aircraft, it is recommended that emissions from the full flight (gate-to-gate) should be accounted for if sufficient information is available. Volume 2, Chapter 3 of the IPCC (2006) guidelines indicate that aircraft GHG emissions should be attributed to the departure country. This *Guidebook* recognizes that many approaches are available—ranging from not including aircraft in the inventory to including both the arrival and departure-related emissions in each airport's inventory. However, in keeping with the IPCC international protocol, this *Guidebook* recommends that each flight's emissions be attributed to the departure airport only. If all airports take this approach, this will provide consistency with each airport's inventory, avoid double counting, and allow individual airport inventories to be compared with, or aggregated to, larger scale inventories such as state inventories or USEPA's national inventory. This approach is the preferred approach for aircraft, because—if uniformly applied—it avoids double counting.

Where possible, aircraft emissions should be assessed by individual legs of a flight rather than the departure and final destination of multi-leg flights. For instance, emissions from a flight that leaves JFK to fly to ORD, then to DEN, and then to SFO, should be attributed as shown below and in Figure 2-2.

- Emissions of flight from JFK to ORD should be attributed to JFK,
- Emissions of flight from ORD to DEN should be attributed to ORD, and
- Emissions of flight from DEN to SFO should be attributed to DEN.

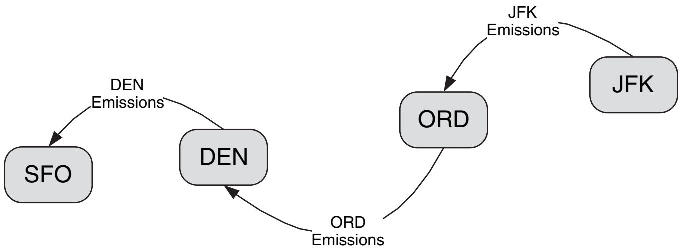

Figure 2-2. Attribution of aircraft emissions to the departure airport based on single flight legs.

> All of the emissions from aircraft flights are allocated to the departure airport.

As an option, the flights (and hence, emissions) can be further categorized into domestic and international flights, as follows:

- A domestic flight is from a U.S. airport to another U.S. airport.
- An international flight is from a U.S. airport to a non-U.S. airport; for non-U.S. airports, an international flight is from a non-U.S. airport to a U.S. airport.

It should be noted that when all of a flight's emissions are attributed to the departure airport, it results in a geographically distorting effect—the location of the point of actual emissions do not align with the geographic location of the airport as they do with the traditional assessment of criteria pollutants within the LTO cycle. Also, the total departure flight emissions attributed to an airport could be different than the total emissions derived from summing half the emissions from arriving flights and half the emissions from departing flights. Notwithstanding the technical difficulties (e.g., potential for overlaps with other airport inventories) associated with such an approach, this could at least geographically "center" the emissions at the airport. These issues need to be carefully considered, especially as policies are made regarding attribution of GHG emissions to airports. Similar concerns can also be raised for GAVs, construction equipment, etc., that operate outside of the airport property.

For publicly owned and controlled GAV travel, emissions resulting from full round-trips should be captured. An example of a round-trip would be for a passenger who travels from his/her home to the airport, and upon completion of the air travel, returns home. Thus, for GAVs, the emissions from origin to the airport and the return segment should be quantified even if a passenger was dropped off at the airport. This could also apply to airport operator and tenant employees who travel to or from the airport, as well as the movement of construction equipment. Ideally, multipurpose trips (e.g., involving travel to a store before returning to the origin) should only account for the direct distance from the origin to the airport and vice versa. Such side trips should not be included in the inventory as they are not a part of the purpose for the airport trip. However, if the side trips are already embedded as part of the data available (e.g., total VMT data), it may be difficult—and resource intensive—to attempt to remove the side-trip contributions. Therefore, side trips could be left in the data and properly documented to reflect this, especially since the overall effect on the inventory will likely be small.

2.6 Data Availability

As with any new evaluation process, an airport operator may not have data collected in a format and depth necessary to undertake some of the preferred approaches to quantifying emissions from a specific source. Alternatively, less detailed data may be available requiring the use of alternative quantification approaches. Additionally, many airports may not have any data concerning a specific source, particularly those associated with a tenant. The *Guidebook* recommends that the documentation accompanying the inventory clearly identify the data that were available (and their source), how the data were used, and any issues associated with that data. Such documentation should strive for the greatest clarity and ability to replicate the results outside of the report. Depending on data availability, airport operators may not be able to perform any quantification of emissions for certain sources. All such cases should be clearly documented.

2.7 Reporting Units for Pollutants

GHG emissions are typically reported in metric tons. However, depending on the units of the source data (e.g., emission factors), emissions calculations can directly result in either English (e.g., lbs) or metric (e.g., g, kg) units. These should all be converted to a common unit, preferably the metric ton. Using this common unit allows easy reviews and comparisons with other inventories. The following conversions may be useful in preparing an inventory:

- 1 lb = 0.0004536 metric ton,
- 1 g = .000001 metric ton,
- 1 kg = 0.001 metric ton,
- 1 Mg = 1 metric ton,
- 1 Gg = 1,000 metric tons, and
- 1 Tg = 1,000,000 metric tons.

CHAPTER 3

Emissions Calculations and Application of CO_2 Equivalencies

This chapter provides instructions on how to calculate GHG emissions and CO_2 equivalencies. The sections are arranged by source with emissions calculations followed by calculation procedures for creating CO_2 equivalencies. Further background information on the methods used can be found in Appendices C and D.

Since the majority of GHG emissions at most airports is generated by aircraft and GAVs, different methods of evaluation for these specific sources are provided. For aircraft and GAV, the evaluation focused mainly on three of the six Kyoto pollutants (CO_2, CH_4, and N_2O), since these sources emit little or no amount of the other pollutants (HFC, PFC, and SF_6). In large part, this is due to the lack of data for these other pollutants. In general, if the data are lacking (or not established) for a pollutant in each source category, that pollutant is not addressed in the respective section. The purpose of the method levels and the structure of this *Guidebook* is to provide airport operators with evaluation methods that can be matched with the resources and data that are most commonly available. Generally, the higher the method number, the more detailed the data that are required to undertake the analysis.

Most of the emissions calculations for each source are based on estimating or obtaining fuel use (or activity) information and then multiplying by the appropriate GHG emission factor, as follows:

$$\text{Emissions} = (\text{fuel use or activity}) \times (\text{emission factor})$$

Emission factors should be obtained from reliable sources such as IPCC, EIA, USEPA, etc. Emission factors from these different sources may vary but the differences will likely be small. For consistency, the same data sources and methods should be used, especially if tracking changes over time. Some representative emission factors are presented in the following sections, but it is the inventory developer's responsibility to make sure all emission factors are appropriate; this includes being up to date and specific to each fuel type. For example, emission factors for some of the lesser-used fuels (e.g., ethanol, biodiesel, etc.) can be found in the same sources that provide data for gasoline and diesel.

The inventory developer is also responsible for determining when to use more appropriate (i.e., more specific, as reflected in the highest method level) data when available rather than more generalized data (as related to a lower method level). It is not the intention of this *Guidebook* to suggest a single set of emission factors but to allow the inventory developer to determine the most appropriate emission factors based on the needs of the emissions inventory.

> Although guidance is provided on how to calculate GHG emissions, the inventory developer is ultimately responsible for making sure the data and methods presented herein (or referred to) are appropriate for the airport.

Although the use of continuous emissions monitoring (CEM) equipment to more accurately determine emission factors might be possible for some sources, this *Guidebook* does not directly address their use. CEM use is feasible for some sources (e.g., stationary sources), but the use of measured data is not necessary for airport inventories because the data for significant sources (e.g., aircraft and GAVs) either are usually available or reasonable approximations of them can be made.

This *Guidebook* identifies **preferred methods** for each source to prepare inventories. Recognizing that one size does not always fit all, **alternate methods** are also identified, especially for situations where data are not available to enable use of the preferred method. Table 3-1 summarizes the preferred and alternate methods for each source documented in the follow-

Table 3-1. Summary of preferred and alternate methods by source.

Source	Comments	Preferred Method	Alternate Method
Aircraft	In preparing this *Guidebook*, new sources were identified that may be superior to Method 2. FAA has volunteered to make these data available for public use as described under Method 3.	Methods 2 or 3, depending on availability and quality of data; Method 3 is subject to FAA availability of data	Method 1
APU		Method 2, with APUs included as part of cruise emissions	Method 1
GSE		Method 2, using the noted models	Method 1
GAV	Need to carefully consider the utility of running models like MOBILE6.2 (USEPA 2002). If the vehicle-specific VMT data are not available, no fidelity is gained from using MOBILE6.2.	Method 3 and the noted models	Method 1 or 2
Stationary Sources—Combustion Activities		Method 2 stationary source fuel use and specific emission factors	Method 1
Stationary Sources—Facility Power (Purchased Electricity)	Always falls under the Scope 2 category	Power demand and local emission rate	Power demand and EPA eGRID rates
Stationary Sources—Waste Management Activities		USEPA's WARM with appropriate activity data	NA
Training Fires		Fire training fuel and suppressant data	NA
Construction		USEPA's NONROAD or equivalent model	NA

ing sections (to point them out clearly, the preferred methods are listed in bold in the following sections).

The methods overviewed in Table 3-1 correspond to the pollutants categorized under Level 2 reporting (i.e., the six Kyoto pollutants), but mainly focus on CO_2, CH_4, and N_2O. These methods currently do not encompass life-cycle analysis, which is outside the scope of the *Guidebook*.

Also, for clarity, the term *method* is used to refer to the hierarchy of methods adopted in this *Guidebook* for calculating emissions for each source. In contrast, IPCC uses the term *tier* to describe their hierarchy of methods. For example, *Method 1* refers to a lower fidelity method (lower relative to the methods identified herein) adopted as part of this *Guidebook,* while *Tier 1* refers to a lower fidelity method from IPCC (lower relative to Tiers 2 or 3).

3.1 Aircraft

The calculation of aircraft emissions closely follows, but is not identical, to the methods prescribed in IPCC. The following methods are recommended herein:

> Aircraft emissions calculations closely follow the tiered IPCC guidelines. FAA is expected to begin releasing Method 3 data publicly in the near future for airport operator use. Thus, it may be the preferred method for U.S. airports.

- Method 1: Use fuel sales data for the airport to calculate total emissions for all departure flights. Fuel sales should represent Jet A (or other jet fuels) as well as Avgas fuels.
- **Method 2: Use fuel sales data in combination with methods or models to separately calculate LTO emissions. This method enables the emissions to be separated by those occurring from aircraft in the local environment (as defined by the LTO cycle) and those outside the local environment (referred to as cruise).** These data also reflect APU use, and, in some contexts, are referred to as residual/cruise/APU.
- **Method 3: Rather than using fuel sales data, this method relies on models capable of calculating fuel consumption**

and emissions associated with all modes of flight including cruise.

Section 2.3 of this report discussed three levels of evaluation relative to various pollutants. For aircraft, sources of preparing a Level 1 inventory (CO_2 only) or Level 2 inventory (all six Kyoto pollutants) were identified. As information for many criteria pollutants is generally not available for all phases of aircraft flight, a complete Level 3 analysis is not possible.

3.1.1 Aircraft Method 1

This method relies on the use of aircraft fuel sales data with appropriate emission factors to calculate emissions. *Aircraft fuel sales* refers to the gallons or pounds of fuel dispensed at an airport, sometimes called aircraft fuel uplift (uplifted to aircraft). Although this is the overall method, as shown in Figure 3-1, two GHG quantification approaches are described exemplifying the use of different conversion factors. The choice of these two methods depends on how the fuel sales data are reported. These data may be obtained from several organizations, including the airport properties division, the fuel consortium, airport fixed-based operators, etc. If they cannot provide the data directly, it is likely that they will be able to specify the appropriate contact.

For this calculation, the inventory developer must obtain total fuel sales data, which is typically available from the fuel providers at an airport. This information can then be converted to CO_2 emissions using typical emission factors such as the following:

- Jet A fuel = 21.095 lbs CO_2 per gallon Jet A (EIA 2008) and
- Avgas = 18.355 lbs CO_2 per gallon of Avgas (EIA 2008).

The following provides a sample calculation assuming 20,000 gallons of Jet A fuel consumption:

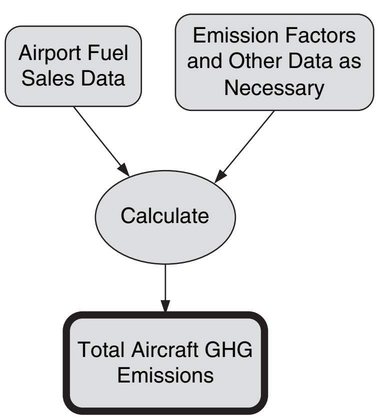

Figure 3-1. Overview of Aircraft Method 1.

$$CO_2 \text{ Emissions} = (20{,}000 \text{ gal}) \times (21.095 \text{ lbs } CO_2/\text{gal}) = 421{,}900 \text{ lbs } CO_2$$

To convert pounds to metric tons, the total pounds of CO_2 should be multiplied by 0.0004536 metric tons/lb. Thus,

$$421{,}900 \text{ lbs } CO_2 \times 0.0004536 \text{ metric tons/lb} = 191.4 \text{ metric tons } CO_2$$

It is important to note that some fuel sales are reported in pounds of fuel sold and not in gallons. Depending on local conditions, 1 gal of Jet A fuel generally weights 6.84 lbs, but Avgas (100LL) generally weighs 6.0 lbs/gal. These conversions are recommended to ensure calculation consistency.

Similar to CO_2 calculation, emissions of CH_4 and N_2O can be calculated using the following generic emission factors provided by the USEPA's Climate Leaders (USEPA[a] 2005), which have been adopted by TCR:

- Jet fuel = 0.27 g CH_4/gal fuel,
- Aviation gasoline = 7.04 g CH_4/gal fuel,
- Jet fuel = 0.21 g N_2O/gal fuel, and
- Aviation gasoline = 0.11 g N_2O/gal fuel.

Thus, for the 20,000 gal of Jet A fuel in the preceding example, 5,400 g of CH_4 (20,000 gal × 0.27 g/gal = 5,400 g) and 4,200 g of N_2O (20,000 gal × 0.21 g/gal = 4,200 g) would be emitted.

The quantity in grams can be converted to metric tons by multiplying the grams by 0.000001 metric ton/g. Thus, in the example, 0.0054 ton of CH_4 and 0.0042 ton of N_2O would be emitted.

The use of fuel sales data will prevent double counting at each airport since only the fuel used at an airport (i.e., for departure) will be used to represent GHG emissions at that airport. None of the methods recommended herein account for fuel tankering as such data are not publicly available. Fuel tankering is the practice of purchasing more fuel than necessary to fly an aircraft from one airport to the next. In general, it represents an economic strategy to take advantage of lower fuel costs in certain regions. Depending on where the tankering is conducted (i.e., based on fuel prices at different locations), a GHG inventory could either under- or overestimate aircraft GHG emissions from departure flights at an airport when using fuel sales data.

An issue to be considered in using fuel sales data is whether the inventory should or needs to identify the effects of various policies such as fuel taxes. For an airport located in city X (Airport X), if a notable number of flights tanker fuel, the emissions quantified using fuel sales could be understated relative to the fuel required to power flight for Airport X. Thus, fuel associated with those flights could be similarly overstated at the airports where the flights originated (Airports Y and Z). This might be illustrated when comparing the fuel or emissions results of Method 3 with those of Methods 1 or 2. The leakage of emissions (i.e., the consequence of policies that result in a local decrease due to the policy but increase emissions elsewhere) caused by the fuel tax policy could only be captured through a comparison of the fuel required by actual flight (as estimated by Method 3) as compared to the fuel dispensed at an airport.

3.1.2 Aircraft Method 2

This method involves using the same fuel sales data as in Method 1, but improving the resolution of the data by calculating LTO emissions separately, as shown in Figure 3-2. Figure 3-2 shows the cruise derivation being performed with emissions, but it can also be conducted with fuel consumption before computing emissions.

In air quality evaluations, flight operations in the local environment are referred to as the LTO cycle. One aircraft LTO cycle is equivalent to two aircraft operations (one landing and one takeoff). The standard LTO cycle begins when the aircraft crosses into the mixing zone (about 3,000 ft altitude) as it approaches the airport on its descent from cruising altitude, lands, and taxis to the gate. The cycle continues as the aircraft taxis back out to the runway for takeoff and climbs out to cross the mixing zone. The operating modes in a standard LTO cycle are as follows:

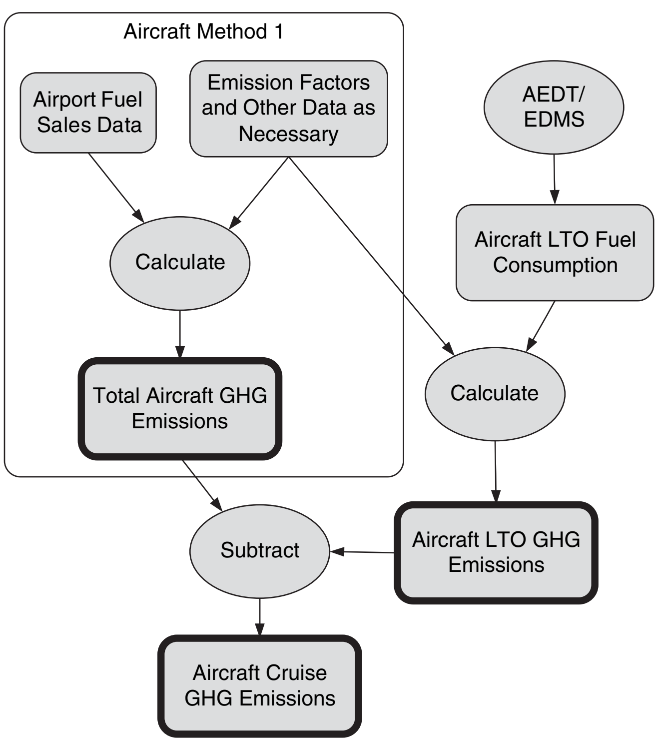

Figure 3-2. Overview of Aircraft Method 2.

- Approach—portion of flight from the time the aircraft reaches the mixing height or 3,000 ft altitude and exits the runway;
- Taxi/idle-in, taxi/idle-out (often combined into taxi/idle/delay)—time aircraft is moving on the taxiway system until reaching the gate, and on departure from the gate until taxied on to the runway;
- Takeoff—the roll down the runway through lift-off up to about 1,000 ft; and
- Climbout—the departure segment from takeoff until exiting the mixing height or 3,000 ft.

The LTO cycle has been used extensively in modeling criteria pollutants (e.g., CO, NO_x, etc.). Therefore, the same methods for each of the pollutants apply in this method.

Unless other methods are available, the FAA's AEDT/EDMS (FAA[a] 2007) can be used to estimate fuel consumption during the LTO cycle, as well as to estimate the criteria pollutants emitted in this operating phase. The LTO-based fuel consumption information can be used with the appropriate emission factors noted in Method 1 to calculate emissions for CO_2, CH_4, and N_2O. AEDT/EDMS (on the layer titled "Aircraft by Mode") reports the fuel burn by each aircraft type in units that can be selected by the user, ranging from grams to short tons. Thus, the fuel sales data and the LTO aircraft fuel burn from AEDT/EDMS must be converted to common units—either gallons of fuel or pounds are preferred, as noted in the Method 1 discussion.

Using the LTO-based fuel consumption produced by AEDT/EDMS (or derived LTO emissions) and the total fuel sales data (or derived total emissions), cruise fuel consumption (or the derived cruise) emissions can be determined as follows through difference:

- Cruise emissions = (total emissions) – (LTO emissions) or
- Cruise fuel consumption = (total fuel sales) – (LTO fuel consumption)

For example, if the fuel sales data noted that 20,000 gallons of Jet A fuel were sold at the airport, and the AEDT/EDMS run for the airport indicated aircraft consumed 1,670 gallons (reported as 5,181 kg) in the LTO mode, this calculation would indicate 18,330 gal were consumed during cruise (20,000 − 1,670 = 18,330). As a result, 175.4 metric tons of CO_2 (18,330 gal × 21.095 lbs CO_2/gal fuel × 0.0004536 metric ton/lb) emissions would be attributed to cruise.

Disaggregating the emissions into LTO and cruise allows for better tracking of emissions over time.

Using Method 2 would improve the Method 1 evaluation by allowing emissions to be reported in a disaggregated form (LTO and cruise). As a result, tracking of these emissions over time would be improved.

3.1.3 Aircraft Method 3

Unlike the other methods, Method 3 does not rely on the use of fuel sales information to provide (encompass) cruise fuel use. Rather, Method 3 involves the use of sophisticated methods/models to predict fuel usage for the entire flight as shown in Figure 3-3.

Although some European methods/models exist, the premier U.S. model that should be used is the FAA's AEDT/System for Assessing Aviation's Global Emissions (SAGE) (FAA[b] 2005). AEDT/SAGE and other models that could be used for this Method 3 require extensive information about the aircraft fleet, flight schedules, trajectories, and aircraft performance. Note that while preparing this report, concern was expressed with the accuracy of fuel sales data to reflect fuel consumed in a flight segment because some flights may tanker fuel for use on later segments. At this time, it is not possible to estimate how fuel sales may compare to the fuel burn evaluation computed by AEDT/SAGE. Currently, AEDT/SAGE is a research tool and is not available to the general public. However, the FAA intends to make fuel burn and CO_2 data (totals for each airport) available in the following form for each U.S. airport:

- Ground level (reflecting the previously defined taxi/idle mode),
- Above ground to below 3,000 ft (reflecting the takeoff, climb-out, and approach modes),
- Above 3,000 ft (reflecting cruise), and
- Total.

The FAA AEDT/SAGE-based aircraft fuel burn and CO_2 data are expected to be made available on an annual basis for each U.S. airport and, as such, could be the **preferred aircraft emissions method.** Both fuel consumption and CO_2 emissions data are available, and the data are expected to be further separated into domestic and international categories. The stratification by the different modes (ground, above ground, above 3,000 ft, and total) is expected to enable airport operators and other parties to identify the effects of various actions on emissions on aircraft operations in these general geographic areas. The fuel data can be used with appropriate emissions factors (see Section 3.1.1) to calculate emissions of CH_4 and N_2O.

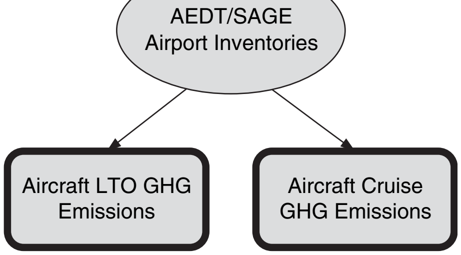

Figure 3-3. Overview of Aircraft Method 3.

> The AEDT/SAGE data are 100% consistent with EDMS results for the LTO cycle (except for startup emissions) and are also consistent with the EPA's national GHG inventory.

Due to the model integration work under the FAA's AEDT project, both AEDT/SAGE and AEDT/EDMS use common computational components. Hence, the aircraft LTO fuel consumption (below 3,000 ft) computations from AEDT/SAGE are identical to those from AEDT/EDMS except for the start-up emissions, which are currently only modeled in AEDT/EDMS and not in AEDT/SAGE. Also, since AEDT/SAGE inventories are currently used by the USEPA as part of the U.S. national GHG inventory development, the AEDT/SAGE airport data promulgated as part of this method is fully consistent with the national inventory.

Note the following information about backcasting and forecasting. For airports that require either a backcast or forecast condition, it is likely that the FAA AEDT/SAGE dataset will not include the data that the analysis may require. Thus, there may be some inconsistencies between the existing inventory (if reflecting the FAA's Method 3 or AEDT/SAGE data), and the use of Method 1 or Method 2 for backcast or forecast condition. This can be handled in one of two ways. First, airport operators could note that the backcast and forecast conditions are prepared with differing methods, reflecting the state of available data. Alternatively, an airport could prepare its existing inventory using Method 2 and compare the results to the FAA's Method 3 (AEDT/SAGE) dataset for the same year. One difference in the results could be due to fuel tankering (fuel transported on the aircraft that is being used for later flight segments). Another could just have to do with the precision of the methods. The purpose of this comparison would be to identify any substantial variances in the fuel sales data relative to the Method 3 (AEDT/SAGE) calculation and use that information to assist with adjusting the Method 2 backcast and forecast analysis. Using a Method 2 approach for the backcast and forecast, the results of the Method 2 data could be adjusted in a manner reflecting the variance. It needs to be reiterated that care must be taken when backcasting and/or forecasting since the data (e.g., source activities, emission factors, etc.) to support these processes may not be very accurate.

3.1.4 Other Pollutants

For some of the pollutants in Level 3 (beyond the six Kyoto pollutants in Level 2), AEDT/EDMS could be used to derive inventories for many of these pollutants, but only for the LTO portion. The inventory developer will need to determine the usefulness of such data based on airport needs. IPCC provides cruise-related emission factors for NO_x in Volume 2, Chapter 3, Table 3.6.10 of its guidelines (IPCC 2006). Potentially, the fuel use derived from Method 2 could be used with these emission factors. Emissions of H_2O and SO_x can be estimated using fuel composition data with mass balance, as indicated in Appendix C.

Emissions of fluorinated compounds (e.g., HFC and PFC) from fire extinguishers can also be taken into account. Volume 3, Chapter 7 of the IPCC guidelines (IPCC 2006) and Annex 3 of the EPA inventory report (USEPA[b] 2008) provide methods and data for calculating emissions from fire extinguishers. Discussions with manufacturers and airlines have indicated that no data currently exists to directly support the modeling of emissions from the Halon systems on an aircraft (Bennett 2008; Valeika 2008).

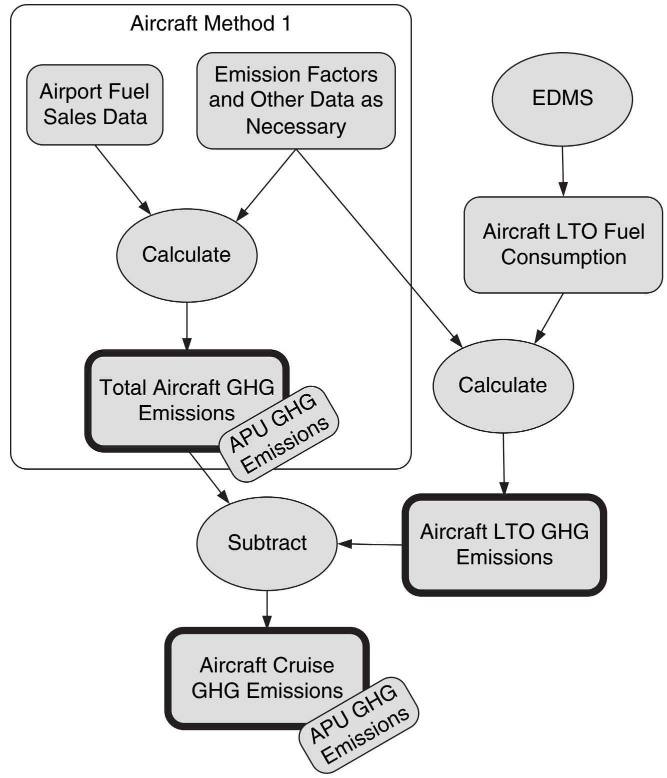

Figure 3-4. APU emissions accounted as part of aircraft emissions using either Aircraft Method 1 (upper box) or Aircraft Method 2 (overall figure).

3.2 Auxiliary Power Unit

At this time, APU-related GHG emissions can only be accounted for through Aircraft Methods 1 and 2 (fuel sales data). As discussed later in this section, a subsequent dataset is expected to be released in the future, which will reflect the ability to separately itemize APU emissions.

The fuel used by onboard aircraft APUs is accounted for in the fuel sales data (fuel dispensed) as the main aircraft engines are powered by the same fuel that powers the APU. Therefore, both Methods 1 and 2 in Sections 3.1.1 and 3.1.2, respectively, account for APU fuel use, as shown in Figure 3-4.

Although Aircraft Methods 1 and 2 account for APU emissions, it should be understood that the AEDT/EDMS (FAA[a] 2007) results for aircraft LTO fuel consumption, as shown in Figure 3-4, presently do not include APU contributions. Therefore, since the LTO emissions are subtracted from the total airport emissions to derive what is previously labeled *cruise,* the APU emissions would be included but as part of the cruise emissions results for Method 2. This could potentially be rectified as APU-specific fuel consumption and emissions data become available. Assuming the same combustion efficiency for jet engines, the same calculation methods from Section 3.1 can be used to convert APU fuel consumption to APU emissions.

The International Coordinating Council of Aerospace Industries Association (ICCAIA) is developing an APU database to be managed by the Swedish Defense Research Agency (FOI). The database is expected to contain fuel consumption and CO_2 emission factors. However, under directions from ICCAIA and the manufacturers, it is expected that the Swedish FOI will only make the database available to certain organizations (e.g., government agencies) for research purposes and will likely have stipulations that the data not be published in any form. Another potential source of APU data is a USEPA report entitled, "Technical Data to Support FAA's Advisory Circular on Reducing Emissions from Commercial Aviation" (1995). Although this document appears to be publicly available, it is not recommended for use since it does not appear to have been intended for public review because it was never finalized. Therefore, unless the availability/usability of these datasets changes, airports would not be able to specifically quantify APU emissions outside of the total aircraft and cruise emissions determined from the Aircraft Methods 1 and 2, respectively. If Aircraft Method 3 is used, the SAGE data would not include APU emissions because it only represents aircraft emissions. The inventory documentation should clearly indicate which of these methods was used, and the reasons for use, to provide an explanation of how the APU emissions were handled. In the future, the FAA has indicated that they will include APU data within AEDT/EDMS to allow modeling of GHG emissions.

3.3 Ground Support Equipment

Unlike criteria pollutant emissions, AEDT/EDMS (FAA[a] 2007) currently cannot be used to calculate GHG emissions from GSE because emission factors for those pollutants are currently not covered by this model. Therefore, a mixture of AEDT/EDMS and other methods would need to be employed. For CO_2 calculations, the following two methods are suggested:

- Method 1: Use fuel consumption data for GSE equipment to calculate emissions.
- **Method 2: Use models such as NONROAD to determine emission factors.**

Sections 3.3.1 and 3.3.2 discuss the calculation of CO_2. Section 3.3.3 discusses the methodology for Level 2 and Level 3 pollutants.

3.3.1 GSE Method 1

If fuel-use information (e.g., fuel sales) for equipment is available, that information could be used with suitable emission factors to calculate GHG emissions as shown in Figure 3-5. For these vehicles, the airport operator would need to have records concerning the gallons of fuel that were dispensed to its vehicles, and similar records would be required for all tenant GSE. It is likely that most airports retain records concerning the fuel dispensed to their own vehicles. Fewer airports are expected to have access to the quantities of fuel consumed or dispensed by their tenants to their tenants' vehicles.

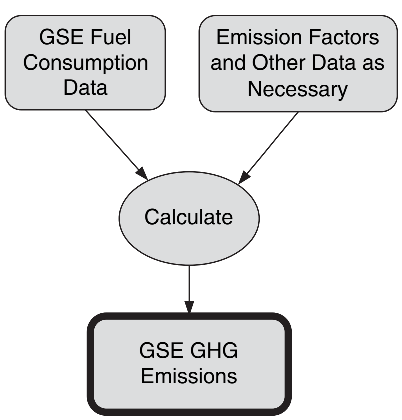

Figure 3-5. Overview of GSE Method 1.

The following are some examples of fuel-based CO_2 emission factors:

- Motor/auto gasoline = 19.564 lbs CO_2/gal fuel (EIA 2008) or 8.81 kg CO_2/gal fuel (USEPA[a] 2005),
- Diesel = 22.384 lbs CO_2/gal fuel (EIA 2008) or 10.15 kg CO_2/gal fuel (USEPA[a] 2005),
- Liquefied petroleum gas (LPG) = 12.805 CO_2/gal fuel (EIA 2008) or 5.79 kg CO_2/gal fuel (USEPA[a] 2005), and
- Liquefied natural gas (LNG) = 4.46 kg CO_2/gal fuel (USEPA[a] 2005).

A sample calculation, assuming 150,000 gal of motor/auto gasoline was used by GSE, is as follows:

$$\begin{aligned} CO_2 \text{ emissions} &= (150{,}000 \text{ gal fuel}) \times (19.564 \text{ lbs } CO_2/\text{gal fuel}) \\ &= 2{,}934{,}600 \text{ lbs } CO_2. \end{aligned}$$

When converted to metric tons, this equates to 1,331 metric tons CO_2 (2,934,600 lbs × 0.00045359237 metric tons/lb).

3.3.2 GSE Method 2

At some airports, fuel use is not available, but the time that specific equipment is used is available or can be estimated. In these cases, USEPA's NONROAD2005 (or similar models such as CARB's OFFROAD2007, which should only be applied to airports in California) could be used to determine emission factors for representative equipment, as shown in Figure 3-6.

For those airports that have information concerning the use of each piece of GSE, the data would indicate category of

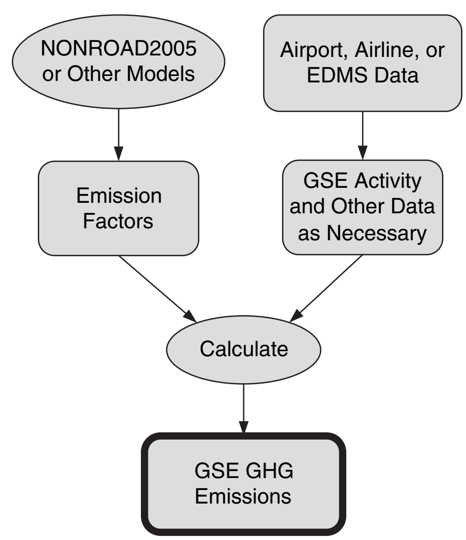

Figure 3-6. Overview of GSE Method 2.

equipment, specific engine, date manufactured, horsepower of the equipment, and annual hours of use. Then, specific emission factors can be obtained from the respective model. These data represent the GSE vehicle mix-use data.

For those airports that have not conducted a GSE inventory (for either their owned equipment or their tenants' equipment), estimates of such vehicle use can be prepared. For airport-owned equipment, it is best to survey the airport staff responsible for that equipment. However, in most cases, GSE Method 1 is recommended for airport-owned equipment (fuel dispensed to these vehicles). For airline GSE, AEDT/EDMS provides default GSE-use based on the aircraft fleet mix considered. This information will provide types of equipment, horsepower setting, and annual hours of use.

Once the GSE vehicle mix-use data are obtained, the NONROAD model can be accessed to obtain emission factors that are generally representative of the vehicle mix. NONROAD can be run for the nation as a whole or for a state or county. Given the general nature of the data, it is at the discretion of the user as to whether national averages, state averages, or county local data are used. In many cases, exact vehicle matches are not possible and therefore, estimates of equipment may be made based on knowledge of the specific GSE used at the airport. Alternatively, emission factors could potentially be obtained directly from the manufacturers of the GSEs. Although this is a less likely source of information and would be time consuming, it would provide improved estimates of GSE emissions. Potentially, manufacturer specification sheets (if they do not have emission factors) could also provide useful information in matching a GSE to an appropriate equipment type in NONROAD.

The following provides a sample calculation assuming 120 annual hr of 112 hp Bobtail GSE activity, where the Bobtail generates 871.4 g/hp-hr:

$$\begin{aligned} CO_2 \text{ emissions} &= (120\text{ h}) \times (871.4\text{ g }CO_2/\text{h}) \\ &= 104{,}568\text{ g }CO_2 \text{ or } 0.1046 \text{ metric tons} \\ &\quad \text{of } CO_2 \text{ (converting the grams to} \\ &\quad \text{metric tons, by multiplying the grams} \\ &\quad \text{of } CO_2 \text{ by } 0.000001\text{ g/metric ton).} \end{aligned}$$

3.3.3 Other Pollutants

Emission factors of CH_4 and N_2O are provided by both the USEPA's Climate Leaders (USEPA[a] 2008) and IPCC Volume 2, Chapter 3 of their guidelines (IPCC 2006) for a variety of nonhighway mobile sources (e.g., small utility, large utility, etc.). Since IPCC data represent international defaults, USEPA data are preferred. It is up to the inventory developer to determine the appropriateness of this information in estimating GSE emissions for those pollutants.

For GSE that has air conditioning, IPCC Volume 3, Chapter 7 of their guidelines (2006) provides a method to derive emissions for HFC and PFC based on default parameters related to mobile air conditioning. Designated as a screening method, both the USEPA Climate Leaders and TCR have adopted this method. The inventory developer will need to determine if this method is justifiable and the corresponding data are appropriate for the airport.

For the other pollutants in Level 3 (beyond the six Kyoto pollutants), NONROAD2005 or similar models like OFFROAD-2007 can be used to obtain emission factors. The pollutants include various gases and PM. Emissions of H_2O and SO_x can potentially be estimated using fuel composition data with mass balance as indicated in Appendix C.

3.4 Ground Access Vehicles

When preparing inventories of GAV, care must be exercised in evaluating travel for on-airport, as well as off-airport, roadways. Most airports have data concerning on-airport travel; large airports are likely to have actual vehicle count data; small airports may have more limited datasets. A review of the available inventories prepared to date indicates that the evaluation of GAV emissions may require approximations of vehicle counts and travel.

Due to the scale differences between the national inventories developed under the IPCC methods and airport inventories, the calculation methods for GAVs presented herein do not correlate directly with the tiers used by IPCC. However, they share common components that are consistent. The following methods are presented in this *Guidebook* for GAVs:

- Method 1: Use average vehicle miles traveled (VMT) estimates with appropriate emission factors for an average vehicle.
- Method 2: Use vehicle-specific VMT data with appropriate vehicle-specific emission factors.
- **Method 3: Use vehicle-specific VMT data with models such as MOBILE6.2 to calculate vehicle-specific emission factors.**

Although Method 3 is preferred, few airports have data at this level for the entire set of GAV that are suggested for inclusion in the GHG inventory. Therefore, it may be appropriate to use Method 3 for some subset of GAVs, such as the on-airport movement, and a lower method for the off-airport movement. It is within the GAV category of sources that data availability is likely to represent the greatest difficulty for most airports. The documentation that accompanies the inventory should clearly document the data sources and their use.

Based on the availability of data, inventory developers are encouraged to use the highest method for the data available. The following three subsections discuss the calculation of

CO_2, with Section 3.4.4 discussing the methodology for the Level 2 and Level 3 pollutants for GAV.

3.4.1 GAV Method 1

Method 1 calculations involving the determination of GHG emissions from GAVs basically determine fuel consumption values for use with the appropriate emission factors. This is the general method described under both Tiers 1 and 2 of the emissions section in Volume 2, Chapter 3 (IPCC 2006). However, unlike using the IPCC tiers, national fuel consumption data specific to an airport and the vehicles that use an airport are not available. Therefore data surrogates are used to provide an indication of the distance that vehicles travel and the fuel economy of those vehicles. The overall method for airport GAV emissions is presented in Figure 3-7.

The first step in calculating GAV emissions is to collect VMT data for all vehicles. The total origin-destination distance should be included to allow proper accounting of GHG emissions based on the influence of the airport. Such data could potentially be derived from passenger surveys or estimates of passenger trip distances. Although passenger vehicles will tend to account for the biggest portion of GAV emissions, other vehicles, such as those used by airport employees and shuttle buses, should also be included. Each of these vehicles should also be categorized by fuel type (e.g., gasoline, diesel, etc.).

In the simplest form, the vehicles using an airport can be categorized by passengers, employees, cargo, and service delivery. If specific vehicle data are not available, the inventory developer will be required to estimate the number of vehicles and distance traveled of the various vehicle types. In the passenger category, vehicles can be further identified by the mode of travel—private vehicle, taxi, shared van, etc. For many airports, data of this nature are not available. Thus, sources of data that the inventory developer might consult could include: total airport activity characteristics (passenger, operations, and cargo including the FAA's Terminal Area Forecast), airport parking revenue (for vehicles accessing the airport parking lots), passenger surveys (for modes of travel and distance traveled), metropolitan planning organization (MPO is responsible for regional surface traffic analysis) traffic analysis for the area, airport employee parking and badge office information (concerning employees and their travel), airport master plans and environmental analysis (for ground travel information), rental car revenue data (to identify rental car companies and percentage of market shares), etc.

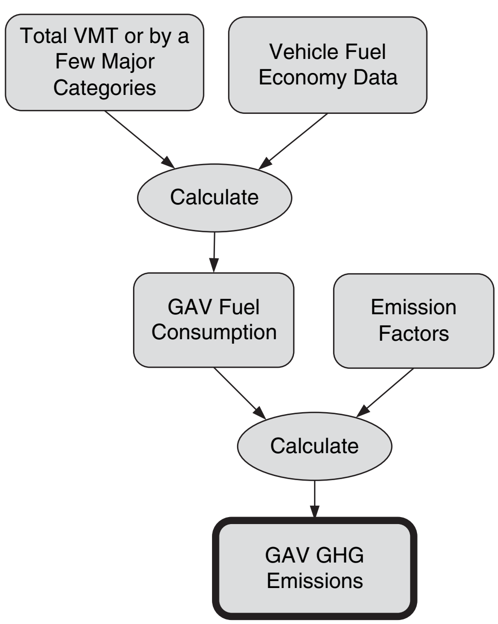

Figure 3-7. Overview of GAV Method 1.

In order to calculate GAV fuel consumption, fuel economy data would need to be obtained from sources such as the USEPA (USEPA[b] 2005), FHWA (FHWA 2002), and DOE (DOE 2007). For national averages, some typical values are as follow:

- Passenger cars = 23.9 mpg (USEPA[b] 2005),
- Passenger cars = 22.1 mpg (FHWA 2002), and
- Cars (2005) = 22.9 mpg (DOE 2007).

Any of these example fuel economy values could be used since they are all from reputable sources. The inventory developer needs to clearly document the sources and should consider the potential need for consistency with previous inventories when choosing which values to use. If more specific fuel economy data are available (i.e., more specific to airport GAVs), they should be used instead of the national averages. Although the data could be segregated into categories (e.g., cars and trucks), the purpose of this method is to conduct a relatively "simple" assessment using average values. Using these national averages, fuel consumption would be calculated as exemplified below.

The following sample calculation is for one round trip:

$$\text{Fuel consumption} = (40\text{ mi})/(23.9\text{ mpg fuel economy}) = 1.67\text{ gal fuel.}$$

To calculate GHG emissions, emission factors can be obtained from the following variety of sources:

- Motor gasoline = 19.564 lbs CO_2/gal fuel (EIA 2008),
- Diesel = 22.384 lbs CO_2/gal fuel (EIA 2008),
- LPG = 12.805 lbs CO_2/gal fuel (EIA 2008),
- Gasoline = 8.81 kg CO_2/gal fuel (USEPA[a] 2005),
- On-road diesel fuel = 10.15 kg CO_2/gal fuel (USEPA[a] 2005),
- LPG = 5.79 kg CO_2/gal fuel (USEPA[a] 2005),
- LNG = 4.46 kg CO_2/gal fuel (USEPA[a] 2005), and
- Gasoline = 19.4 lbs CO_2/gal fuel (USEPA[b] 2005 and CFR 2003).

The following is a sample calculation for one round trip:

$$CO_2 \text{ emissions} = (1.67 \text{ gal fuel}) \times (19.564 \text{ lbs } CO_2/\text{gal fuel})$$
$$= 32.67 \text{ lbs } CO_2. \text{ This equates to 0.0148 metric tons which is derived using a conversion factor of 0.0004536 metric tons/lb.}$$

3.4.2 GAV Method 2

Method 2 is similar to Method 1 except that the VMT data are expanded to show a range of vehicle types (e.g., cars, trucks, motorcycles, etc.) and potentially other specific categorizations including vehicle age, mileage, emissions controls, etc. This is indicated in Figure 3-8.

These specific categorizations would allow better tracking of emissions over time. The inventory developer must determine the range of specific categorizations that would be appropriate for the airport. In each of these cases, because the data are still in a general form, fuel economy data are suggested to quantify the fuel consumed by these vehicles. Some examples of more specific fuel economy data than that shown in Section 3.4.1 are as follows:

- Light truck = 17.4 mpg (USEPA[b] 2005),
- Light truck = 17.6 mpg (FHWA 2002),
- Two-axle, four-tire truck = 16.2 mpg (DOE 2007),
- Medium truck (10,000 to 26,000 lbs) = 8.0 mpg (DOE 2007), and
- Heavy truck (more than 26,000 lbs) = 5.8 mpg (DOE 2007).

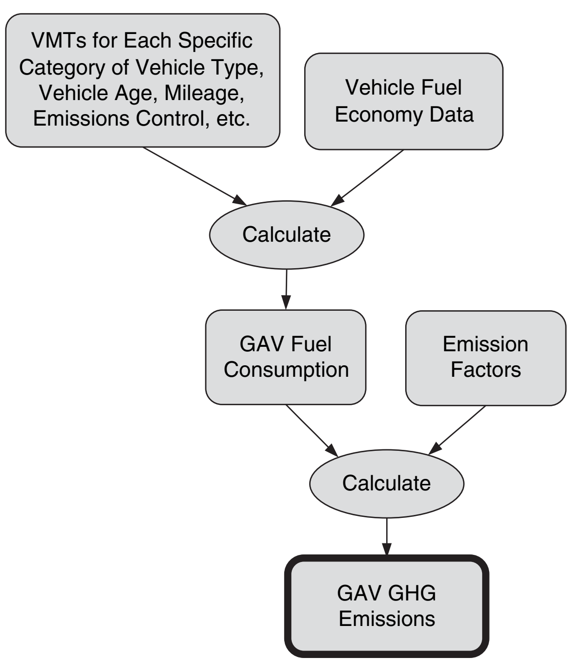

Figure 3-8. Overview of GAV Method 2.

3.4.3 GAV Method 3

As an alternative to the use of these fuel-based emission factors in Methods 1 and 2, the USEPA's MOBILE6.2 model can be used to generate CO_2 emission factors for different vehicle types (USEPA 2002). Similarly, the USEPA's MOVES2004 (USEPA[b] 2004) can be used to estimate fuel consumption (and hence, CO_2 emissions) as well as emissions of CH_4 and N_2O. These provide another option in calculating higher resolution emissions (e.g., by specific vehicle types, age, mileage, emissions controls, etc.) to better track emissions over time. An overview of Method 3 is provided in Figure 3-9.

This method is contingent upon having the VMT data for the specific vehicle categories. If those data are not available, there would be no fidelity gained from trying to use the specific emission factors from a model like MOBILE6.2. In such a situation, it would be more appropriate to simply use the MOBILE6.2 composite emission factor. In that case, the fidelity and resolution would essentially be the same as Method 1, and hence, no advantage would be gained from using MOBILE6.2.

> Method 3 for GAVs is contingent upon the availability of VMT data for specific vehicle categories; no fidelity is gained from using MOBILE6.2 without such data.

The following example calculation is for one round trip using an emission factor from MOBILE6.2:

$$CO_2 \text{ emissions} = (40 \text{ mi}) \times (0.25 \text{ kg } CO_2/\text{mi})$$
$$= 10 \text{ kg } CO_2. \text{ This equates to 0.01 metric tons } CO_2 \text{ when using a conversion factor of 0.001 metric ton/kg.}$$

This example calculation would correspond to a specific category of vehicle type, age, mileage, emissions control, etc.—again, depending on the needs of the airport.

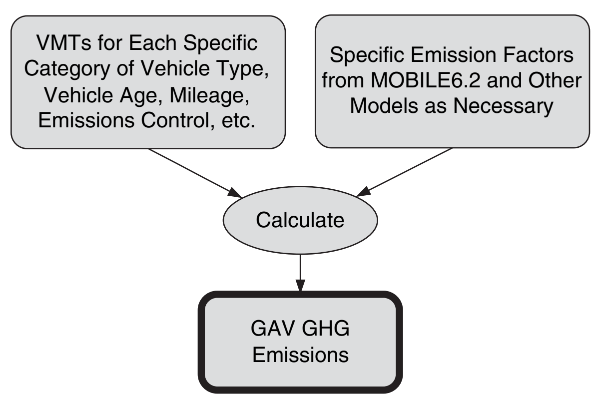

Figure 3-9. Overview of GAV Method 3.

Since emission factors for CH_4 and N_2O are highly dependent on vehicle type, operating conditions, control technology, etc., IPCC only allows the calculation of these emissions within its Tier 3 method. Although IPCC and other sources such as USEPA provide emission factors for these sources, there are no average values; they are provided for the specific categories. It is up to the inventory developer to properly (and reasonably) employ these specific emission factors. IPCC data for these pollutants can be found in Volume 2, Chapter 3, Tables 3.2.2 to 3.2.5 of the 2006 guidelines (IPCC 2006). The USEPA data can be found in Annex 3 Tables A-88 to 89 of the 2008 national GHG inventory report (USEPA[b] 2008).

3.4.4 Other Pollutants

For HFC and PFC, IPCC provides methods to derive emissions for these pollutants based on default parameters related to mobile air conditioning. The IPCC methods can be found in Volume 3, Chapter 7 of the IPCC guidelines (IPCC 2006). Both the USEPA Climate Leaders (USEPA[c] 2008) and TCR (TCR[a] 2008) provide simplified explanations and emission factors based on the same information from IPCC.

The overall method is based on material balancing of the emissions taking into account the charging, operating, and disposal of refrigerants. The USEPA Climate Leader's simplified view of the emission factors and related parameters is presented in Table 2 of their Refrigeration and Air Conditioning emissions guidance document (USEPA[c] 2008). The inventory developer will need to determine if this method is warranted and the corresponding data are appropriate for the airport.

For the other pollutants in Level 3 (beyond the six Kyoto pollutants), USEPA's MOBILE6.2 (USEPA 2002) or similar CARB's EMFAC2007 (CARB[b] 2007) can be used to predict emission factors for GAV. The pollutants include various gases and PM. Emissions of other pollutants (H_2O and SO_x) based on fuel composition potentially can be estimated using fuel composition data with mass balance as indicated in Appendix C.

3.5 Stationary Sources

With the broad range of sources covered under this category, the methods to calculate GHG emissions from stationary sources have been grouped into the following categories:

- Stationary source combustion activities,
  - Method 1: Use average emission factors,
  - **Method 2: Use technology-specific emission factors,**
- Electricity usage.

This section includes subsections devoted to CO_2 emissions from the above categories. The final subsection addresses the remaining GHGs.

3.5.1 Stationary Source Combustion Activities—Method 1

Method 1 embraces both IPCC Tier 1 and 2 for emissions from stationary source combustion. Both of these IPCC tiered methods involve the use of fuel consumption data associated with these sources, coupled with emission factors to calculate GHG emissions. IPCC differentiates between these two tiers by distinguishing between the use of default IPCC emission factors in its Tier 1 method and use of country-specific data in its Tier 2 method. As such, data specific to the United States are preferred under Method 1 described herein. Method 1 involves the use of average emission factors as indicated in Figure 3-10.

The stationary source fuel consumption data can be obtained from various fuel purchase or financial records and should be separated by sources owned by the airport operator versus those owned by tenants. For locations where purchased natural gas or electrical records are not absolutely clear as to the quantities that are the responsibility of the airport operator versus that of the tenants, the following guidance is provided: (1.) any purchased electricity or natural gas invoices received by the airport operator, even if directly metered to a tenant, are the responsibility of the airport operator and thus their emissions should be categorized under the airport-owned category; and (2.) if invoices are received by the tenant and the airport can either gain access to them or an estimate can be made of the tenant electricity/energy usage, the associated emissions should be categorized under the "tenant" category. In any case, these emissions should all be included as part of an airport GHG inventory. Airport-owned electricity purchases should be classified as Scope 2 emissions whereas tenant-owned electricity purchases should be characterized as Scope 3 emissions.

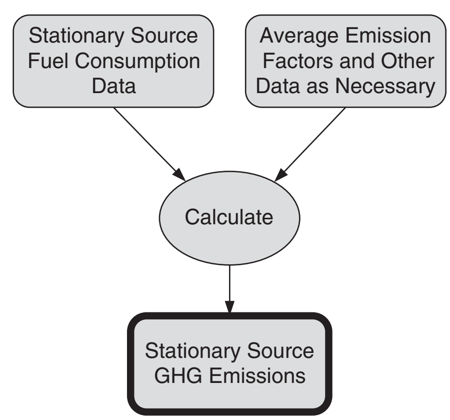

Figure 3-10. Overview of Stationary Source Combustion Method 1.

Utilities emissions are reported based on the party receiving the invoice for the utility (natural gas, purchased electricity, etc.).

Appropriate conversion units may need to be applied depending on the units of the fuel consumption values and the emission factors used. The activity/fuel data should be multiplied by an emission factor. Emission factors can be obtained from sources such as the USEPA and EIA. Some examples of average emission factors are

Btu—British thermal units
mmBtu—Million Btu
TJ—Tera joules
GJ—Giga joules
ft^3—Cubic feet

- Natural gas (U.S. average) = 53.06 kg CO_2/mmBtu fuel (TCR[a] 2008 and USEPA[b] 2008),
- Natural gas (U.S. average) = 120.593 lbs CO_2/1,000 ft^3 fuel (EIA 2008),
- Natural gas for commercial/institutional purposes = 56,100 kg CO_2/TJ fuel (IPCC 2006),
- Natural gas for commercial/institutional purposes = 5 g CH_4/GJ fuel (USEPA[b] 2008),
- Natural gas for commercial/institutional purposes = 0.1 g N_2O/GJ fuel (USEPA[b] 2008),
- Natural gas for commercial/institutional purposes = 5 kg CH_4/TJ fuel (IPCC 2006), and
- Natural gas for commercial/institutional purposes = 0.1 kg N_2O/TJ fuel (IPCC 2006).

The following is an example calculation using 200,000 million therms of natural gas usage:

The 200,000 million therms equates to 20,000 mmBtu using a conversion factor of 0.1 mmBtu/therm.

$$\text{Therefore, } CO_2 \text{ emissions} = (20{,}000 \text{ mmBtu}) \times (53.06 \text{ kg } CO_2/\text{mmBtu}) = 1.061 \text{ million kg } CO_2.$$

This equates to 1,061 metric tons of CO_2 when using a conversion factor of 0.001 metric ton/kg.

3.5.2 Stationary Source Combustion Activities—Method 2

In keeping with the IPCC Tier 3 method for stationary combustion, the Method 2 presented herein involves the same calculation procedures as in Method 1 but using technology-specific emission factors as indicated in Figure 3-11.

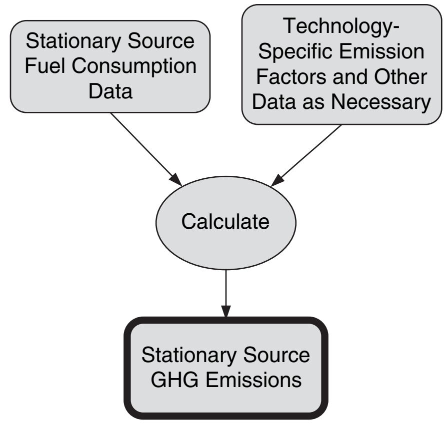

Figure 3-11. Overview of Airport Facility Combustion Method 2.

The stationary source fuel consumption data can be obtained from various fuel purchase or financial records and should be separated by sources owned by the airport operator versus those owned by tenants. For locations where purchased natural gas or electrical records are not absolutely clear as to the quantities that are the responsibility of the airport operator versus that of the tenants, the following guidance is provided: **Any invoices for purchased electricity received by the airport operator, even if directly metered to a tenant, are the responsibility of the airport operator and thus those emissions should be categorized under the airport-owned category.** If invoices are received by the tenant and the airport can either gain access to tenant electrical consumption or an estimate can be made of the tenant electricity/energy usage, the associated emissions should be categorized under the "tenant-owned" category. In any case, these emissions should all be included as part of an airport GHG inventory. As noted earlier, airport-owned emissions resulting from purchased electricity should be classified as Scope 2 emissions, whereas tenant purchased electricity should be classified as Scope 3 emissions.

Appropriate conversion units may need to be applied depending on the units of the fuel consumption values and the emission factors used. Emission factors can be obtained from sources such as USEPA's Technology Transfer Network (TTN) (USEPA[d] 2008), Annex 2 of the USEPA's 2008 GHG inventory report (USEPA[b] 2008) and IPCC Volume 2, Chapter 2 of the 2006 guidelines (IPCC 2006). The inventory developer must make sure to use the appropriate emission factors for each technology and operating condition.

3.5.3 Electricity Usage (Utility Purchases)

This section covers indirect emissions (Scope 2) resulting from electricity used by the airport (electricity not generated

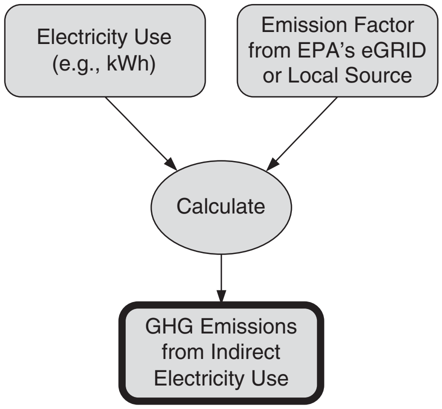

Figure 3-12. Overview of indirect GHG emissions calculations from airport electricity use.

by the airport). Any emissions from electricity generated by the airport through combustion of fuel should be categorized under Section 3.5.1 or 3.5.2. As shown in Figure 3-12, the method for calculating emissions from non-airport-generated electricity involves using electricity consumption (energy consumption) information with the appropriate emission factor.

With electricity usage generally reported in kilowatt hours (kWh), emission factors from local utility providers or from USEPA's eGRID system are recommended (USEPA[f] 2007). Airports are suggested to use local factors if available to ensure consistency of local inventories. In lieu of local factors, the USEPA's model should be used. The eGRID emission factors are typically in lbs CO_2 per MWh (megawatt hours).

The following is an example calculation with 300,000 kWh of electricity use:

$$CO_2 \text{ emissions} = (300{,}000 \text{ kWh}) \times (1{,}388 \text{ lbs } CO_2/\text{MWh for Georgia 2004}) \times (1 \text{ MWh}/1{,}000 \text{ kWh}) = 416{,}400 \text{ lbs } CO_2.$$ This equates to 188.9 metric tons when using a conversion factor of 0.0004536 metric ton/lb.

Emission factors for CH_4 and N_2O are also available from the USEPA's Climate Leaders in Appendix B of their Indirect Emissions from Purchased/Sold Electricity guidance document (USEPA[a] 2004). Based on fuel use data from eGRID, the USEPA developed emission factors for these pollutants.

3.5.4 Other Pollutants

For HFC and PFC, IPCC provides methods to derive emissions for these pollutants based on default parameters related to air conditioning and refrigeration. The IPCC methods can be found in Volume 3, Chapter 7 of the IPCC 2006 guidelines (IPCC 2006). Both the USEPA Climate Leaders (USEPA[c] 2008) and TCR (TCR[a] 2008) provide simplified explanations and emission factors based on the same information from IPCC.

The overall method is based on material balancing of the emissions taking into account the charging, operating, and disposal of refrigerants. The USEPA Climate Leader's simplified view of the emission factors and related parameters is presented in Table 2 of their Refrigeration and Air Conditioning emissions guidance document (USEPA[c] 2008). The inventory developer will need to determine if this method is warranted and the corresponding data are appropriate for the airport.

Although IPCC (2006) provides methods to predict emissions of SF_6 from industrial-type activities such as electronics etching, cleaning, and temperature control applications, these are not typical activities at an airport. The methods and data necessary for predicting emissions of SF_6 from these types of activities can be found in Volume 3 (Industrial Processes and Product Use) from the IPCC 2006 guidelines (IPCC 2006). The inventory developer needs to determine if any of these activities occur at the airport, and if so, use the appropriate methods and data to determine the associated SF_6 emissions. Also, IPCC provides a mass balance method to account for SF_6 emissions from electricity transmission that is consistent with the method from the USEPA's Emission Reduction Partnership for Electric Power Systems. However, this method is not intended for use by an entity that uses the electricity; rather, it is intended for the entity that owns the transmission lines. Hence, no SF_6 emissions from electricity transmission lines can feasibly be allocated to airports at this time.

For the other pollutants in Level 3 (beyond the six Kyoto pollutants), AEDT/EDMS (FAA[a] 2007) provides coverage of a wide range of pollutants (e.g., CO, NO_x, VOC, etc.) for various stationary sources. The USEPA's eGRID also provides emission factors for SO_2 and NO_x. In addition, if the fuel composition is known or estimated, a mass balance could be conducted to derive emission factors for H_2O and SO_x (modeled as SO_2) as indicated in Appendix C.

3.6 Waste Management Activities

Most airports have implemented waste management activities designed to recycle various forms of waste. These activities produce GHG emission reductions when contrasted with activities that do not recycle. The emissions associated with waste reduction-related equipment owned and operated by airport operators should be captured in the stationary source methodologies discussed previously (see Section 3.5). This section discusses capturing the GHG emission reduction associated with lifecycle-related waste management activities.

Few methodologies exist to capture the lifecycle emissions benefits associated with waste management activities. It is recommended that airport inventories not attempt to capture the full lifecycle emissions benefits associated with waste management activity, especially reduction-related activities. Rather, only the direct emissions from energy necessary to

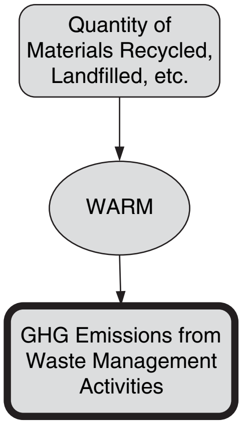

Figure 3-13. Overview of using USEPA's WARM to calculate GHG emissions.

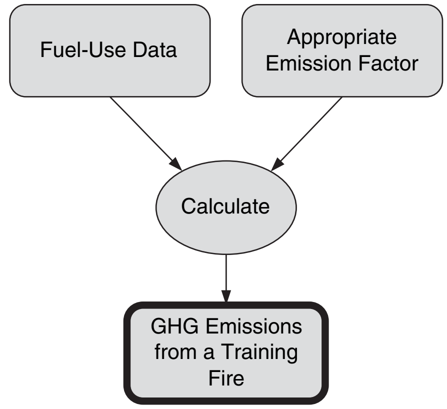

Figure 3-14. Overview of GHG emissions calculations from training fires.

handle waste (e.g., incineration, disposal, etc.) can be reflected. The *Guidebook* does not address upstream and downstream emissions at this time.

For airports that are required for local reasons to consider the GHG consequence of various waste management strategies, the USEPA's Waste Reduction Model (WARM) (USEPA[b] 2007) is recommended as indicated in Figure 3-13. However, the USEPA's website specifically notes the following regarding this model, which reflects a lifecycle approach to considering such emissions: "This lifecycle approach is not appropriate for use in inventories because of the diffuse nature of the emissions and emission reductions contained in a single emission factor."

As indicated by USEPA, WARM models source reduction, recycling, combustion, composting, and landfilling. Some examples of materials covered by the model include aluminum cans, glass, plastic, and paper. WARM also provides several options for landfill emissions modeling, including whether or not landfill gases are recovered. WARM uses national average emission factors. Modeled results are provided in metric tons of carbon equivalent (MTCE) and metric tons of CO_2 equivalent ($MTCO_2E$). Because few airport inventories would include waste management emissions, such users are referred to the USEPA website for information about this model, data requirements, and reporting (USEPA[b] 2007).

3.7 Training Fires

GHG emissions can be calculated from a training fire using the fuel usage information and an appropriate emission factor as indicated in Figure 3-14.

The fuel-use data for fire training activities (to the degree training occurs at an airport) are typically maintained by airport operations or the fire department. Fuels used in creating live fires are typically reported in gallons. Fire suppressants should also be reviewed to determine the GHG consequence of the materials. The GHG emission factors depend on the fuel and may be obtained from sources such as EIA (2008); examples of emission factors for some different types of fuel were indicated in Section 3.1.1. Alternatively, for fuels specifically geared toward training exercises, such as Tekflame, emission factors could potentially be obtained from manufacturers.

The following is an example calculation assuming a hypothetical 10 gal of fuel and 20 lbs/gal emission factor for CO_2:

$$\begin{aligned} CO_2\text{ emissions} &= (10\text{ gal fuel})\times(20\text{ lbs }CO_2/\text{gal fuel}) \\ &= 200\text{ lbs }CO_2.\text{ This equates to} \\ &\quad 0.09072\text{ metric ton when using a conversion} \\ &\quad \text{factor of }0.0004536\text{ metric ton/lb.} \end{aligned}$$

If the CO_2 emission factor is not directly available, but the fuel composition data are (or can be estimated), the emission factor can be derived using mass balance and assuming complete combustion as indicated in Appendix C.

Emissions of fluorinated compounds (e.g., HFC and PFC) from fire extinguishers also need to be taken into account. Volume 3, Chapter 7 of the IPCC guidelines (IPCC 2006) and Annex 3 of the EPA inventory report (USEPA[b] 2008) provide methods and data for calculating emissions from fire extinguishers.

Emissions of various other pollutants (e.g., CO, NO_x, VOC, etc.) are also generated during combustion of the fuel. These can also be predicted by AEDT/EDMS (FAA[a] 2007) using the stationary source definitions within the model.

3.8 Construction Activities

The calculation of construction activity emissions for criteria pollutants is a well-established and understood process. The evaluation of construction emissions for GHG emissions uses the same models and data. Therefore, it is recommended that USEPA's NONROAD2005 (or CARB's OFFROAD2007 for airports in California) be used to determine emission factors for representative equipment as shown in Figure 3-15 (USEPA[c] 2005 and CARB[a] 2007).

To use emission factors from this model, the airport operator is required to identify the specific construction vehicles that would be deployed on the construction, as well as the annual hours of use, equipment horsepower, and load factor. This information is further described in the user's manuals for the models.

In modeling these emission factors, reasonable approximations may need to be made based on the data available in NONROAD and knowledge of the local construction vehicle mix. The inventory developer needs to make this determination based on knowledge of the specific equipment used at the airport. Alternatively, emission factors could potentially be obtained directly from the manufacturers. Although this would be a time-consuming effort, it would provide improved emissions estimates. Potentially, manufacturer specification sheets could also provide useful information in matching a construction vehicle to an appropriate equipment type in NONROAD.

Once the emission factors are known, activity information needs to be estimated. Since emission factors from NONROAD are provided in grams per break horsepower-hour, suitable load factors would need to be used. If the loading data are not available, assumptions could be made based on the inventory developer's experience.

The following provides an example calculation assuming 1 h activity for one piece of construction equipment:

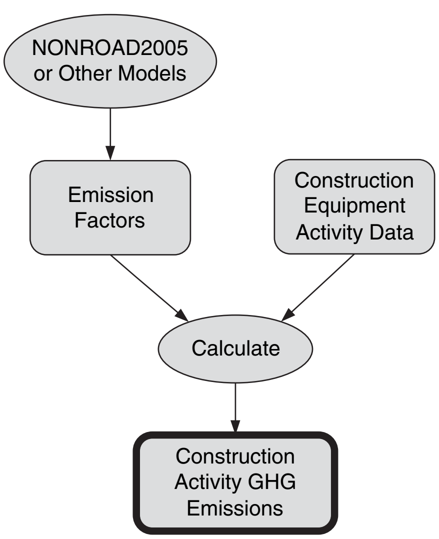

Figure 3-15. Overview of GHG emissions calculations for construction activities.

$$CO_2 \text{ emissions} = (1\ \text{h}) \times (10{,}000\ \text{g}\ CO_2/\text{h}) = 10{,}000\ \text{g}\ CO_2$$

This equates to 0.01 metric ton when using a conversion factor of 0.000001 metric ton/g.

Emission factors for CH_4 and N_2O are provided by both the USEPA's Climate Leaders and IPCC for various non-highway mobile sources (e.g., small utility, large utility, etc.). The emission factors can be found in the Climate Leaders mobile source inventory guidance document (USEPA[a] 2008) and Volume 2, Chapter 3 of the IPCC 2006 inventory guidance (IPCC 2006). Since the IPCC data represent international defaults, the USEPA's data are preferred. It is up to the inventory developer to determine the appropriateness of this information in estimating emissions for construction equipment.

For construction equipment that has air conditioning, the IPCC provides a method to derive emissions for HFC and PFC based on default parameters related to mobile air conditioning. The IPCC methods can be found in Volume 3, Chapter 7 of the IPCC 2006 guidelines (IPCC 2006). Both the USEPA Climate Leaders (USEPA[c] 2008) and TCR (TCR[a] 2008) provide simplified explanations and emission factors based on the same information from IPCC.

The overall method is based on material balancing of the emissions, taking into account the charging, operating, and disposal of refrigerants. The USEPA Climate Leader's simplified view of the emission factors and related parameters is presented in Table 2 of their Refrigeration and Air Conditioning emissions guidance document (USEPA[c] 2008). The inventory developer will need to determine if this method is warranted and the corresponding data are appropriate for the airport.

For the other pollutants in Level 3 (beyond the six Kyoto pollutants), NONROAD2005 (USEPA[c] 2005) or similar models like OFFROAD2007 (CARB[a] 2007) can be used to predict emission factors. The pollutants include various gases and PM. Emissions of H_2O and SO_x can potentially be estimated using fuel composition data with mass balance as indicated in Appendix C.

3.9 Other Airport Sources

The preceding sections identify the common sources of GHG emissions at an airport. Since every airport is different, it is likely that there are unique sources operating at an airport that are not captured in the preceding sections. Therefore, **the *Guidebook* recommends that the inventory developer consider the principles noted in the previous sections in developing a methodology to capture the emissions from other sources** (i.e., making logical choices of using appropriate emission factors and applying them to the associated activity data for each source). The methodology should be clearly documented in the text that accompanies the resulting inventory.

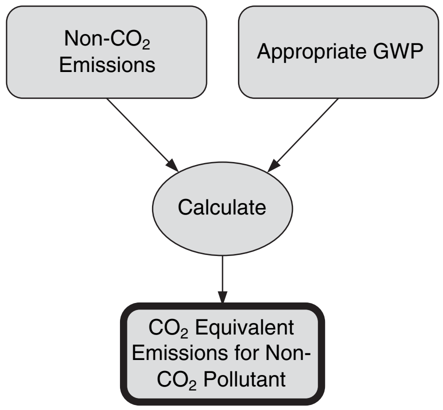

Figure 3-16. Overview of CO_2 equivalency calculations.

3.10 Calculation of CO_2 Equivalencies

After each applicable source has been addressed and the emissions of each pollutant have been calculated, CO_2 equivalencies need to be developed as indicated in Figure 3-16.

The GWPs from the IPCC's fourth and most recent assessment report (IPCC 2007) should be used, and this source needs to be clearly cited. However, based on the needs of the airport (e.g., comparisons to older inventories), GWPs from other reports could potentially be used as long as the sources are clearly stated. GWPs from the IPCC *Fourth Assessment Report* are reproduced in Table 3-2 for some pollutants.

> Sources of GWP factors should be clearly identified, as well as the emissions of individual pollutants prior to the application of the GWP.

GWPs for HFC and PFC depend on the specific fluorinated species. Values for some other pollutants can be found in the IPCC report. However, most of the pollutants outside of the six Kyoto pollutants (e.g., precursors) will not have GWPs. So,

Table 3-2. 100-year GWPs from IPCC *Fourth Assessment Report.*

Pollutant	GWP_{100}
CO_2	1
CH_4	25
N_2O	298
SF_6	22,800

for any of these other pollutants reported in the inventory, no CO_2 equivalent (CO_{2e}) emissions can be developed. Even if GWPs are available for a pollutant, the original mass emissions for that pollutant should still be reported in addition to the CO_{2e} emissions.

> Both the mass emissions of each of the non-CO_2 pollutants and its CO_{2e} emissions should be reported.

The 100-year notation in Table 3-2 refers to the corresponding time horizon for the GWP values. In keeping with the general protocols of both IPCC and USEPA, the GWP_{100} values should always be used. Whether the GWPs for other time horizons should be used (i.e., in addition to GWP_{100}) will depend on the needs of the airport and/or the purpose of the inventory.

The following is an example calculation for 10 metric tons of CH_4:

$$CO_{2e}\text{ emissions} = (10\text{ metric tons }CH_4)\times(25\ GWP_{100}\text{ for }CH_4) = 250\text{ metric tons }CO_{2e}$$

The recommended format for reporting CO_{2e} is exemplified in Table 3-3.

As indicated in the table, the mass emissions of each pollutant are reported along with CO_{2e} values. This is recommended as it would enable swift updates to the CO_{2e} should new and improved GWPs be developed in the future. Further information on CO_{2e} can be found in Appendix D.

Table 3-3. Example format for reporting equivalencies (CO_{2e}).

	Annual Metric Tons				
Metrics	CO_2	CH_4	N_2O	SF_6	Others
Source X Emissions	1,000	4	2	0.01	Not Assessed
GWP_{100}	1	25	298	22,800	
CO_{2e}	1,000	100	596	228	Not Assessed
Total CO_{2e}	1,924				

Note: The above GWP_{100} factors represent emissions from IPCC's *Fourth Assessment Report*.

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Acronyms

AB32	Assembly Bill 32 (California)
AEDT	Aviation Environmental Design Tool
AERO2K	The EC's Global Aircraft Emissions Inventory Model/Project
ALP	Airport Layout Plan
APU	Auxiliary power unit
AVI	Automatic Vehicle Identification
BFFM2	Boeing Fuel Flow Method 2
Btu	British thermal unit
C	Carbon
CAEP	Committee on Aviation Environmental Protection
CARB	California Air Resources Board
CCP	Climate Protection Program of ICLEI
CEQ	Council on Environmental Quality
CEQA	California Environmental Quality Act
CFR	Code of Federal Regulations
CH_4	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
DLR	Deutsche Forschungsanstalt fur Luft- and Raumfahrt
EC	European Commission
EDMS	Emissions and Dispersion Modeling System
EF	Emission factor
EI	Emission index
EIA	Energy Information Administration of the Department of Energy
EIR	Environmental Impact Report
EMFAC	CARB's Mobile Source Emission Factor Model
FB	Fuel burn
FOA	First Order Approximation
FOI	Swedish Defense Research Agency
ft^3	Cubic feet
GAV	Ground access vehicle
GHG	Greenhouse gas
GJ	Giga joules
GSE	Ground support equipment
GTP	Global temperature potential
GWP	Global warming potential
g-bhp-hr	Grams per brake horsepower hour
H_2O	Water
HAP	Hazardous air pollutant
HFC	Hydrofluorocarbons
ICAO	International Civil Aviation Organization
ICCAIA	International Coordinating Council for Aerospace Industries Associations
ICLEI	International Council for Local Environmental Initiatives
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hour
LPG	Liquefied petroleum gas
LTO	Landing and takeoff
MEPA	Massachusetts Environmental Policy Act
Mini-NEPA	State equivalents of the National Environmental Policy Act (such as MEPA, CEQA), etc.
mmBtu	Million British thermal units
MMT	Million metric tons per year
MOBILE	EPA's Mobile Source Emissions Model
MOVES	Motor Vehicle Emissions Simulator
MSW	Municipal solid waste
MTCE	Metric tons of carbon equivalent
$MTCO_2E$	Metric tons of carbon dioxide equivalent
MWh	Megawatt hour
N_2O	Nitrous oxide
NEG/ECP	New England Governors and Eastern Canadian Premiers
NEPA	National Environmental Policy Act
NMHC	Non-methane hydrocarbons
NMOG	Non-methane organic gases
NMVOC	Non-methane volatile organic compounds
NO_2	Nitrogen dioxide

NONROAD	EPA's Non-Road Equipment Emissions Model
NO_x	Nitrogen oxides
O_3	Ozone
OD	Origin-destination
OFFROAD	CARB's Off-Road Equipment Emissions Model
PFC	Passenger facility charges
PFC	Perfluorocarbons
PM	Particulate matter
$PM_{2.5}$	Particulate matter with aerodynamic diameters less than 2.5 μm
PM_{10}	Particulate matter with aerodynamic diameters less than 10 μm
POV	Privately owned vehicle
RF	Radiative forcing
RFI	Radiative forcing index
SAGE	System for assessing aviation's global emissions
SCP	Seattle Climate Partnership
SEPA	Washington State Environmental Policy Act
SMF	Sacramento International Airport
SN	Smoke number
SO_x	Sulfur oxides
TCR	The Climate Registry
THC	Total Hydrocarbons
TJ	Tera joules
TOG	Total organic gases
TPY	Short tons per year
TTN	Technology Transfer Network
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compounds
WRI	World Resources Institute
WBCSD	World Business Council for Sustainable Development

Glossary

Absorption of Radiation: The uptake of radiation by a solid body, liquid, or gas. The absorbed energy may be transferred or re-emitted.

Aerosol: Particulate matter, solid or liquid, larger than a molecule but small enough to remain suspended in the atmosphere. Natural sources include salt particles from sea spray, dust and clay particles as a result of weathering of rocks, both of which are carried upward by the wind. Aerosols can also originate as a result of human activities and are often considered pollutants. Aerosols are important in the atmosphere as nuclei for the condensation of water droplets and ice crystals, as participants in various chemical cycles, and as absorbers and scatterers of solar radiation, thereby influencing the radiation budget of the Earth's climate system.

Air Carrier: An operator (e.g., airline) in the commercial system of air transportation consisting of aircraft that hold certificates of Public Convenience and Necessity issued by the department of transportation to conduct scheduled or nonscheduled flights within the country or abroad.

Air Pollution: One or more chemicals or substances in high enough concentrations in the air to harm humans, other animals, vegetation, or materials. Such chemicals or physical conditions (such as excess heat or noise) are called air pollutants.

Alternative Energy: Energy derived from nontraditional sources (e.g., compressed natural gas, solar, hydroelectric, wind).

Anthropogenic: Human made. In the context of GHGs, anthropogenic emissions are produced as the result of human activities.

Atmosphere: The mixture of gases surrounding the Earth. The Earth's atmosphere consists of about 79.1% nitrogen (by volume), 20.9% oxygen, 0.036% carbon dioxide, and trace amounts of other gases. The atmosphere can be divided into a number of layers according to its mixing or chemical characteristics, generally determined by its thermal properties (temperature). The layer nearest the Earth is the troposphere, which reaches up to an altitude of about 8 km (about 5 mi) in the polar regions, and up to 17 km (nearly 11 mi) above the equator. The stratosphere, which reaches to an altitude of about 50 km (31 mi) lies atop the troposphere. The mesosphere extends from 80 to 90 km (50 to 56 mi) atop the stratosphere, and finally, the thermosphere, or ionosphere, gradually diminishes and forms a fuzzy border with outer space. There is relatively little mixing of gases between layers.

Aviation Gasoline: All special grades of gasoline for use in aviation reciprocating engines, as cited in ASTM Specification D 910. Includes all refinery products within the gasoline range that are to be marketed straight or in blends as aviation gasoline without further processing (any refinery operation except mechanical blending). Also included are finished components in the gasoline range, which will be used for blending or compounding into aviation gasoline.

Biodegradable: Material that can be broken down into simpler substances (elements and compounds) by bacteria or other decomposers. Paper and most organic wastes such as animal manure are biodegradable.

Biofuel: Gas or liquid fuel made from plant material (biomass). Includes wood, wood waste, wood liquors, peat, railroad ties, wood sludge, spent sulfite liquors, agricultural waste, straw, tires, fish oils, tall oil, sludge waste, waste alcohol, municipal solid waste, landfill gases, other waste, and ethanol blended into motor gasoline.

Biomass: Total dry weight of all living organisms that can be supported at each tropic level in a food chain. Also, materials that are biological in origin, including organic material (both living and dead) from above and below ground, for example, trees, crops, grasses, tree litter, roots, and animals and animal waste.

Biomass Energy: Energy produced by combusting biomass materials such as wood. The carbon dioxide emitted from burning biomass will not increase total atmospheric carbon dioxide if this consumption is done on a sustainable basis (i.e., if in a given period of time, re-growth of biomass takes up as much carbon dioxide as is released from biomass combustion). Biomass energy is often suggested as a replacement for fossil fuel combustion.

British Thermal Unit (Btu): The quantity of heat required to raise the temperature of one pound of water one degree of Fahrenheit at or near 39.2 degrees Fahrenheit.

Bunker Fuel: Fuel supplied to ships and aircraft for international transportation, irrespective of the flag of the carrier, consisting primarily of residual and distillate fuel oil for ships and jet fuel for aircraft.

Carbon Black: An amorphous form of carbon, produced commercially by thermal or oxidative decomposition of hydrocarbons and used principally in rubber goods, pigments, and printer's ink.

Carbon Cycle: All carbon reservoirs and exchanges of carbon from reservoir to reservoir by various chemical, physical, geological, and biological processes. Usually thought of as a series of the four main reservoirs of carbon interconnected by pathways of exchange. The four reservoirs, regions of the Earth in which carbon behaves in a systematic manner, are the atmosphere, terrestrial biosphere (usually includes freshwater systems), oceans, and sediments (includes fossil fuels). Each of these global reservoirs may be subdivided into smaller pools, ranging in size from individual communities or ecosystems to the total of all living organisms (biota).

Carbon Dioxide: A colorless, odorless, nonpoisonous gas that is a normal part of the ambient air. Carbon dioxide is a product of fossil fuel combustion. Although carbon dioxide does not directly impair human health, it is a GHG that traps terrestrial (i.e., infrared) radiation and contributes to the potential for global warming.

Carbon Equivalent (CE) or Carbon Dioxide Equivalent (CO_{2e}): A metric measure used to compare the emissions of the different GHGs based upon their global warming potential (GWP). GHG emissions in the United States are most commonly expressed as "million metric tons of carbon equivalents" (MMTCE). Global warming potentials are used to convert GHGs to carbon dioxide equivalents.

Carbon Sequestration: The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, release the oxygen and store the carbon. Fossil fuels were at one time biomass and continue to store the carbon until burned.

Carbon Sinks: Carbon reservoirs and conditions that take in and store more carbon (i.e., carbon sequestration) than they release. Carbon sinks can serve to partially offset GHG emissions. Forests and oceans are large carbon sinks.

Carbon Tetrachloride (CCl_4): A compound consisting of one carbon atom and four chlorine atoms. It is an ozone-depleting substance. Carbon tetrachloride was widely used as a raw material in many industrial applications, including the production of chlorofluorocarbons, and as a solvent. Solvent use was ended in the United States when it was discovered to be carcinogenic.

Chlorofluorocarbons (CFCs): Organic compounds made up of atoms of carbon, chlorine, and fluorine. An example is CFC-12 (CCl_2F_2), used as a refrigerant in refrigerators and air conditioners and as a foam-blowing agent. Gaseous CFCs can deplete the ozone layer when they slowly rise into the stratosphere, are broken down by strong ultraviolet radiation, release chlorine atoms, and then react with ozone molecules.

Climate: The average weather, usually taken over a 30-year time period, for a particular region and time period. Climate is not the same as weather, but rather, it is the average pattern of weather for a particular region. Weather describes the short-term state of the atmosphere. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hailstorms, and other measures of the weather.

Climate Change: The term *climate change* is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, *climate change* has been used synonymously with the term *global warming;* scientists however, tend to use the term in the wider sense to also include natural changes in climate.

Climate Feedback: An atmospheric, oceanic, terrestrial, or other process that is activated by direct climate change induced by changes in radiative forcing. Climate feedbacks may increase (positive feedback) or diminish (negative feedback) the magnitude of the direct climate change.

Climate System (or Earth System): The atmosphere, the oceans, the biosphere, the cryosphere, and the geosphere, together make up the climate system.

Combustion: Chemical oxidation accompanied by the generation of light and heat.

Concentration: Amount of a chemical in a particular volume or weight of air, water, soil, or other medium.

Contrail: Contrails are line-shaped clouds or condensation trails, composed of ice particles that are visible behind jet aircraft engines, typically at cruise altitudes in the upper atmosphere. Aircraft engines emit water vapor, carbon dioxide (CO_2), small amounts of nitrogen oxides (NO_x), hydrocarbons, carbon monoxide, sulfur gases, and soot and metal particles formed by the high-temperature combustion of jet fuel during flight.

Criteria Pollutant: A pollutant determined to be hazardous to human health and regulated under the USEPA's National Ambient Air Quality Standards. The 1970 amendments to the Clean Air Act require USEPA to describe the health and welfare impacts of a pollutant as the "criteria" for inclusion in the regulatory regime. In this report, emissions of the criteria pollutants are carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and sulfur oxides (SO_x).

Distillate Fuel Oil: A general classification for the petroleum fractions produced in conventional distillation operations. Included are products known as No. 1, No. 2, and No. 4 fuel oils and No. 1, No. 2, and No. 4 diesel fuels. Used primarily for space heating, on- and off-highway diesel engine fuel (including railroad engine fuel and fuel for agricultural machinery), and electric power generation.

Emission Factor: The rate at which pollutants are emitted into the atmosphere by one source or a combination of sources.

Emission Inventory: A list of air pollutants emitted into the atmosphere of a community, state, nation, or the Earth, in amounts per some unit time (e.g., day or year) by type of source. An emission inventory has both political and scientific applications.

Emissions Coefficient/Factor: A unique value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g., grams of carbon dioxide emitted per barrel of fossil fuel consumed).

Emissions: Releases of gases to the atmosphere (e.g., the release of carbon dioxide during fuel combustion). Emissions can be either intended or unintended releases.

Energy Conservation: Reduction or elimination of unnecessary energy use and waste.

Energy Intensity: Ratio between the consumption of energy to a given quantity of output; usually refers to the amount of primary or final energy consumed per unit of gross domestic product.

Energy Quality: Ability of a form of energy to do useful work. High-temperature heat and the chemical energy in fossil fuels and nuclear fuels are concentrated high-quality energy. Low-quality energy such as low-temperature heat is dispersed or diluted and cannot do much useful work.

Energy: The capacity for doing work as measured by the capability of doing work (potential energy) or the conversion of this capability to motion (kinetic energy). Energy has several forms, some of which are easily convertible and can be changed to another form useful for work. Most of the world's convertible energy comes from fossil fuels that are burned to produce heat that is then used as a transfer medium to mechanical or other means in order to accomplish tasks. In the United States, electrical energy is often measured in kilowatt hours (kWh), while heat energy is often measured in British thermal units (Btu).

Energy-Efficiency: The ratio of the useful output of services from an article of industrial equipment to the energy use by such an article; for example, vehicle miles traveled per gallon of fuel (mpg).

Enhanced Greenhouse Effect: The concept that the natural greenhouse effect has been enhanced by anthropogenic emissions of GHGs. Increased concentrations of carbon dioxide, methane, and nitrous oxide, CFCs, HFCs, PFCs, SF_6, NF_3, and other photochemically important gases caused by human activities such as fossil fuel consumption, trap more infrared radiation, thereby exerting a warming influence on the climate.

Enplanements: The number of passengers on a departing aircraft.

Ethanol (C_2H_5OH): Otherwise known as ethyl alcohol, alcohol, or grain spirit. A clear, colorless, flammable oxygenated hydrocarbon with a boiling point of 78.5 degrees Celsius in the anhydrous state. In transportation, ethanol is used as a vehicle fuel by itself (E100), blended with gasoline (E85), or as a gasoline octane enhancer and oxygenate (10% concentration).

FAA ASDi (Aircraft Situation Display to Industry): This represents data collected by the FAA that tracks the minute-by-minute progress of their aircraft in real-time. The ASDI information includes the location, altitude, airspeed, destination, estimated time of arrival, and tail number or designated identifier of air carrier and general aviation aircraft operating on IFR flight plans within U.S. airspace.

FAA T-1 Data: This database refers to information collected by the FAA and reported by the Bureau of Transportation Statistics concerning on-time arrival data for non-stop domestic flights by major air carriers, and provides such additional items as departure and arrival delays, origin and destination airports, flight numbers, scheduled and actual departure and arrival times, cancelled or diverted flights, taxi-out and taxi-in times, air time, and non-stop distance.

Fixed-Based Operator (FBO): A private operator that may conduct refueling, aircraft, or ground support equipment services for others at the airport.

Fluorocarbons: Carbon-fluorine compounds that often contain other elements such as hydrogen, chlorine, or bromine. Common fluorocarbons include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

Forcing Mechanism: A process that alters the energy balance of the climate system (i.e., changes the relative balance between incoming solar radiation and outgoing infrared radiation from Earth). Such mechanisms include changes in solar irradiance, volcanic eruptions, and enhancement of the natural greenhouse effect by emission of carbon dioxide.

Forest: Terrestrial ecosystem (biome) with enough average annual precipitation (at least 76 cm or 30 in.) to support growth of various species of trees and smaller forms of vegetation.

Fossil Fuel: A general term for buried combustible geologic deposits of organic materials, formed from decayed plants and animals that have been converted to crude oil, coal, natural gas, or heavy oils by exposure to heat and pressure in the Earth's crust over hundreds of millions of years.

Fossil Fuel Combustion: Burning of coal, oil (including gasoline), or natural gas. The burning needed to generate energy releases carbon dioxide by-products that can include unburned hydrocarbons, methane, and carbon monoxide. Carbon monoxide, methane, and many of the unburned hydrocarbons slowly oxidize into carbon dioxide in the atmosphere. Common sources of fossil fuel combustion include cars and electric utilities.

Freon: See *chlorofluorocarbons.*

Fugitive Emissions: Unintended gas leaks from the processing, transmission, and/or transportation of fossil fuels, CFCs from refrigeration leaks, SF_6 from electrical power distributor, etc.

General Aviation: The portion of civil aviation that encompasses all facets of aviation except air carriers. It includes any air taxis, commuter air carriers, and air travel clubs that do not hold Certificates of Public Convenience and Necessity.

Global Warming Potential (GWP): The index used to translate the level of emissions of various gases into a common measure in order to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emissions of 1 kg of a GHG to that from the emission of 1 kg of carbon dioxide over a period of time (usually 100 years). Gases involved in complex atmospheric chemical processes have not been assigned GWPs.

Global Warming: The progressive gradual rise of the Earth's surface temperature thought to be caused by the greenhouse effect and responsible for changes in global climate patterns.

Greenhouse Effect: Trapping and build-up of heat in the atmosphere (troposphere) near the Earth's surface. Some of the heat flowing back toward space from the Earth's surface is absorbed by water vapor, carbon dioxide, ozone, and several other gases in the atmosphere and then reradiated back toward the Earth's surface. If the atmospheric concentrations of these GHGs rise, the average temperature of the lower atmosphere will gradually increase.

Greenhouse Gas (GHG): Any gas that absorbs infrared radiation in the atmosphere. GHGs include, but are not limited to, water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrochlorofluorocarbons (HCFCs), ozone (O_3), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Halocarbons: Chemicals consisting of carbon, sometimes hydrogen, and either chlorine, fluorine, bromine, or iodine.

Hydrocarbons: Substances containing only hydrogen and carbon. Fossil fuels are made up of hydrocarbons.

Hydrochlorofluorocarbons (HCFCs): Compounds containing hydrogen, fluorine, chlorine, and carbon atoms. Although ozone-depleting substances, they are less potent at destroying stratospheric ozone than chlorofluorocarbons (CFCs). They have been introduced as temporary replacements for CFCs and are also GHGs.

Hydrofluorocarbons (HFCS): Compounds containing only hydrogen, fluorine, and carbon atoms. They were introduced as alternatives to ozone-depleting substances in serving many industrial, commercial, and personal needs. HFCs are emitted as by-products of industrial processes and are also used in manufacturing. They do not significantly deplete the stratospheric ozone layer, but they are powerful GHGs with global warming potentials ranging from 140 (HFC-152a) to 11,700 (HFC-23).

Hydrosphere: All of the Earth's liquid water (oceans, smaller bodies of fresh water, and underground aquifers), frozen water (polar ice caps, floating ice, and frozen upper layer of soil known as permafrost), and small amounts of water vapor in the atmosphere.

Infrared Radiation: The heat energy that is emitted from all solids, liquids, and gases. In the context of the greenhouse issue, the term refers to the heat energy emitted by the Earth's surface and its atmosphere. GHGs strongly absorb this radiation in the Earth's atmosphere, and re-radiate some of it back toward the surface, creating the greenhouse effect.

Inorganic Compound: Combination of two or more elements other than those used to form organic compounds.

Intergovernmental Panel on Climate Change (IPCC): The IPCC was established jointly by the United Nations Environment Programme and the World Meteorological Organization in 1988. The purpose of the IPCC is to assess information in the scientific and technical literature related to all significant components of the issue of climate change. The IPCC draws upon hundreds of the world's expert scientists as authors and thousands as expert reviewers. Leading experts on climate change and environmental, social, and economic sciences from some 60 nations have helped the IPCC prepare periodic assessments of the scientific underpinnings for understanding global climate change and its consequences. With its capacity for reporting on climate change, its consequences, and the viability of adaptation and mitigation measures, the IPCC is also looked to as the official advisory body to the world's governments on the state of the science of the climate change issue. For example, the IPCC organized the development of internationally accepted methods for conducting national GHG emission inventories.

International Council for Local Environmental Initiatives (ICLEI): http://rds.yahoo.com/_ylt=A0oGklceR8tGshwA61NXNyoA;_ylu=X3oDMTE5NmF1MzA3BHNlYwNzcgRwb3MDMQRjb2xvA3NrMQR2dGlkA0Y4NjJfMTI1BGwDV1Mx/SIG=119u5jimp/EXP=1187813534/**http%3a/www.iclei.org/ is an international association of local governments and national and regional local government organizations that have made a commitment to sustainable development. More than 630 cities, towns, counties, and their associations worldwide comprise ICLEI's growing membership. ICLEI works with these and hundreds of other local governments through international performance-based, results-oriented campaigns and programs. The ICLEI Cities for Climate Protection (CCP) Campaign assists cities in adopting policies and implementing quantifiable measures to reduce local GHG emissions, improve air quality, and enhance urban livability and sustainability. More than 800 local governments participate in the CCP, integrating climate change mitigation into their decision-making processes. See http://www.iclei.org/index.php?id=800

Jet Fuel: Includes both naphtha-type and kerosene-type fuels meeting standards for use in aircraft turbine engines. Although most jet fuel is used in aircraft, some is used for other purposes such as generating electricity.

Joule: The energy required to push with a force of one Newton for one meter.

Kerosene: A petroleum distillate that has a maximum distillation temperature of 401 degrees Fahrenheit at the 10% recovery point, a final boiling point of 572 degrees Fahrenheit, and a minimum flash point of 100 degrees Fahrenheit. Used in space heaters, cookstoves, and water heaters, and suitable for use as an illuminant when burned in wick lamps.

Kyoto Protocol: An international agreement struck by nations attending the Third Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (held in December of 1997 in Kyoto, Japan) to reduce worldwide emissions of GHGs. If ratified and put into force, individual countries have committed to reduce their GHG emissions by a specified amount.

Landing and Takeoff Cycle (LTO): One aircraft LTO is equivalent to two aircraft operations (one landing and one takeoff). The standard LTO cycle begins when the aircraft crosses into the mixing zone as it approaches the airport on its descent from cruising altitude, lands, and taxis to the gate. The cycle continues as the aircraft taxis back out to the runway for takeoff and climbout as it heads out of the mixing zone and back up to cruising altitude. The five specific operating modes in a standard LTO are: approach, taxi/idle-in, taxi/idle-out, takeoff, and climbout. Most aircraft go through this sequence during a complete standard operating cycle.

Lifetime (Atmospheric): The lifetime of a GHG refers to the approximate amount of time it would take for the anthropogenic increment to an atmospheric pollutant concentration to return to its natural level (assuming emissions cease) as a result of either being converted to another chemical compound or being taken out of the atmosphere via a sink. This time depends on the pollutant's sources and sinks as well as its reactivity. The lifetime of a pollutant is often considered in conjunction with the mixing of pollutants in the atmosphere; a long lifetime will allow the pollutant to mix throughout the atmosphere. Average lifetimes can vary from about a week (e.g., sulfate aerosols) to more than a century (e.g., CFCs, carbon dioxide).

Light-Duty Vehicles: Automobiles and light trucks combined.

Liquefied Natural Gas (LNG): Natural gas converted to liquid form by cooling to a very low temperature.

Liquefied Petroleum Gas (LPG): Ethane, ethylene, propane, propylene, normal butane, butylene, and isobutane produced at refineries or natural gas processing plants, including plants that fractionate new natural gas plant liquids.

Longwave Radiation: The radiation emitted in the spectral wavelength greater than 4 μm corresponding to the radiation emitted from the Earth and atmosphere. It is sometimes, although somewhat imprecisely, referred to as terrestrial radiation or infrared radiation.

Low-Emission Vehicle (LEV): A vehicle meeting the low-emission vehicle standards.

Methane (CH_4): A hydrocarbon that is a GHG with a global warming potential most recently estimated at 21. Methane is produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and petroleum, coal production, and incomplete fossil fuel combustion. The atmospheric concentration of methane has been shown to be increasing at a rate of about 0.6% per year and the concentration of about 1.7 per million by volume (ppmv) is more than twice its pre-industrial value. However, the rate of increase of methane in the atmosphere may be stabilizing.

Methanol (CH_3OH): A colorless, poisonous liquid with essentially no odor and little taste. It is the simplest alcohol with a boiling point of 64.7 degrees Celsius. In transportation, methanol is used as a vehicle fuel by itself (M100) or blended with gasoline (M85).

Metric Ton: Common international measurement for the quantity of GHG emissions. A metric ton is equal to 1,000 kg, 2,204.6 lbs, or 1.1023 short tons.

Mixing Height: The height of the completely mixed portion of atmosphere that begins at the earth's surface and extends to a few thousand feet overhead where the atmosphere becomes fairly stable.

Mobile Source: A moving vehicle that emits pollutants. Such sources include airplanes, cars, trucks, and ground support equipment.

Montreal Protocol on Substances that Deplete the Ozone Layer: The Montreal Protocol and its amendments control the phase-out of ozone-depleting substances production and use. Under the Protocol, several international organizations report on the science of ozone-depletion, implement projects to help move away from ozone-depleting substances, and provide a forum for policy discussions. In the United States, the Protocol is implemented under the rubric of the Clean Air Act Amendments of 1990.

Natural Gas: Underground deposits of gases consisting of 50% to 90% methane (CH_4) and small amounts of heavier gaseous hydrocarbon compounds such as propane (C_3H_4) and butane (C_4H_{10}).

Nitrogen Cycle: Cyclic movement of nitrogen in different chemical forms from the environment to organisms, and then back to the environment.

Nitrogen Oxides (NO_x): Gases consisting of one molecule of nitrogen and varying numbers of oxygen molecules. Nitrogen oxides are produced, for example, by the combustion of fossil fuels in vehicles and electric power plants. In the atmosphere, nitrogen oxides can contribute to formation of photochemical ozone (smog), impair visibility, and have health consequences; they are considered pollutants.

Nitrous Oxide (N_2O): A powerful GHG with a global warming potential most recently evaluated at 310. Major sources of nitrous oxide include soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

Nonbiodegradable: Substance that cannot be broken down in the environment by natural processes.

Non-Methane Volatile Organic Compounds (NMVOCs): Organic compounds, other than methane, that participate in atmospheric photochemical reactions.

Non-Point Source: Large land area such as crop fields and urban areas that discharge pollutant into surface and underground water over a large area.

Nuclear Electric Power: Electricity generated by an electric power plant whose turbines are driven by steam generated in a reactor by heat from the fissioning of nuclear fuel.

Nuclear Energy: Energy released when atomic nuclei undergo a nuclear reaction such as the spontaneous emission of radioactivity, nuclear fission, or nuclear fusion.

Organic Compound: Molecule that contains atoms of the element carbon, usually combined with itself and with atoms of one or more other element such as hydrogen, oxygen, nitrogen, sulfur, phosphorus, chlorine, or fluorine.

Oxidize: To chemically transform a substance by combining it with oxygen.

Oxygen Cycle: Cyclic movement of oxygen in different chemical forms from the environment to organisms, and then back to the environment.

Ozone: A colorless gas with a pungent odor, having the molecular form of O_3, found in two layers of the atmosphere, the stratosphere and the troposphere. Ozone is a form of oxygen found naturally in the stratosphere that provides a protective layer shielding the Earth from ultraviolet radiation's harmful health effects on humans and the environment. In the troposphere, ozone is a chemical oxidant and major component of photochemical smog. Ozone can seriously affect the human respiratory system.

Ozone-Depleting Substance (ODS): A family of man-made compounds that includes, but is not limited to, chlorofluorocarbons (CFCs), bromofluorocarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These compounds have been shown to deplete stratospheric ozone, and therefore are typically referred to as ODSs.

Ozone Layer: Layer of gaseous ozone (O_3) in the stratosphere that protects life on Earth by filtering out harmful ultraviolet radiation from the sun.

Ozone Precursors: Chemical compounds, such as carbon monoxide, methane, non-methane hydrocarbons, and nitrogen oxides that, in the presence of solar radiation, react with other chemical compounds to form ozone, mainly in the troposphere.

Particulate Matter (PM): Solid particles or liquid droplets suspended or carried in the air.

Parts Per Billion (ppb): Number of parts of a chemical found in one billion parts of a particular gas, liquid, or solid mixture.

Parts Per Million (ppm): Number of parts of a chemical found in one million parts of a particular gas, liquid, or solid.

Perfluorocarbons (PFCs): A group of human-made chemicals composed of carbon and fluorine only. These chemicals (predominantly CF_4 and C_2F_6) were introduced as alternatives, along with hydrofluorocarbons, to ozone-depleting substances. In addition, PFCs are emitted as by-products of industrial processes and are also used in manufacturing. PFCs do not harm the stratospheric ozone layer, but they are powerful GHGs: CF_4 has a global warming potential (GWP) of 6,500 and C_2F_6 has a GWP of 9,200.

Petroleum: A generic term applied to oil and oil products in all forms, such as crude oil, lease condensate, unfinished oils, petroleum products, natural gas plant liquids, and non-hydrocarbon compounds blended into finished petroleum products.

Point Source: A single identifiable source that discharges pollutants into the environment. Examples are a smokestack, sewer, ditch, or pipe.

Pollution: A change in the physical, chemical, or biological characteristics of the air, water, or soil that can affect the health, survival, or activities of humans in an unwanted way. Some expand the term to include harmful effects on all forms of life.

Polyvinyl Chloride (PVC): A polymer of vinyl chloride. It is tasteless, odorless, and insoluble in most organic solvents. A member of the family vinyl resin, used in soft flexible films for food packaging and in molded rigid products, such as pipes, fibers, upholstery, and bristles.

Radiation: Energy emitted in the form of electromagnetic waves. Radiation has differing characteristics depending upon the wavelength. Because the radiation from the Sun is relatively energetic, it has a short wavelength (e.g., ultraviolet, visible, and near infrared) while energy re-radiated from the Earth's surface and the atmosphere has a longer wavelength (e.g., infrared radiation) because the Earth is cooler than the Sun.

Radiative Forcing: A change in the balance between incoming solar radiation and outgoing infrared (i.e., thermal) radiation. Without any radiative forcing, solar radiation coming to the Earth would continue to be approximately equal to the infrared radiation emitted from the Earth. The addition of GHGs to the atmosphere traps an increased fraction of the infrared radiation, reradiating it back toward the surface of the Earth and thereby creates a warming influence.

Recycling: Collecting and reprocessing a resource so it can be used again. An example is collecting aluminum cans, melting them down, and using the aluminum to make new cans or other aluminum products.

Reforestation: Replanting of forests on lands that have been harvested recently.

Renewable Energy: Energy obtained from sources that are essentially inexhaustible, unlike, for example, fossil fuels, of which there is a finite supply. Renewable sources of energy include wood, waste, geothermal, wind, photovoltaic, and solar thermal energy.

Residence Time: Average time spent in a reservoir by an individual atom or molecule. Also, this term is used to define the age of a molecule when it leaves the reservoir. With respect to GHGs, residence time usually refers to how long a particular molecule remains in the atmosphere.

Sector: Division, most commonly used to denote type of energy consumer (e.g., residential) or according to the Intergovernmental Panel on Climate Change, the type of GHG emitter (e.g., industrial process).

Short Ton: Common measurement for a ton in the United States. A short ton is equal to 2,000 lbs. or 0.907 metric tons.

Sink: A reservoir that uptakes a pollutant from another part of its cycle. Soil and trees tend to act as natural sinks for carbon.

Solar Energy: Direct radiant energy from the Sun. It also includes indirect forms of energy such as wind, falling or flowing water (hydropower), ocean thermal gradients, and biomass, which are produced when direct solar energy interacts with the Earth.

Solar Radiation: Energy from the Sun. Also referred to as short-wave radiation. Of importance to the climate system, solar radiation includes ultraviolet radiation, visible radiation, and infrared radiation.

Source: Any process or activity that releases a GHG, an aerosol, or a precursor of a GHG into the atmosphere.

Special Naphtha: All finished products within the naphtha boiling range that are used as paint thinners, cleaners, or solvents. Those products are refined to a specified flash point.

Still Gas: Any form or mixture of gases produced in refineries by distillation, cracking, reforming, and other processes. Principal constituents are methane, ethane, ethylene, normal butane, butylene, propane, propylene, etc. Used as a refinery fuel and as a petrochemical feedstock.

Stratosphere: Second layer of the atmosphere, extending from about 19 to 48 km (12 to 30 mi) above the Earth's surface. It contains small amounts of gaseous ozone (O_3), which filters out about 99% of the incoming harmful ultraviolet (UV) radiation. Most commercial airline flights operate at a cruising altitude in the lower stratosphere.

Stratospheric Ozone: See *ozone layer.*

Sulfur Cycle: Cyclic movement of sulfur in different chemical forms from the environment to organisms, and then back to the environment.

Sulfur Dioxide (SO_2): A compound composed of one sulfur and two oxygen molecules. Sulfur dioxide emitted into the atmosphere through natural and anthropogenic processes is changed in a complex series of chemical reactions in the atmosphere to sulfate aerosols. These aerosols are believed to result in negative radiative forcing (i.e., tending to cool the Earth's surface) and do result in acid deposition (e.g., acid rain).

Sulfur Hexafluoride (SF_6): A colorless gas soluble in alcohol and ether, slightly soluble in water. A very powerful GHG used primarily in electrical transmission and distribution systems and as a dielectric in electronics. The global warming potential of SF_6 is 23,900.

Synthetic Natural Gas (SNG): A manufactured product chemically similar in most respects to natural gas, resulting from the conversion or reforming of petroleum hydrocarbons. It may be substituted easily for, or interchanged with, pipeline quality natural gas.

Temperature: Measure of the average speed of motion of the atoms or molecules in a substance or combination of substances at a given moment.

Terrestrial: Pertaining to land.

Terrestrial Radiation: The total infrared radiation emitted by the Earth and its atmosphere in the temperature range of approximately 200 to 300 degrees K. Terrestrial radiation provides a major part of the potential energy changes necessary to drive the atmospheric wind system and is responsible for maintaining the surface air temperature within limits of livability.

Transportation Sector: Consists of private and public passenger and freight transportation, as well as government transportation, including military operations.

Troposphere: The lowest layer of the atmosphere, which contains about 95% of the mass of air in the Earth's atmosphere. The troposphere extends from the Earth's surface up to about 10 to 15 km (6 to 12 mi). All weather processes take place in the troposphere. Ozone that is formed in the troposphere plays a significant role in both the GHG effect and urban smog.

Ultraviolet Radiation (UV): A portion of the electromagnetic spectrum with wavelengths shorter than visible light. The sun produces UV, which is commonly split into three bands of decreasing wavelength. Shorter wavelength radiation has a greater potential to cause biological damage on living organisms. The longer wavelength ultraviolet band, UVA, is not absorbed by ozone in the atmosphere. UVB is mostly absorbed by ozone, although some reaches the Earth. The shortest wavelength band, UVC, is completely absorbed by ozone and normal oxygen in the atmosphere.

United Nations Framework Convention on Climate Change (UNFCCC): The international treaty unveiled at the United Nations Conference on Environment and Development (UNCED) in June 1992. The UNFCCC commits signatory countries to stabilize anthropogenic (i.e., human-induced) GHG emissions to "levels that would prevent dangerous anthropogenic interference with the climate system." The UNFCCC also requires that all signatory parties develop and update national inventories of anthropogenic emissions of all GHGs not otherwise controlled by the Montreal Protocol. See http://www.ipcc.ch/

Vehicle Miles Traveled (VMT): One vehicle traveling the distance of 1 mi. Thus, total vehicle miles is the total mileage traveled by all vehicles.

Volatile Organic Compounds (VOCs): Organic compounds that evaporate readily into the atmosphere at normal temperatures. VOCs contribute significantly to photochemical smog production and certain health problems.

Water Vapor: The most abundant GHG; it is the water present in the atmosphere in gaseous form. Water vapor is an important part of the natural greenhouse effect. Although humans are not significantly increasing its concentration, it contributes to the enhanced greenhouse effect because the warming influence of GHGs leads to a positive water vapor feedback. In addition to its role as a natural GHG, water vapor plays an important role in regulating the temperature of the planet because clouds form when excess water vapor in the atmosphere condenses to form ice and water droplets and precipitation.

Weather: Weather is the specific condition of the atmosphere at a particular place and time. It is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour to hour, day to day, and season to season. Climate is the average of weather over time and space. A simple way of remembering the difference is that climate is what you expect (e.g., cold winters) and weather is what you get (e.g., a blizzard).

World Resource Institute (WRI): The World Resources Institute (WRI) is an environmental think tank. WRI, in combination with the World Business Council for Sustainable Development published guidance in 2005 concerning the development of GHG inventories. See www.wri.org

Frequently Asked Questions

1. **Question: Why should an airport prepare a GHG inventory and what are the benefits of having one?**

   Answer: Currently, GHG inventories are voluntary on a national level, but there may be state or local requirements to prepare an inventory. Such local requirements could be to (1.) include the inventory in a climate action plan, (2.) meet a local requirement to register a governmental entity's emissions in a climate registry, (3.) meet a state NEPA-like disclosure requirement. All other inventories would likely be voluntary. Section 1.4 of the *Guidebook* discusses the categories of inventories.

   The benefits of preparing an inventory include: being prepared for future legislation and related requirements, understanding emissions and fuel consumption-related efficiencies, and demonstrating environmental leadership. By preparing GHG inventories over time, an airport can consider trends and compare these inventories against other airport inventories as well as other emission sources.

2. **Question: What sources are to be captured in the airport inventory?**

   Answer: The sources to be reflected in an inventory depend on the purpose of the inventory. As discussed in Sections 2.1 to 2.4 of the *Guidebook,* a climate action inventory generally reflects all sources that operate at an airport, ranging from aircraft to GSE to GAVs, etc. The geographic boundary of the inventory ranges from departing aircraft (the entire flight segment from the airport to its destination) to ground access vehicles for the entire ground movement associated with the air travel (such as the ground travel to arrive at the airport and then return upon completion of the air travel).

   To enable the inventory to be policy relevant (a term used by various organizations to reflect the influence that an entity can have over the emissions), sources reflected in the inventory should be categorized by ownership and control. Thus, the sources that are owned and controlled by the airport operator should be noted first, followed by the sources owned and controlled by the airport tenants (airlines, fixed-based operators, concessions, etc), followed by other ground access vehicular access to the airport, referred to as the public category.

   For inventories prepared for purposes of a sustainability plan or NEPA-like state requirements, the inventories will typically focus on a subset of sources that are affected by the plan or the airport project. These inventories can present emissions using the same approach that is used for climate action plans, but limited to the sources reflected in the plan or project.

   Alternatively, sources can be reported as Scope 1, 2, or 3, which are shown in Table 2-2 of the *Guidebook,* relative to the specific sources, as follows:

   Scope 1/Direct emissions are from sources that are owned or controlled by the reporting entity. For an airport, the Scope 1 emissions would be those associated with ground vehicles owned and operated by the airport, as well as stationary sources.

   Scope 2/Indirect emissions are those from the generation of purchased electricity consumed by the entity.

   Scope 3/Indirect and Optional emissions are a consequence of the activities of the entity, but occur at sources owned or controlled by another party. Scope 3 would be the largest quantity of emissions at an airport, as they would include aircraft-related emissions, emissions from all tenant-related activities (including aircraft operations and the associated ground support activities) as well as the public's ground travel to and from the airport.

3. **Question: For what emissions is the airport operator responsible?**

   Answer: When evaluating ways to reduce emissions, the airport operator would be responsible for emissions that it owns and controls or over which it has some influence. The emissions that the airport owns and controls are the primary responsibility. This is further explained in Section 2.4.

4. **Question: How do I ensure that double counting does not occur with flight segments at other airports?**

   Answer: The approach recommended by this *Guidebook* strives to avoid double counting for all sources. When computing aircraft emissions, unless the airport operator owns aircraft, such emissions are associated with the tenant category and are considered Scope 3. To avoid double counting among airports, the calculation of aircraft emissions is recommended to represent one of the following two approaches:

   1. Fuel dispensed at an airport (Method 1 or 2) or
   2. If calculating emissions from each flight, only reflecting emissions from departures from the airport in Method 3.

   In this later approach, aircraft emissions should be assessed by individual legs of a flight, rather than the departure and final destination of multi-leg flights. For instance, a flight that leaves JFK, flying to ORD, then to DEN, and then to SFO, should attribute the flight from JFK to ORD to JFK, the flight from ORD to DEN to ORD, and the flight from DEN to SFO to DEN. Section 3.1 of the *Guidebook* discusses the methodology associated with all of these methods.

5. **Question: Won't including aircraft emissions for an entire flight (i.e., attributing all of a flight's emissions to the departure airport) give the wrong impression that the particular airport and jurisdiction is responsible for GHGs other than occurring within the jurisdiction?**

   Answer: Since the attribution of a flight's emissions is to the departure airport, the emissions are no longer "centered" around the airport as they are for criteria pollutants under the LTO cycle. As a result, this geographic distortion must be understood when policy decisions are made concerning the attribution of emissions to airports. This *Guidebook* currently follows the IPCC methodology in attributing all of a flight's emissions to the departure airport, which—when used uniformly—results in the prevention of double counting and consistency with the national EPA inventories. Section 2.5 provides further information on this issue.

6. **Question: Do I need to account for emissions above the mixing height (e.g., 3,000 ft or 914.4 m)?**

   Answer: Unlike criteria pollutants, GHGs emitted below the mixing height have an affect on global climate change; criteria pollutants emitted under the mixing height generally exert their primary effects locally. Therefore, the approach recommended to compute aircraft emissions reflects the emissions that occur below the mixing height as well as above. Aircraft Method 1 (using fuel-dispensed data) captures the fuel necessary to power aircraft from one airport to another. Method 2 uses the Method 1 quantity, but separates the emissions from below the mixing height versus above (with the LTO reflecting emissions below the mixing height). Method 3, as is expected to be provided annually by the FAA, will present emissions in the following three areas: ground, ground to 3,000 ft, and above 3,000 ft. Section 3.1 of the *Guidebook* discusses the procedures associated with all three methods.

7. **Question: Should emissions reductions from recycling be included?**

   Answer: Most airports have employed some form of recycling including passenger-related internal terminal waste, concessions food waste, construction materials and debris, etc. The *Guidebook*'s Section 3.6 provides methods that would enable the airport to capture the emissions reduction benefits associated with recycling (waste management) activities.

8. **Question: Should indirect emissions (e.g., electricity generation off airport property) be accounted for in the inventories?**

   Answer: In general, the answer to this depends on the purpose of the inventory. For climate action plan-type inventories, yes, indirect emissions should be captured. For project-related and sustainability plan inventories, this will depend on the project. Section 3.5.3 of the *Guidebook* provides an approach to account for electricity, which is considered a Scope 2 emission (see Section 2.2.2), if acquired from local power companies. Most airports purchase electricity from the grid, but those that generate their own electrical power through the consumption of various fossil fuels would report such fuel consumed to generate electricity as Scope 1. WRI and the various registries reflect electrical power acquired as Scope 2 (indirect) emissions.

9. **Question: Why is there a difference in approaches for developing inventories for criteria pollutants and GHG gases?**

   Answer: The international regime for computing criteria pollutants (carbon monoxide and ozone precursors) evolved to its current approach, which reflects local emissions (emissions within the mixing height, generally under 3,000-ft elevation) that occur by the main source categories of aircraft, GSE, GAV, and stationary sources.

Learning from this approach, the international approach to quantifying GHGs has evolved to reflect similar inventorying methods, but based on ownership and control. As is reflected in several of the documents supporting this approach, the inventory should relate to the ability of various parties to effect change and reduce emissions associated with the source. This is further discussed in Sections 1.7 and 2.4. Also, unlike criteria pollutants, the effects of GHGs cannot be attributed to a specific location (e.g., an "airport boundary"). As explained in Section 2.5, GHG emissions from aircraft and vehicles influenced by the airport need to be accounted for irrespective of where those emissions occur (e.g., beyond the airport boundary and above the mixing height).

10. **Question: How do the results of this *Guidebook* compare with the online carbon calculators for air travel?**

    Answer: A number of evaluations have been conducted by various parties; some of these are publicly available on Internet sites. As many of these reviews have shown, a user may get one result with one online calculator and a different result with another. These calculators are primarily designed to provide the user the emissions from one person's air travel, principally associated with aircraft usage. In contrast, the inventory produced using this *Guidebook* is designed to capture all of the emissions from sources at an airport (not just single flights), with aircraft likely to be the dominant source. The results of an airport inventory are not easily compared with those of an online calculator unless the airport inventory can identify the average flight distance of flights at an airport.

11. **Question: Why do online carbon calculators use a Radiative Forcing Index (RFI) and how do these relate to the methods in the *Guidebook*?**

    Answer: Several online calculators employ an RFI to account for many of the unknowns about the effects of aircraft emissions on climate change and some incorrectly use the RFI. The *Guidebook* does not recommend the use of an RFI for airport-related GHG inventories. Rather, similar to protocols for other industries, this *Guidebook* recommends that at a minimum, Level 1 inventories be prepared to show CO_2 emissions. For the standard Level 2 inventories, reflecting emissions of the six Kyoto GHGs, a CO_2 equivalent (CO_{2e}) is to be generated, reflecting the potential effect that non-CO_2 pollutants have on climate change, through the use of Global Warming Potentials (GWPs). As indicated in Section 3.8, the IPCC *Fourth Assessment Report* GWPs are suggested, but GWPs from older IPCC reports (e.g., *Second Assessment Report*) may be used for consistency with previous inventories and/or other protocols. Appendix D contains a discussion of RFI, GWPs, and other metrics.

12. **Question: The *Guidebook* recommends calculations for all sources. What should I do if data are not available for a specific source?**

    Answer: The *Guidebook* identifies a preferred method for the quantification of emissions for each source category. It was recognized that not all airports may have data at this level of detail, and thus, alternative methods are identified, some of which require lesser quantities of data. The *Guidebook* recommends using the highest level of data available for each source so as to aid in identifying key (major) sources.

13. **Question: Is it acceptable to use the preferred methods for certain sources and alternative methods for other sources?**

    Answer: Yes. The *Guidebook* recommends using the highest level of data available for each source so as to aid in identifying key (major) sources. Each data source and the methods that are used should be clearly documented by the developers of the inventory.

14. **Question: Should multiple formats be used to report the airport inventory?**

    Answer: This depends on the purpose of the inventory. The *Guidebook* recommends that the documentation specifying the inventory note the methods and sources that are commensurate with the reporting format. Some airports may wish to report their emissions in a simple format whereas others may wish to use multiple formats. For instance, if an airport chooses to report their inventory to TCR, the format for this registry must be used. However, to aid the airport in understanding and monitoring its emissions, the airport may choose to have an alternative planning format.

15. **Question: For aircraft emissions, the FAA AEDT/SAGE data source presents current (historical) emissions. How should I estimate future aircraft emissions?**

    Answer: Airports can estimate future emissions in a number of ways. First, Aircraft Methods 1 and 2 are available to airports for use if forecasts of fuel dispensed are available. Many airports increase existing fuel-dispensed quantities in proportion to the change in aircraft operations over time. Some airports have aviation activity forecasts that would enable use of Method 2 for future years. Although Methods 1 and 2 are not preferred, they are acceptable alternative methods.

16. **Question: For aircraft emissions, the FAA AEDT/SAGE data source presents emissions assuming the mixing height is 3,000 ft. At my airport, the mixing height is not 3,000 ft. Does this matter? And if so, where?**

    Answer: No. The FAA source is provided to enable all airports to have access to a common source of aircraft emissions using the IPCC Tier 3 method, referred to in the *Guidebook* as the preferred Aircraft Method 3. The fact that the mixing height is different from the 3,000-ft height does not affect the GHG inventories since the total AEDT/SAGE GHG data (above and below 3,000 ft) for an airport still represents the total GHG emissions from aircraft. In evaluating criteria pollutants, some airports use the local mixing height in their modeling as recommended by USEPA and state air agencies. Therefore, should an airport choose to generate a Level 2 or Level 3 pollutant evaluation reflecting criteria pollutants using a different mixing height, these airports should note the different assumptions in the documentation. This would not affect the total emissions for aircraft, but would affect the subset of total emissions reported for "ground to 3,000 ft" and "above 3,000 ft."

APPENDICES A THROUGH F

Appendices A through F as submitted by the research agency are not published herein. These appendices are available as *ACRP Web-Only Document 2* at (http://trb.org/news/blurb_detail.asp?id=10029). The titles are as follows:

Appendix A	Reasons for Developing GHG Inventories
Appendix B	Emissions and Sources
Appendix C	Methods for Calculating GHG Emissions
Appendix D	Methods for Calculating CO_2 Equivalencies
Appendix E	Inventory Development Protocols
Appendix F	Approaches Used in Airport Inventories Prepared to Date

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation