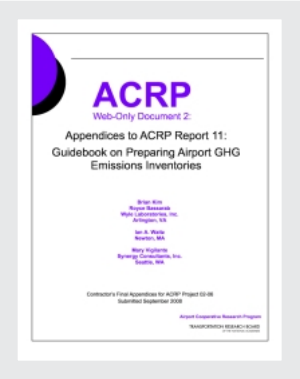

Appendices to ACRP Report 11: Guidebook on Preparing Airport GHG Emissions Inventories

DETAILS

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Introduction to Appendices

These appendices provide background information on inventory protocols and calculation methods. The intention is to support the Guidebook by providing further details and explanations for the specific procedures and recommendations specified by the Guidebook. As such, the appendices should be seen as a companion to the Guidebook that the inventory developer can use to better understand the inventory development process.

The appendices were separated from the Guidebook to allow the Guidebook to be a streamlined and focused document. Although the Guidebook may provide some background information, its purpose is mainly to provide instructions on how to develop an inventory rather than explaining all of the reasoning behind each method. As users gain experience from the two documents and become adept at developing airport GHG inventories, they should be able to refer to just the Guidebook for their needs.

The Guidebook is published separately as *ACRP Report 11*.

It is recommended that all users start with the Guidebook and refer to these appendices as questions arise. The appendices include:

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

Appendix A: Reasons for Developing GHG Inventories

A.1 Introduction

When considering the approach to preparing a greenhouse gas inventory, consideration has been, and should continue to be, focused on the purpose of the inventory. For example, what are the goals of the inventory and how is the information to be used? While there are numerous reasons why an airport might prepare an inventory, they can largely be grouped under the following categories:

- Climate Change Initiatives (also called Climate Action Plans)
- Environmental Management and Sustainability Programs
- Disclosure of Project/Action Effects
- Future Regulations

Figure A-1 shows the relationships between these different reasons in terms of source coverage. As indicated, the Regulatory-Based Project Plan and the Sustainability Project Plan are subsets of the Climate Action Plan which comprehensively covers all sources.

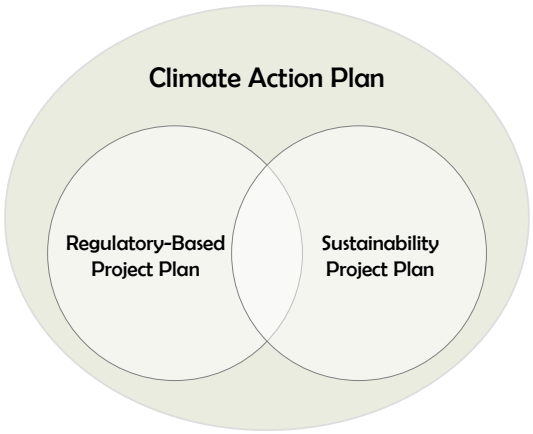


Figure A-1. Relationship Showing Source Coverage by Different Inventory Purposes

These reasons generally agree with the few airport GHG inventories that have been developed to date. The following sections provide a brief overview of these inventory reasons and their needs.

A.2 Climate Change Initiatives – GHG Reduction Goals

In the U.S., there are no current national regulations specifically controlling greenhouse gases. Concentrations of a few gasses that exert GHG effects (directly or indirectly), such as

NO_x, O_3, and CO, are regulated by the Clean Air Act for visibility and human health implications rather than for climate change effects. Internationally and in the U.S., there are various parties and mechanisms that have been set up to control or at least quantify GHG emissions.

The Climate Change Initiative category of emissions inventories are targeted at inventories that are used for purposes of identifying sources of emissions, their contribution to regional, state, local, or national inventories, and then form the basis for examining ways to reduce emissions from these sources. Included in this category are inventories prepared for purposes of climate action registries, such as The Climate Registry (TCR 2008) and the California Climate Action Registry (CCAR 2008).

The activities of the primary parties currently addressing greenhouse gases and climate change are generally described by international activities and domestic activities:

A.2.1 International

- The **Kyoto Protocol to the United Nations Framework Convention on Climate Change** (UNFCCC) is a supplement to the international treaty on climate change, assigning mandatory targets for the reduction of greenhouse gas emissions to signatory nations. 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.

  Governments are separated into two general categories: developed countries, referred to as Annex 1 countries who have accepted greenhouse gas emission reduction obligations; and developing countries, referred to as Non-Annex 1 countries that have no greenhouse gas emission reduction obligations. As of January 15, 2008, a total of 177 countries and the EEC have ratified the agreement (representing 63.7% of emissions from Annex I countries) (UN 1998). A notable exception is the United States (U.S.). Other developing countries, such as India and China, which have ratified the protocol, are not required to reduce carbon emissions under the present agreement despite their relatively large populations.

  According to Article 25 of the protocol, it enters into force "on the ninetieth day after the date on which not less than 55 Parties to the Convention, incorporating Parties included in Annex I which accounted in total for at least 55% of the total CO_2 emissions for 1990 of the Parties included in Annex I, have deposited their instruments of ratification, acceptance, approval or accession." Of the two conditions, the "55 parties" clause was reached in 2002. The ratification by Russia in late 2004 satisfied the "55%" clause and brought the treaty into force, effective February 2005.

  Emissions from international aviation were specifically excluded from the targets agreed 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 continues to consider the potential for using market-based mechanisms. ICAO is currently developing guidance for states who wish to include aviation in an emissions trading scheme (ETS) to meet their Kyoto commitments,

and for airlines who wish to participate voluntarily in a trading scheme. Emissions from domestic aviation are included within the Kyoto targets agreed by countries.

Although a signatory to the protocol, the U.S. has neither ratified nor withdrawn from the protocol. In late 1998, then Vice President Al Gore signed the protocol; however, both Gore and Senator Joseph Lieberman indicated that the protocol would not be acted upon in the Senate until there was participation by the developing countries. The Clinton Administration never submitted the protocol to the Senate for ratification due to estimates of large declines in the Gross Domestic Product associated with compliance. To date, the Bush Administration has not supported the Kyoto principles because of the exemption granted to China which recently surpassed the U.S. as the greatest emitter of carbon.

- Recognizing the problem of potential global climate change, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the **Intergovernmental Panel on Climate Change** (IPCC) in 1988. While not a group that has established greenhouse gas reduction goals, the IPCC plays a major role in guiding international and national emission quantification and reduction work. It is open to all members of the United Nations (UN) and WMO. The role of the IPCC is to understand the risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation. The IPCC does not carry out research or establish regulation. It bases its assessments mainly on peer reviewed and published scientific/technical literature. The IPCC has completed four assessment reports, developed methodology guidelines for national greenhouse gas inventories, special reports, and technical papers. The IPCC has three working groups and an emissions inventory task force.

A.2.2 Domestic

Although the U.S. has not signed on to the Kyoto Protocol, a national greenhouse gas reduction goal has been established. In February 2002, the President affirmed his commitment to the UNFCCC and its central goal of stabilizing atmospheric greenhouse gas concentrations and committed the United States to a comprehensive strategy to reduce the greenhouse gas emission intensity by 18 percent by 2012. According to the USEPA web site (USEPA[c] 2007):

> Greenhouse gas intensity is the ratio of greenhouse gas emissions to economic output. The U.S. goal is to lower emissions from an estimated 183 metric tons per million dollars of Gross Domestic Product (GDP) in 2002, to 151 metric tons per million dollars of GDP in 2012. The U.S. commitment will achieve 100 million metric tons of reduced emissions in 2012 alone, with more than 500 million metric tons in cumulative savings over the entire decade. The policy focuses on reducing emissions through technology improvements and dissemination, improving the efficiency of energy use, voluntary programs with industry and shifts to cleaner fuels.

Even though the U.S. has not ratified Kyoto, various regional, state, and local agencies have started to take action to quantify and/or reduce GHG emissions.

A.2.3 State and Local

The **U.S. Mayors Climate Protection Agreement** was launched on February 16, 2005 (the same day as the Kyoto Protocol came into effect) to advance the goals of the Kyoto Protocol through leadership and action. Two years later, when participation reached over 500 cities, the U.S. Conference of Mayors launched its own Climate Protection Center to administer and track the Agreement. Under the Climate Protection Agreement, participants commit to:

- Strive to meet or beat the Kyoto Protocol targets in their own communities;
- Urge their state governments, and the federal government, to enact policies and programs to meet or beat the greenhouse gas emission reduction target suggested for the U.S. in the Kyoto Protocol -- 7% reduction from 1990 levels by 2012; and
- Urge the U.S. Congress to pass the bipartisan greenhouse gas reduction legislation, which would establish a national emission trading system.

In addition, an extensive number of states, cities, and counties have launched climate change initiatives. A few of these are noted below:

In July of 2000, the **Conference of New England Governors and Eastern Canadian Premiers** (NEG/ECP) adopted Resolution 25-9 on global warming and its impacts on the environment. As a result, the NEG/ECP Climate Change Action Plan was developed that includes regional emission reduction goals:

- Short-term Goal: Reduce regional emissions to 1990 emissions by 2010.
- Mid-term Goal: Reduce regional emissions by at least 10% below 1990 emissions by 2020, and establish an iterative five-year process, commencing in 2005, to adjust the goals if necessary and set future emissions reduction goals.
- Long-term Goal: Reduce regional emissions sufficiently to eliminate any dangerous threat to the climate; current science suggests this will require reductions of 75–85% below current levels.

In June 2005, the **Governor of California** signed Executive Order S-3-05 which established statewide greenhouse gas emission targets and directed the Secretary of the California Environmental Protection Agency to lead the effort to achieve the targets. The targets developed are (SOC 2008).

- By 2010, reduce greenhouse gases to 2000 emission levels
- By 2020, reduce to 1990 emission levels
- By 2050, reduce to 80% below 1990 levels

California's **Global Warming Solutions Act** (also known as Assembly Bill 32 or **AB32**) was signed on September 2006 codifying in state law the Executive Order. It sets up the first enforceable state-wide program in the U.S. to cap all greenhouse gas emissions from major industries and includes penalties for non-compliance.

In March 2006, the County Executive for **King County Washington** issued **Executive Orders on Global Warming Preparedness** which directed the County to reduce greenhouse gas emissions and to prepare for anticipated climate change impacts. These Executive Orders mandated that County departments take climate change actions with regard

to land use, transportation, environmental management and clean energy use. In October 2006, the King County Council mandated that the County submit a Global Warming Mitigation and Preparedness Plan (the "Climate Plan"), as well as an annual report in each subsequent year. Consistent with the Executive Orders, the Council required specific actions to be taken relative to emissions inventories, greenhouse gas reduction targets, land use, environmental management, emergency preparedness, energy use and transportation.

Table A-1 identifies the eight (8) current regional greenhouse gas initiatives. The USEPA further indicates that as of end of 2007, only California has enacted a formal emission reduction cap, but that four other states (WA, OR, NM, and AZ) are in the process of enacting a cap, and two (WI and NJ) have proposed capping greenhouse gases (USEPA[d] 2007). In addition, 14 states have adopted statewide greenhouse gas targets, with two additional states proposing targets.

Table A-1. Summary of Regional Greenhouse Gas Initiatives

Effort	Description of Activities	Participating States
New England Governors: Climate Action Plan	A goal of achieving 1990 greenhouse gas emission levels by 2010 and 10% below 1990 levels by 2020.	CT, ME, MA, NH, RI, and VT
Regional Greenhouse Gas Initiative (RGGI)	RGGI is an effort by Northeastern and Mid-Atlantic states to reduce CO_2 emissions through a cap and trade program. Phase I (2009-2015) will stabilize emissions at 121.3 million short tons of CO_2 (this is a little above 2000-2004 levels). Phase II (2015-2020) will reduce emissions by 10% below Phase 1 levels (roughly equivalent to 1990 levels).	CT, DE, ME, MD (2007), NH, NJ, NY, and VT. (PA and RI are observers; MA participated in the design)
The Climate Registry (TCR)	TCR is an effort to develop a greenhouse gas Registry that will measure, track, verify and publicly report emissions accurately, transparently and consistently across borders and industry sectors. TCR will support voluntary, market-based and regulatory emissions reporting programs and will start accepting data in Jan. 2008.	AZ, CA, CO, CT, DE, FL, HI, IL, KS, ME, MD, MA, MI, MN, MS, MO, NH, NJ, NM, NY, NC, OH, OR, PA, RI, SC, UT, VT, WA, WI, and WY.
Southwest Climate Change Initiative (SCCI)	Launched in 2006, the SCCI creates ways for the two states to collaborate on climate change and emission reduction strategies.	AZ and NM
"Powering the Plains" Initiative	This initiative addresses climate issues surrounding energy and agriculture while adding value to the region's economy and mitigating the risk of climate change and other environmental concerns.	IA, MN, ND, SD, and WI
West Coast Governors' Global Warming Initiative	An effort between the Governors of Washington, Oregon, and California to reduce greenhouse gas emissions from their respective states.	CA, OR, and WA
Western Governor's	Participating states agreed to examine the feasibility of:	AK, AZ, CA, CO, HI, ID, KS, MT,

Association Clean and Diversified Energy Initiative	o Developing 30,000 Megawatts of clean and diverse energy by 2015. o Increasing energy efficiency 20 percent by 2020. o Providing adequate transmission to meet the region's needs through 2030.	NE, NV, ND, OR, SD, TX, UT, WA, and WY
Western Regional Climate Action Initiative	The Governors of 5 western states established this initiative in 2007, committing to establish an overall regional goal to reduce greenhouse gas emissions within 6 months, develop a design for a regional market-based multi-sector mechanism within 18 months to achieve the regional goal, and participate in a multi-state greenhouse gas registry.	AZ, CA, NM, OR, and WA.

Source: USEPA[d] 2007.

As part of the regional, state, and local climate action initiatives, voluntary **greenhouse gas/climate registries** have evolved. Many cities, counties and corporate entities have already voluntarily joined the registries. Each registry has developed its protocol for generating emission inventories as well as the verification/certification process. According to The Climate Registry (TCR), the benefits of participation in a registry are:

- Demonstrate environmental leadership
- Document early actions to voluntarily emissions
- Identify and manage greenhouse gas risks and opportunities
- Gain access to user-friendly web-based software and technical assistance as you develop your inventory
- Participate in policy discussions relevant to your industry and evolving greenhouse gas policy
- Gain competitive advantage by increasing operational efficiency

TCR was formed in 2007 and reflects the combination of four main regional registries: California Climate Action Registry, Eastern Climate Registry, the Lake Michigan Air Directors Consortium, and the Western Regional Air Partnership. As of March 31, 2008 TCR represented 39 U.S. states, 5 Canadian provinces, and 6 Mexican states. Some of states and provinces that are members of TCR have adopted or are in the process of adopting mandatory reporting requirements, either individually or as part of regional GHG reduction programs. Thus, the registries are attempting to have a common inventory/reporting protocol.

A.3 Environmental Management and Sustainability Programs

As the aviation industry has grappled with the future of the aviation system and the Next Generation Air Transport System (NextGen) designed to efficiently accommodate future demand for air travel, airports individually have adopted sustainability practices. Through the Airports Council International - North America (ACI-NA), a Sustainability Committee came together with the following mission (ACI-NA 2008):

> "We will define and promote Aviation Sustainability as a standard business practice.

> The ACI-NA Sustainability Committee serves the Aviation Industry through specific initiatives that are tailored to the industry and created for the purpose of defining aviation sustainability as a business strategy that promotes the core benefits of economic viability, operational efficiency, natural resource conservation and social responsibility.
>
> The Committee is a cooperative and collaborative body of airport directors, consultants and relevant stakeholders whose foremost interest is one of developing and delivering these benefits for the Aviation Industry."

The Transportation Research Board (TRB) in its 2005 conference proceedings, "Integrating Sustainability into the Transportation Planning Process" envisioned sustainability at its most basic level as "one that meets the transportation and other needs of the present without compromising the ability of future generations to meet their needs." The TRB Committee on Environmental Impacts of Aviation (AV030) has also organized a subcommittee on aviation sustainability to provide a forum for all aviation constituents to discuss these important issues. More information on this committee and their subcommittee activities can be found at http://www.trbav030.org.

These efforts have defined sustainability as "a holistic approach to managing an airport so as to ensure the integrity of the Economic viability, Operational efficiency, Natural Resource Conservation and Social responsibility (EONS) of the airport."

Airports that have adopted sustainability practices may wish to quantify greenhouse gas emission reduction benefits associated with their sustainability practices. In this case, it may be the airport as a system or it may be 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 affected by the action might be considered. For instance, 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).

It is anticipated that as planning progresses at airports and more sustainability plans are developed and implemented, airports will likely include the quantification of greenhouse gases as part of their plans both from the tactical perspective (the emission changes associated with actions), but 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).

A.4 Disclosure of Project/Action Effects

In addition to requirements that may exist for preparing inventories to support commitments under regional, state and local climate action plans, inventories may also be required to support actions involving state and possibly federal approvals of airport improvements. In the United States, this project/action effect disclosure can occur in the form of documents prepared under the **National Environmental Policy Act (NEPA**) or based on state requirements that are similar to NEPA.

Under the NEPA, before federal agencies can approve an action, certain environmental reviews may be required. Federal actions in the context of airports can involve the following: approval of Federal funding for airport development projects; approval of a location for a new, public use airport; approval of an Airport Layout Plan (ALP); authorizing use of Passenger Facility Charges (PFC); approval to use or transfer Federally-owned land, etc. Documents prepared in support of the NEPA address issues ranging from air quality, to noise, and cumulative impacts.

In October 1997, the President's Council on Environmental Quality (CEQ) circulated a draft memo for review by federal agencies concerning climate change (CEQ 1997). The draft memo concluded with:

> Global climate change is a serious environmental concern which, given the current state of scientific knowledge, must be viewed under NEPA as a reasonably foreseeable impact of continued emissions and changes in sinks of greenhouse gases. Thus, federal agencies must analyze the extent to which both their proposed and ongoing programs or other activities might influence such emissions and sinks, thereby continuing to, or reducing, the problems of global warming. Such analyses can best be done in the context of NEPA and should look at how federal actions may affect global climate change and, to the extent possible given the current state of scientific knowledge, how federal actions may be affected by global climate change.

It is important to note that a final CEQ guidance does not appear to have been issued.

Separately, FAA issues guidance for the compliance with the NEPA for FAA actions in terms of three documents: FAA Order 1050.1E Environmental Impacts: Policies and Procedures, FAA Order 5050.4B National Environmental Policy Act (NEPA) Implementing Instructions For Airport Actions, and Order 5050.4B's accompanying Environmental Desk Reference for Airport Actions. No specific guidance is available in these documents concerning greenhouse gas emissions (FAA 2004, FAA 2006, and FAA[b] 2007) .

Several states have adopted requirements similar to NEPA (called mini-NEPA). For instance, the **California Environmental Quality Act** (CEQA), **Washington State Environmental Policy Act** (SEPA), **and Massachusetts Environmental Policy Act** (MEPA), are mini NEPA-like laws. These state regulations require evaluations to be conducted for actions occurring within these states subject to certain conditions. In each of the three cited cases, the regulations are beginning to require the preparation of greenhouse gas emissions inventories, and may have specific analysis requirements:

- **Massachusetts Environmental Policy Act** (MEPA): On December 24, 2007, the State of Massachusetts Office of Energy and Environmental Affairs issued its final policy titled "MEPA Greenhouse Gas Emissions Policy and Protocol" (MEPA 2008). The policy requires that certain projects undergoing review by the MEPA Office quantify the project's greenhouse gas emissions and identify measures to avoid, minimize, or mitigate such emissions. In addition to quantifying project-related emissions, the policy also requires proponents to quantify the impact of proposed mitigation in terms of emissions and energy savings.

  Elements of this policy that would influence the approach to quantifying emissions are:

  > "… this Policy is not intended to create a numerical GHG emission limit or a numerical GHG emission reduction target. Rather, in keeping with MEPA's overall purpose to evaluate alternatives that avoid, minimize and mitigate environmental impacts, the Policy is intended to ensure that Project proponents and reviewers have carefully considered the GHG impact of their Projects and taken all feasible means and measures to reduce those impacts."
  >
  > "The proponent is then required to quantify the potential annual GHG emissions from the proposed Project according to the GHG Quantification

> Protocol (the Protocol) outlined below (or other protocols that are accepted on a case-by-case basis), and report in the EIR on the results of the analysis. Emissions should be expressed in short tons (2,000 lbs) per year (tpy)."
>
> "… the proponent should also outline and commit to a series of mitigation measures that will help to reduce GHG emissions from the proposed Project. To demonstrate the efficacy of the mitigation, the proponent should measure emissions reductions and energy savings from the proposed measures according to the Protocol and discuss the impact of proposed mitigation…"
>
> "At the current time, the analysis will focus primarily on the primary greenhouse gas, carbon dioxide (CO_2). While there are other GHGs, CO_2 is the predominant contributor to global warming, and emissions can be calculated for CO_2 with readily accessible data. The analysis of other GHGs may be required for certain Projects, such as methane emissions from landfills and wastewater treatment plants…"
>
> "EEA will require analysis of both "direct" GHG emissions … and 'indirect' emissions …."

- As noted earlier, the State of California passed the **California Global Warming Solutions Act**, thereby being the first state to adopt limits on greenhouse gases. As a result of this act, and subsequent litigation over CEQA documents, most evaluations are now quantifying greenhouse gases. The first airport-project to include a greenhouse gas inventory was prepared for the Master Plan at Sacramento International Airport (SMF) (SC 2007). Later in 2007, a similar CEQA document was prepared for San Diego International Airport which included a greenhouse gas inventory.

- At present, the Washington State Environmental Policy act (SEPA) does not specifically require the evaluation of greenhouse gases. However, the **King County Climate Action Plan**, which governs activities in the two most populated cities in the state, will require the preparation of greenhouse gas inventories. Effective September 1, 2007, all County environmental reviews conducted under the SEPA must include a greenhouse gas inventory per a recently enacted Executive Order. The County has indicated plans to develop significance thresholds for greenhouse gases and a requirement for mitigation by the end of 2008. On December 3, 2007, Seattle's City Council adopted Ordinance 122574 that requires City departments that prepare environmental reviews under SEPA to evaluate greenhouse gas (GHG) emissions. To assist with that review, the City has prepared a worksheet to aid in those reviews which focus on new housing and commercial/industrial development (http://www.seattle.gov/dpd/Planning/GreenhouseGas/ClimateChangeImpactsWorksheet/default.asp).

In these cases, a NEPA or mini-NEPA evaluation by definition focuses on the project-related effects of an action that is the subject of the evaluation. As has been the case of air quality assessments for criteria pollutants, FAA guidance has limited the evaluation of air quality to 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 extended runway) would be inventoried; the primary analysis function of NEPA is to consider the effect of the project relative to what would happen if the project

were not undertaken. In the example case, the analysis may 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 (would it induce additional flights). If additional flights would be induced, then additional support activity might occur requiring the consideration of other sources.

A.5 Future Regulations

In addition to local efforts to require the quantification and reduction in greenhouse gases, there are have also been pushes to require regulation including the recent Supreme Court case of Massachusetts vs. USEPA. On April 2, 2007, the Supreme Court ruled on a 5-to-4 vote that USEPA does have the authority to regulate GHG emissions and that USEPA must re-evaluate 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 previously noted, several local parties are beginning to regulate greenhouse gases for all sources with possible specific controls on aviation-related emissions. It is anticipated that further regulations will develop, and some anticipate that the U.S. government may begin to regulate greenhouse gases. Evidence of movement in the U.S. toward national GHG regulations may be evident in a number of areas as noted in the following discussions.

Increasing concerns have arisen with the U.S. position on the Kyoto Protocol (that the Protocol has not been adopted by the U.S.). In December 2007, the UNFCC Conference in Bali brought together representatives of over 180 countries with observers from intergovernmental and nongovernmental organizations. The two week period included the sessions of the Conference of the Parties to the UNFCCC, its subsidiary bodies as well as the Meeting of the Parties of the Kyoto Protocol. The conference culminated in the adoption of the "Bali roadmap," which charts the course for a new negotiating process to be concluded by 2009 that will ultimately lead to a post-2012 international agreement on climate change. Ground-breaking decisions were made which form core elements of the roadmap in which the U.S. participated. While it is uncertain as to how this will affect regulation in the U.S., many believe that the roadmap process may ultimately provide a mechanism for U.S. participation.

Separately, litigation and local action is moving toward increasing regulation. For instance, the Clean Air Act which regulates the emission of pollutants has provided another venue for seeing regulation. The most notable case making use of this theory was Massachusetts v. USEPA, 415 F.3d 50 (D.C. Cir. 2005) in which 12 states brought suit against the U.S. Environmental Protection Agency (USEPA). The U.S. Supreme Court decided the case on April 2, 2007 in a 5-4 decision. The court found that the Clean Air Act gives USEPA the authority to regulate tailpipe emissions of greenhouse gases, and the USEPA is required to review its contention that it has discretion in regulating CO_2 and other greenhouse gases. Specifically, the court found that USEPA's current rationale for not regulating GHG emissions was found to be inadequate, and the agency must articulate a reasonable basis in order to avoid regulation.

In December 2007, the USEPA responded to the California's waiver request with a denial of approval. Rather, the Bush Administration announced that it is moving forward with a national solution to reduce greenhouse gas emissions from autos in the form of a unified auto fuel economy standard. USEPA Administrator Johnson noted that "The Bush Administration is moving forward with a clear national solution – not a confusing patchwork of state rules – to reduce America's climate footprint from vehicles…" USEPA determined

that a unified federal standard of 35 miles per gallon will deliver significant reductions in greenhouse gas emissions from cars and trucks.

In early 2008, a coalition of states, cities and environmental organizations petitioned the USEPA to determine that greenhouse gases contribute to potentially harmful air pollution and to have USEPA adopt regulations to control such emissions. The petitioners, consisting of six states and several non-governmental organizations, are seeking to have USEPA consider emissions limitations and fees, operational practices, a cap-and-trade system, and measures to reduce taxi time and increase use of ground-based electrical power.

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, airports may be able to take advantage of the opportunities to develop and sell carbon credits.

Appendix B: Emissions and Sources

B.1 Introduction

The starting point for the pollutants studied under this project are the six pollutants agreed to for reductions as part of the Kyoto Protocol and which are also targeted by various other protocols: CO_2, CH_4, N_2O, SF_6, HFC, and PFC. In particular, the 2006 IPCC Guidelines for National GHG Inventories focuses on these primary pollutants, but includes various other halogenated gases including NF_3, SF_5CF_3, CF_3I, etc. In addition, the precursor emissions of NO_x, NH_3, NMVOC, CO, and SO_2 also need to be considered. Pollutants are referred to as precursors if they react to form other greenhouse gases. These precursors generally tend to produce very little direct GHG effects but can form secondary pollutants (e.g., O_3) which can cause much greater effects.

Some of the precursors, such as NH_3, may not be applicable as there are generally no associated sources at an airport. In addition to the precursors, H_2O and PM should also be considered in part due to the potential for changes to cloud particles and contrail formation which is unique to aircraft sources. The direct release of H_2O in the stratosphere also warrants the need to quantify those emissions. Overall, the inclusion of these precursors in a GHG inventory provides a comprehensive accounting of GHG emissions from airport sources. In summary, these pollutants can be categorized as follows:

- Main contributor to global warming: CO_2
- Six Kyoto pollutants (primary pollutants): CO_2, CH_4, N_2O, SF_6, HFC, and PFC
- Precursors: NO_x, NH_3, NMVOC, CO, and SO_2 (IPCC 2006)
- Other pollutants: Halogenated gases beyond those included in the six Kyoto pollutants, H_2O, and PM.

In Volume 1, Chapter 7 of their 2006 guidance, IPCC has recognized the five precursor pollutants listed above. The recognition of the halogenated gases under the "other pollutants" category are also based on the 2006 IPCC guidance (see Volume 1, Chapter 1 of that guidance). H_2O and PM are included based on a preponderance of the evidence largely found in the IPCC publications (e.g., IPCC 1999) that inclusion of these pollutants within an inventory would help to comprehensively account for all GHG effects. Table B-1 provides an overview of each airport source, the general emissions process, and the corresponding pollutants.

Table B-1. Airport Sources and Corresponding Emissions

Source	Emission Process	Emissions
Aircraft • Jet • Turboprop • Piston	Combustion	Primary • CO_2, CH_4, N_2O Precursors and Others • H_2O, PM, SO_x, NO_x, CO, NMVOC
	Non-combustion	Precursors and Others • NMVOC
Auxiliary power unit (APU)	Combustion	Primary • CO_2, CH_4, N_2O Precursors and Others • H_2O, PM, SOx, NO_x,

		CO, NMVOC
	Non-combustion	Precursors and Others • NMVOC
Ground support equipment (GSE) • Baggage tractor • Belt loader • Air conditioner • Cabin service truck • etc.	Combustion	Primary • CO_2, CH_4, N_2O • SF_6, HFC, PFC Precursors and Others • H_2O, PM, SO_x, NO_x, CO, NMVOC
	Non-combustion	Primary • SF_6, HFC, PFC Precursors and Others • NMVOC, other halogenated gases
Ground access vehicle (GAV) • Passenger privately owned vehicles (POV) • Airport personnel POVs • Airport property vehicles • Shuttle buses • Cargo trucks • etc.	Combustion	Primary • CO_2, CH_4, N_2O Precursors and Others • H_2O, PM, SO_x, NO_x, CO, NMVOC
	Non-combustion	Primary • SF_6, HFC, PFC Precursors and Others • NMVOC, other halogenated gases
Stationary sources • Power/electricity consumption • Boiler/heater • Aircraft engine testing • Surface coating/painting • Degreasing • etc.	Combustion	Primary • CO_2, CH_4, N_2O Precursors and Others • H_2O, PM, SO_x, NO_x, CO, NMVOC
	Non-combustion	Primary • SF_6, HFC, PFC Precursors and Others • PM, NMVOC, other halogenated gases
Training fires	Combustion	Primary • CO_2, CH_4, N_2O Precursors and Others • H_2O, PM, SO_x, NO_x, CO, NMVOC
Construction activities • Runway extension or development • Terminal building and gate area expansion • New taxiways • etc.	Combustion	Primary • CO_2, CH_4, N_2O Precursors and Others • H_2O, PM, SO_x, NO_x, CO, NMVOC
	Non-combustion	Primary • SF_6, HFC, PFC Precursors and Others • NMVOC, other halogenated gases
Waste management activities	Combustion	Primary • CO_2, CH_4, N_2O Precursors and Others • H_2O, PM, SO_x, NO_x, CO, NMVOC
	Non-combustion	Primary

		• SF_6, HFC, PFC Precursors and Others • PM, NMVOC, other halogenated gases

The non-combustion category includes volatilization and fugitive releases. The pollutants cited under "waste management activities" is meant to provide a loose guide since this category encompasses a wide variety of processes and technologies. Table B-1 also does not reflect ownership of sources. The ownership information is important in establishing boundaries and criteria for inventory development.

B.2 Primary Emissions

The term **primary emissions (or pollutants)**, is used to refer to those pollutants negotiated under the Kyoto Protocol. They directly absorb infrared radiation resulting from sunlight incident on the Earth's surface.

Carbon dioxide (CO_2) is a gas generated by various processes including respiration and photosynthesis. Unless in highly elevated concentrations (e.g., mining conditions), CO_2 is not considered to have any human health impacts. For purposes of airport emissions inventory development, CO_2 is a product of complete combustion of a hydrocarbon-based fuel. As fuel use is increased, CO_2 emissions will also increase proportionally. Therefore, modes of operation for equipment (e.g., aircraft during cruise) that burn more fuel will produce more CO_2.

Methane (CH_4) is the principal component of natural gas and is both colorless and odorless (an odorant is added to natural gases). It is not considered toxic but is flammable and explosive. For aviation sources, CH_4 is a product of incomplete combustion formed from the carbon (C) and hydrogen (H) in the fuel. Along with other hydrocarbon species, production of CH_4 typically increases when combustion temperatures are lower. As a result, the rate of emission for CH_4 is greater during vehicle and aircraft idling conditions than during the other modes (e.g., acceleration, takeoff, etc.).

Nitrous oxide (N_2O) is a colorless, sweet smelling gas that is often referred to as "laughing gas"; it is used as an anesthetic for medical purposes. The primary source of emissions is agriculture management involving nitrification/denitrification in the soil. A much smaller amount comes from mobile sources where N_2O is a product of combustion at high temperatures between nitrogen (N_2) and oxygen (O_2) from the air, although some elemental nitrogen (N) and oxygen (O) from the fuel (if they are present) may also contribute.

Sulfur hexafluoride (SF_6) is a non-toxic gas that is commonly used in electrical applications as a dielectric (e.g., in circuit breakers, switchgear, etc.). It is also commonly used in the semiconductor industry as an etchant and as a tracer compound for various building ventilation efficiency tests. Emissions from electrical applications at an airport are characterized as fugitive emissions. Of all the identified GHGs, SF_6 is the most potent with a 100-yr GWP of nearly 24,000 (USEPA 2006).

Hydrofluorocarbons (HFC) represent a group of compounds composed of an alkane (such as methane and ethane) and fluorine (F). They are commonly used as refrigerants, propellants, solvents, and in fire extinguishers. Any emissions from these applications are fugitive in nature. They are preferred over their chlorine containing counterparts since HFCs

do not have any known effects on the O_3 layer. Similar to SF_6, HFCs are extremely potent GHGs.

Perfluorocarbons (**PFC)** are considered non-toxic and are essentially composed of a hydrocarbon with the hydrogen (H) atoms replaced by F atoms. PFCs are commonly used as refrigerants, in fire extinguishers, and as propellants. These emissions are also categorized as being fugitive. Similar to the aforementioned fluorine containing compounds, PFCs are potent GHGs with GWPs thousands of times greater than CO_2.

B.3 Precursors and Other Emissions

Precursor pollutants are those that have relatively little or no ability to directly influence the radiative balance. However, they are the source of indirect effects (e.g., formation of other pollutants) that can have significant climate impacts. Based on the IPPC definition, precursors include CO, NOx, NMVOCs, NH_3, and SO_2 (IPCC 2006). Other pollutants that can exert GHG effects are H_2O and PM in addition to the various halogenated gases not included as part of the six Kyoto pollutants.

Carbon monoxide (CO) is a colorless and odorless gas that can cause various physiological damage by displacing oxygen in the bloodstream. It is formed as a product of incomplete combustion between a fuel and oxygen from the air. Combustion conditions that are conducive to CO formation include lower temperatures and higher fuel-to-air ratios. CO has very little direct GHG effect, but like NO_x is a precursor for O_3 formation.

NO_x (nitrogen oxides) is a family of gases mainly represented by NO and NO_2 which can cause respiratory failure. NO_x is generally formed during combustion under high temperature conditions involving N_2 and O_2 mainly from the air, but elemental contributions of N and O from the fuel are also possible. Therefore, NO_x emission rates are greatest for conditions involving acceleration for vehicles, takeoff for aircraft, etc. NO_x exerts little direct GHG effect, but is a precursor (nitric oxide or NO) for O_3 production and accelerated CH_4 removal. Also, NO_x can form nitrate aerosols in the atmosphere providing further GHG effects indirectly.

Non-methane volatile organic compounds (NMVOC) include many compounds, especially hydrocarbons (except for CH_4) which have high vapor pressures to exist as vapors under normal atmospheric conditions and typically participate in photochemical reactions. As a result, NMVOCs are precursors for O_3 formation. These non-halogenated compounds have little direct GHG effects. Similar to CO, they can be formed as products of incomplete combustion, especially under low temperature and fuel-rich environments. They can also be emitted as a part of volatilizations from various activities at an airport including maintenance, degreasing, painting, etc. Furthermore, they can be emitted as fugitive emissions during fueling operations and improper sealing of fuel systems on aircraft and vehicles.

SO_x (sulfur oxides) refers to a family of gases mainly represented by SO_2 which has a "burning sulfur" smell and is an irritant to the respiratory system. SO_x can be produced through the combustion of fuel containing sulfur and can form sulfate aerosols in the atmosphere. These aerosols can exert direct GHG effects and potentially contribute to global warming through changes in cloud properties and creation of contrails, although the link to these effects is not well established.

Water (H_2O) is an abundant substance essential for life, and is also one of the two products of complete combustion. While H_2O is the primary GHG in the atmosphere, anthropogenic

(man-made) contribution is considered small compared to the fluxes within the natural cycle (IPCC 1999). As a result, H_2O emissions are precluded from most GHG emissions inventories. As noted earlier, the two largest individual pollutants emitted by aircraft engines are CO_2 (about 70% of the emissions), and H_2O (nearly 30%). H_2O is most notably emitted by aircraft into the stratosphere, where residence times, and hence, accumulation will increase, potentially leading to greater climate impacts. Between 18% and 44% of aircraft emissions are emitted in the stratosphere[1] (Gettelman 1999). Although most of today's flights occur in the troposphere[2] with some reaching into the lower stratosphere, future flights may make greater use of stratospheric altitudes. Also, the impact of H_2O emissions on contrail formation needs to be considered and is the subject of international research. Although the uncertainties associated with predicting aircraft H_2O contributions to climate change are significant (IPCC 1999), the potential for stratospheric release and contrail formation appear to warrant the need to include H_2O emissions as part of aircraft-related GHG inventories, especially when considering cruise emissions.

Particulate Matter (PM) are tiny solid, liquid, or mixed solid and liquid particles suspended in the air. These are of concern at the Earth's surface since ambient concentrations of PM have been shown to be correlated with serious respiratory illnesses and premature mortality. PM sizes (aerodynamic diameters) range from greater than 100 μm to the ultrafine range of below 0.1 μm. PM emissions from aircraft fuel combustion are generally understood to be in the smaller part of this range. In addition to the nonvolatile soot component, sulfate and other volatile components can be emitted, including contributions from lubrication oil (SAE 2008). Volatile PM can also potentially be emitted from various activities at an airport including maintenance activities. Similar to H_2O, aircraft PM emissions can also have both direct and indirect effects on climate change. Particles can directly absorb and scatter energy although the impact on climate change is generally much smaller than the impacts caused by gases such as CO_2. The indirect effects, through changes in cloud properties as well as the formation of contrails (aviation-induced cirrus cloudiness), are still the subject of high scientific uncertainty, but may be important contributors aviation climate impacts (IPCC 1999). Although the uncertainties associated with these effects are significant, the potential magnitude is sufficiently high to warrant the need to include PM emissions as part of airport GHG inventories. Other PM species such as nitrate (NO_3^-) areosols are generally not present in aircraft emissions or in such small amounts that they can be ignored. Measurement data, such as that from the Aircraft Particle Emissions Experiment (APEX2) sponsored by FAA and the National Aeronautics and Space Administration (NASA) work confirms that "no significant nitrate volatile component is evident, even though this is typically a constituent of background aerosol and nitrogen oxides are emitted in the exhaust" (Lobo 2007).

Other halogenated gases include various other halogen containing compounds not included in the six Kyoto pollutants. Examples include nitrogen fluoride (NF_3) and trifluoromethyl sulphur pnetafluoride (SF_5CF_3). Similar to SF_6, HFCs, and PFCs, these pollutants are potent GHGs.

B.4 Source Descriptions

Aircraft are the main focus of activity at any airport. They impact virtually all levels of activity at an airport including passenger movement, GSE usage, terminal airspace design,

1 The stratosphere occurs between about 6 miles and 31 miles above the surface (10-50km).

2 The troposphere is the lowest level of the atmosphere, and is generally from the ground to 10km (6 miles).

etc. The use or purpose of each aircraft defines which of the following categories it falls into:

- commercial air carrier,
- commuter,
- all-cargo,
- general aviation, or
- military

The aircraft type can also be categorized in terms of the engine technology:

- jet,
- turboprop, and
- piston

These categories largely determine the different types of fuel that can be used. Commercial jet aircraft typically use Jet A, while military jet aircraft commonly use JP-8, and many turboprop and piston-powered aircraft use aviation gasoline (Avgas). In addition to the performance characteristics of the engine, the fuel type will also make a difference in the amount of greenhouse gases emitted during flight.

As with other mobile sources, aircraft have widely varying modes of operation that need to be carefully considered since they use varying levels of fuel consumption and emission rates. The evaluation of criteria pollutants and development of inventories have focused on the local air quality environment, and thus focused on flight operations within the mixing height, generally defined as 3,000 feet above field elevation (AFE) of an airport. In air quality evaluation, flight operations in the local environment are referred to as the **Landing and Takeoff (LTO) cyle**. One aircraft LTO cyle 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 climbs out to cross the mixing zone. The operating modes in a standard LTO cycle are:

- Approach (30% power setting) - refers to the portion of flight from the time the aircraft reaches the mixing height or 3,000 feet altitude and exits the runway;
- Taxi/idle-in (7% power setting), taxi/idle-out (often combined into taxi/idle/delay) - refers to the time aircraft are moving on the taxiway system until reaching the gate, and on departure from the gate until taxied on to the runway;
- Takeoff (100% power setting) - refers to the roll down the runway through lift-off up to about 1000 ft;
- Climbout (85% power setting) - the departure segment from takeoff until exiting the mixing height or 3,000 feet.

The LTO cycle has been used extensively in modeling local air quality, as criteria pollutants (e.g., CO, NO_x, etc.) emitted under the mixing height may adversely affect human health. However, GHGs and their effects are not limited to emissions occurring within this mixing zone. Thus, greenhouse gases inventories typically include emissions within the LTO cycle, as well as during cruise. As noted, cruise related emissions from aircraft have been identified as representing 90% or more of overall aircraft emissions.

Aircraft emissions mainly occur through the combustion of fuel in the engines. However, some fugitive emissions of volatile compounds also occur from the fueling operations. Although it is possible for fugitive emissions of HFC and PFC to occur from the fire suppression system on board an aircraft, these are rarely (if ever) used and no data currently

exists to quantify these emissions. For testing of any handheld fire extinguishers used on aircraft, they are sent to the manufacturers for safe, contained discharges (not released to the atmosphere) (Bennett 2008 and Valeika 2008).

Auxiliary power units (APU) are small gas turbine engines usually built into the aircraft tail that provide power during idling conditions for electricity, air conditioning, etc. Similar to the main engines, APUs also produce emissions through the combustion process, typically drawing from the same fuel source as the engines. In some cases, instead of using the APU on the aircraft, aircraft may connect to a **ground power unit (GPU)** which is essentially a large diesel generator. Most commercial airports provide ground power sources (i.e., electrical hookups) at the gate as well as preconditioned air to reduce the reliance on either APUs or GPUs, and thus reduce emissions.

Ground support equipment (GSE) encompasses a wide range of equipment used to support aircraft operations. These include baggage tractor, belt load, cabin service truck, etc. and generally reflect vehicles that do not leave the airfield. Emissions from GSE mainly occur from the combustion of fuel. Fuel types can vary significantly and includes gasoline, diesel, liquefied petroleum gas (LPG), compressed natural gas (CNG), and electricity. Also, fugitive emissions from both the fuel system and the air conditioning system can occur.

Ground access vehicles (GAV) represent a category that encompasses any and all ground vehicles not categorized as GSE, and generally represents to public roadway-related vehicles that access an airport. This includes vehicles transporting passengers to and from the airport, vehicles parking at an airport, cargo roadway travel, and employee commute. It includes shuttle buses (airport, hotel, etc.), taxis, airport personnel POVs and airport-owned vehicles. Similar to GSEs, GAVs produce emissions mainly through emissions with fuel types that include gasoline, diesel, LPG, CNG, electricity, etc. Fugitive emissions from both the fuel systems and air conditioning systems can also occur. Depending on how much of the traffic outside of the airport property are considered a part of the airport sources, GAVs can be a significant source of emissions, comparable to aircraft.

Stationary Sources are probably the most varied source category at an airport. They include all non-moving sources that cannot be categorized under the other source definitions. These include maintenance, heating, testing, electricity use, etc. which includes both point and area activities. These sources can produce emissions through combustion (e.g., boiler heating), volatilization (e.g., painting), and fugitive emissions (e.g., electric system and fire extinguishers). Training Fires, considered either a point or area source, constitute a small part of the total emissions at an airport. The emissions depend on the fuel used for the training and duration. By definition, all emissions are essentially due to combustion.

Construction activities reflect the use of construction vehicles associated with annual heavy maintenance and infrastructure renewal projects at most airports annually, as well as projects undertaken to improve and expand airport facilities. This equipment includes pavers, excavators, tractors, etc. Similar to the other mobile sources (GSE and GAVs), fuel types can include gasoline, diesel, LPG, and CNG. Emissions are primarily a result of combustion of fuel but also includes fugitive emissions from both the fuel system as well as any air conditioning systems that may be employed. Fugitive emissions should also include dust particles generated from the various construction activities including the use of unpaved roads.

Training Fires involve the use of fuel (e.g., JP4, Tekflame, etc.) to simulate open burning for training purposes. Emissions are mostly due to combustion from the burning of the fuel, but any emissions associated from the use of fire extinguishers or other equipment should be accounted for as well.

Waste Management Activities reflect any processes or use of equipment specifically geared toward waste management. Examples include sorting of waste, shipping to waste management facilities, recycling, and incineration. Emissions associated with these activities need to be carefully considered as the data necessary to support these assessments need to be further developed, and may require life-cycle analyses to fully determine the effects of these activities.

Appendix C: Methods for Calculating GHG Emissions

C.1 Introduction

The methods used to create a GHG emissions inventory are varied. They involve the use of a mixture of emission factors, calculations, and models with necessary approximations as the data and/or methods are not well-developed for many of these pollutants. Various viable methods are described in this section for each source and pollutant. The focus here is to provide coverage of all possible methods and data to serve as background information for guidance development that will take into account the resources that may actually be available to airports. Although some suggestions are made as to the usefulness or applicability of methods and data, no attempt was made to promote a single set of methods.

Reviews of the methods described in the following sub-sections will serve as the starting point for their inclusion in a scheme to create tiers (or levels) of methods that provide differing levels of fidelity for the results, but are still based on the same overall protocol. Section C.2 provides an overview of emissions calculations. Since much of the emissions including CO_2 are based on combustion activities, a primer for the derivation of fuel based emission factors is provided in Section C.3. The remaining subsections provide coverage descriptions of various methods and data specific to each source and pollutant.

C.2 Overview of Emissions Calculations

It is anticipated that several approaches to quantifying greenhouse gases may be warranted, depending on the purpose of the inventory, and generally reflecting the size of the airport and/or the data that is available at an airport. Emission factors range from simplified/generalized rates to more specific rates based on more detailed characteristics of the pollutant source. Many inventory developers will begin their evaluation of greenhouse gases based on basic emission factors produced by sources such as the Energy Information Administration (EIA) that note the following (EIA 2008):

- Jet A fuel – 21.095 lbs CO_2 per gallon Jet A
- Auto gas - 19.564 lbs CO_2 per gallon gas

GHG emissions are generally calculated using a combination of emission factors and activity data. Depending on the emission factor, the activity data can vary as illustrated in Table C-1.

Table C-1. Example Types of Activity Data and Emission Factors

Activity Data…	**…to be used with this Emission Factor**
lbs fuel consumed	lbs CO_2 emissions per lb fuel use
vehicle miles traveled	g CO_2 per mile
kWh energy consumed	lbs CO_2 per kWh
hr duration	g CO_2/hr

Emissions are calculated by multiplying activity data with an emission factor as indicated below:

Emissions = (Activity) x (Emission Factor)

Both the activity data and emission factors can represent averages for a range of scenarios or be specific to each of those scenarios. Depending on the source, some models are also available to predict emission factors and/or emissions. The inventory developer will need to determine the fidelity and resolution needs of the airport in deciding which data or model to use.

C.3 Primer on Derivation of Fuel Mass-Based Emission Factors

This section provides an overview on how to derive emission factors based on fuel composition. Essentially, this involves a mass balance of the fuel as input material and the emitted pollutants as output materials. The term "emissions indices" (EI) is commonly used especially with aircraft to represent emission factors (EF) in terms of mass of pollutant per mass of fuel consumed (e.g., g CO_2 / kg fuel). EIs for CO_2, H_2O, and SO_x are determined based on fuel composition under the assumption of 100% or (nearly 100%) combustion of the fuel. This is reasonable since virtually all of the carbon (C) and hydrogen (H) are converted into CO_2 and H_2O, especially under steady-state operating conditions (e.g., cruise for aircraft). The following derivation of emission indices for these pollutants is derived from the Society of Automotive Engineers (SAE) Aerospace Information Report (AIR) 5715 that is currently in development (SAE 2008). For simplicity, this illustration is based on assuming all of the fuel C and H are converted to CO_2 and H_2O.

$$C_m H_n S_r(\,fuel) + (m + \frac{n}{4} + r)O_2 \text{ ---> } mCO_2 + (\frac{n}{2})H_2O + rSO_2$$

Fuel composition data is often provided (or can be derived) as percent masses:

M = % C by mass
N = % H by mass
R = % S by mass

where M + N + R = 100%

If trace amounts of other elements (e.g., metals) are also specified, then the percentages for C, H, and S can be renormalized to 100% by ignoring the trace elements. This is a reasonable assumption since C, H, and S are the main elements by mass. Therefore, assuming the composition of the fuel can be represented as just $C_mH_nS_r$ with complete combustion of the fuel and using a fuel mass basis of 100 g, the EI values can be computed as follows:

$$m = \frac{M}{12.011}$$

$$n = \frac{N}{1.0079}$$

$$r = \frac{R}{32.06}$$

$$EICO_2 = \frac{(1000)(m)[12.011 + (2)(15.9994)]}{(m)(12.011) + (n)(1.0079) + (r)(32.06)}$$

$$EIH_2O = \frac{(1000)(\frac{n}{2})[(2)(1.0079) + 15.9994]}{(m)(12.011) + (n)(1.0079) + (r)(32.06)}$$

$$EISOx = \frac{(1000)(r)[32.06 + (2)(15.9994)]}{(m)(12.011) + (n)(1.0079) + (r)(32.06)}$$

where m = Carbon coefficient in chemical formula for fuel (moles)
n = Hydrogen coefficient in chemical formula for fuel (moles)
r = Sulfur coefficient in chemical formula for fuel (moles)
EI CO_2 = CO_2 EI (g/kg)
EI H_2O = H_2O EI (g/kg)
EI SO_x = SO_x EI (g/kg)

EI SO_x is derived based on calculations for SO_2 with the assumption that all of the sulfur in the fuel is oxidized. Since the denominators in the above equations for $EICO_2$, EIH_2O, and $EISO_x$ are each equivalent to 100 g, the equations could have been simplified, but their full form have been left intact for easier comprehension. Once derived, these EIs are used as constants irrespective of the equipment type, mode of operation, atmospheric effects, etc.; they are only dependent on fuel composition.

Typically, CO_2 emission factors will be readily available for a fuel, but H_2O and SO_2 will not be available. If the elemental composition of the fuel is either known or can be assumed, the emission factors for H_2O and SO_2 can readily be determined using this mass balance. It should be noted that while the C and H composition will generally be consistent for most fuels, S content can vary significantly between different regions.

C.4 Source-Based Emissions Modeling

The following sections provide comprehensive coverage of airport emissions calculation methods by source. The purpose is to provide a general overview of the methods and sources of data so that the inventory developer is aware of the methods, models, and data that are available.

C.4.1 Aircraft

Numerous methods are available to quantify GHG emissions from aircraft. Such methods vary based on the data available concerning aircraft operations, the boundaries established and the analysis needs discussed earlier. Quantifying aircraft GHG emissions requires the following types of information:

- Fuel dispensed at the airport
- Aircraft activity data including:

  - Aircraft type and engine combination
  - Time in each of the operating modes
  - Cruise flight distance (i.e., city pair) and/or time
- Emission factors for fuel use

Some airports may have access to all of the above data, whereas other airports may only have access to a limited amount. GHG emissions can be calculated using fuel mass-based emissions factors as indicated below:

Emissions = Activity) x (Emission Factor)
= (20,000 gal) x (21.095 lbs CO_2/gal fuel)
= 421,900 lbs CO_2

These fuel mass-based emission factors can be obtained from various sources including EIA, IPCC, and USEPA. In addition to these mass-based emission factors, aircraft GHG emissions can also be computed using energy-based emission factors promulgated by IPCC (2006) some of which are shown below:

- Jet kerosene = 71,500 kg CO_2/TJ fuel
- Aviation Gasoline = 69,300 kg CO_2/TJ fuel
- All aircraft, full flight = 0.5 kg CH_4/TJ fuel
- All aircraft, LTO only = 5.0 kg CH_4/TJ fuel
- All aircraft, full flight = 2.0 kg N_2O/TJ fuel

For aircraft, the term, "emissions index" (EI), is also used to specifically denote a fuel based factor (e.g., mass of pollutant divided by mass of fuel). Depending on the heating value used (e.g., 44.1 TJ/Gg for jet kerosene as suggested in IPCC 2006), the CO_2 EI will be about 3153 g CO_2/kg fuel. This value agrees with that used by Boeing and the FAA (3155 g/kg) in their development of global aircraft emissions inventories (Baughcum 1996, Sutkus 2001, and FAA[b] 2005). Since this value is strictly derived from fuel composition, it does not change with fuel flow or aircraft operations. Some CO_2 EIs from other sources are provided in Table C-2.

Table C-2. Example CO_2 Emission Indices from other Sources

Organization	$EICO_2$(g/kg)	Reference
Deutsche Forschungsanstalt fur Luft- and Raumfahrt (DLR)	3156 g/kg	Rachner 1998
The Netherlands National Aerospace Laboratory (NLR)	3157 g/kg	Middel 2001
The Climate Registry	9.57 kg/gal	TCR 2008

While these EI derivations tend to be aircraft centric (e.g., common units for aircraft emissions), the basic concepts apply for understanding combustion from all sources. For combustion sources, the IPCC typically uses EFs with units reflecting mass of pollutant per unit of fuel energy (e.g., kg CO_2 / TJ fuel). The energy content of fuels is typically based on the net calorific value (lower heating value). These energy-based EFs are also presented in terms of the carbon content of the fuel such as mass of carbon in the fuel per unit of fuel energy (e.g., kg C / TJ fuel). In that case, a conversion factor of 44 CO_2 g / 12 C g can be used to convert between the two different units. If deemed necessary, an oxidation factor can also be applied to account for any portion of the fuel that is not combusted (i.e., unburned fuel). However, the latest version of the IPCC guidelines assume full oxidation

(100% combustion) (IPCC 2006). Using these emission factors, the following formula can be used to compute mass emissions:

$$E = (F)(EF)$$

where E = Emissions (g, kg, etc.)
F = Fuel consumption (kg, TJ, etc.)
EF = Emissions Factor (g/kg, kg/TJ, etc.)

In order to calculate emissions using these EFs (or EIs), fuel burn (or fuel consumption) is necessary which can be obtained through various means as exemplified below:

- Aggregate airport fuel dispensed information for all flights or activities available from the airport
- Aircraft-specific fuel use data tables
  - LTO fuel consumption for commercial (civil) aircraft from IPCC (2006)
  - Average full-flight fuel consumption for military aircraft from IPCC (2006)
  - LTO and cruise fuel consumption for commercial aircraft from the EMEP/CORINAIR dataset (EEA 2006)
- Aircraft-specific performance-based modeling for LTO modes through the FAA's Aviation Environmental Design Tool (AEDT)/Emissions and Dispersion Modeling System (EDMS) (FAA[a] 2007).
- Aircraft-specific performance-based modeling for LTO and cruise modes through the FAA's AEDT/System for assessing Aviation's Global Emissions (SAGE) (FAA[b] 2005)

Emissions for CH_4, and N_2O can be determined using emission factors from the same sources (e.g., IPCC, USEPA, etc.). The IPCC provides tiered guidelines for calculation of aircraft GHG emissions as follows (IPCC 2006):

- Tier 1: Calculate aggregated total aircraft emissions using total fuel dispensed information. In this form, emissions of LTO and cruise are reflected in a single quantification.
- Tier 2: Calculate aggregated total emissions using total fuel dispensed information. Then compute LTO emissions from LTO-specific data. Cruise emissions is the difference between the two.
- Tier 3a: Using specific flight data (movements information) including flight distance, calculate emission for each flight (LTO and cruise separately). The EMEP/CORINAIR dataset can be used under this tier.
- Tier 3b: Use sophisticated computer models such as AEDT/SAGE and the European Commission's (EC) AERO2K (Eyers 2004) to compute emissions along the flight path using detailed aircraft performance and emissions methodologies.

For illustration purposes, the Sea-Tac 2006 GHG inventory used the IPCC Tier 2 approach, whereas the Denver GHG inventory relied upon the Tier 1 method. San Diego and Sacramento only calculated aircraft emissions in the LTO cycle.

In the most simplified form, aircraft emissions can be calculated based on the fuel dispensed at an airport. While IPCC guidance notes the term "fuel used," most airports do not have access to the actual fuel used by individual aircraft, as the aircraft are not owned by the airport operators. To assure that emissions are not double-counted, a surrogate for fuel

usage has been the fuel dispensed by fueling operators at an airport. However, when considering the use of fuel dispensed, an important caution has been raised at a few airports. It is generally understood that airlines may have preferential fueling at one location rather than another due to fuel costs. In this case, an aircraft boards sufficient fuel at one location so as to avoid fueling (or fueling as much) at its next stop. By using fuel dispensed data, the inventory for the second airport would not reflect (or reflect less) the emissions associated with flights that do not fuel (or fuel less) at the airport. Additional research is needed as to the frequency of such occurrence and the implications on GHG inventory accounting. As the airport operator does not own and control emissions from aircraft sources, they are reported for purposes of completing the overall airport's contribution to local and regional emissions.

The current version of the FAA's AEDT/EDMS reports the fuel used in kg during the LTO cycle for aircraft, as well as the emissions of the following pollutants: carbon monoxide (CO), total hydrocarbons (THC), non-methane hydrocarbons (NMHC), volatile organic compounds (VOC), nitrogen oxides (NO_x), sulfur oxides (SO_x), coarse particulate matter (PM10), and fine particulate matter (PM2.5). AEDT/EDMS does not report fuel use for any other source, but does report criteria pollutants for all other pollutant sources. The use of AEDT/EDMS for aircraft emissions requires the input of data concerning: aircraft type, and engine combination, the number of aircraft operations (or LTO), the time in each of the four LTO operating modes, the assigned APU, and the GSE associated with the aircraft operations. However, fuel use by the APU and GSE are not noted in the output of AEDT/EDMS.

Models specifically noted in the IPCC Tier 3b guidance (e.g., AEDT/SAGE and AERO2K) can be used. However, in their present form, these models are not publicly available and require expert knowledge to both understand the datasets involved as well as to run them. In lieu of actually using AEDT/SAGE, FAA is planning to make the AEDT/SAGE airport inventory database publicly available in the latter half of 2008. This will include airport-by-airport fuel burn and CO_2 emissions from aircraft separated into above and below 3000 ft.

Since there are no indications of SF_6, HFC, and PFC emissions from aircraft, these can all be assumed to be zero. Discussions with manufacturer and airline representatives have indicated that the data to support the assessment of emissions from aircraft halon systems currently do not exist (Bennett 2007 and Valeika 2008). In addition, there is no data available to support the assessment of emissions due to fire extinguishers which are virtually never used and are sent to labs for testing (Bennett 2007 and Valeika 2008). Future research could potentially examine this in more detail. Also, there are currently no data available to allow determination of fugitive NMVOC emissions from aircraft fuel systems.

H_2O and SO_x emissions can be determined similar to CO_2 as constant emissions indices can be used with fuel burn for these pollutants. Boeing and FAA have both used emissions indices of 1,237 g/kg and 0.8 g/kg for H_2O and SO_x, respectively, in their global aircraft emissions inventory development work. AEDT/EDMS currently uses an emissions index of 1.36 g/kg based on a sulfur fuel content of 0.068% to model LTO SO_x emissions. Aircraft-specific LTO SO_x (or rather, SO_2) emission factors are also available from IPCC (2006).

PM emissions from aircraft have been difficult to model due to the uncertainties associated with correlating the smoke numbers from the ICAO emissions databank to mass-based values. However, a recent effort by the ICAO Committee on Aviation Environmental Protection (CAEP) Working Group 3 (WG3) to promulgate the First Order Approximation Version 3.0 has shown some promise (ICAO[a] 2007). This is reflected by the current use of the methodology within AEDT/EDMS. Although the application of First Order Approximation within AEDT/EDMS only predicts total PM mass (i.e., Total PM = PM_{10} =

$PM_{2.5}$), the capability exists in First Order Approximation to speciate by black carbon, sulfate, and organics.

Aircraft-specific NO_x, CO, and NMVOC LTO emission factors and NO_x cruise emission factors are available from IPCC (2006). Both LTO and cruise emission factors for NO_x, CO, and total hydrocarbons (THC) are available in the EMEP/CORINAIR dataset. NMVOC emissions can be estimated from THC by using appropriate conversion factors such as that being promulgated through SAE (2008) and used in AEDT/EDMS (FAA[a] 2007): 1 g VOC = 1.0947 g THC.

This factor in conjunction with the assumption that CH_4 represents 10% of the THC emissions (SAE 2008), allows for the derivation of NMVOC emissions (i.e., NMVOC = VOC – CH_4). LTO modeling of these emissions (NO_x, CO, and THC) within AEDT/EDMS is conducted through the use of the Boeing Fuel Flow Method 2 (BFFM2) (DuBois 2006 and SAE 2008). Although only LTO emissions are computed, BFFM2 has the capability to model cruise emissions as is done in AEDT/SAGE. Comparable methods to BFFM2 are the DLR Method and the P3T3 Method which provide varying degrees of fidelity and usability due to data requirements (e.g., combustor T3 and P3 information).

In order to provide consistency with current airport inventory development methods, AEDT/EDMS could potentially be expanded to include the GHG emissions that it lacks: CO_2, CH_4, N_2O, SF_6, HFC, PFC, H_2O, and NMVOC. In addition, the total PM mass predictions from AEDT/EDMS could be speciated into components. Since AEDT/EDMS currently only predicts LTO emissions, a protocol would need to be developed to allow users to predict cruise emissions as well. This would be the ideal, long-term solution for promoting the consistent development of airport GHG emissions.

An alternative solution would involve the development of data tables similar in content to the EMEP/CORINAIR datasets. The tables could be developed from querying the historical AEDT/SAGE global inventories providing representative emission factors by aircraft type and origin-destination (OD) trip distance. Such tables would effectively allow users to develop high fidelity inventories based on the IPCC Tier 3a methodology. However, such use would require airport operators to have aircraft flight information, which is not readily available to every airport. Also, the availability of the AEDT/SAGE airport inventory data currently precludes this possibility, but may be a consideration for future work.

C.4.2 Aircraft Auxiliary Power Units (APUs)

For APUs built into the aircraft, the common assumption is that they use the same fuel as the main engines. As a result, the estimates for total fuel consumption by the aircraft accounts for the APU usage. Such was the approach taken on the 2006 Sea-Tac GHG inventory as well as the Denver GHG Inventory. APU use GHG emissions were not estimated for Sacramento or San Diego. Notwithstanding the uncertainties involved with the data, the total fuel dispensed information would inherently account for APU fuel usage. Therefore, using this fuel dispensed information and the aforementioned emission indices, APU emissions of CO_2, CH_4, N_2O, H_2O, and SO_x would be accounted for.

However, IPCC data tables providing fuel usage by aircraft and mode likely do not include APU fuel consumption. Therefore, while these data may be more accurate for individual flights, they could not be used to calculate APU emissions. Having said that, APU fuel consumption and emissions are generally much smaller than that due to the aircraft proper.

GHG emission factors for APUs are not available from IPCC or other sources. AEDT/EDMS provides estimates of APU emissions for only SO_x, NO_x, CO, and THC (no differentiation between THC, NMHC, and VOC). Potentially, SO_x emissions could be used to derive fuel consumption using the SO_x EI of 1.36 g/kg used in AEDT/EDMS. Notwithstanding the errors due to differences in fuel sulfur content, the derived fuel consumption value would allow for the predictions of CO_2, CH_4, N_2O, and H_2O.

Since APU emissions result from combustion processes, there are no emissions (and no data) available for emissions of SF_6, HFC, and PFC. Similarly, no data exists to allow determination of fugitive NMVOC emissions from the fuel system.

C.4.3 Ground Support Equipment (GSE)

There are generally no primary GHG pollutant emission factors for GSE, and manufacturers are not likely to have this type of information. However, the fuel dispensed to these vehicles or the fuel consumption rate (e.g., mileage) from manufacturer specifications may be available. Using this with estimates of activity (e.g., distance driven, idling time, etc.) and fuel composition CO_2, H_2O, and SO_x emissions can be readily estimated. If specific fuel composition data is not available, it can be reasonably assumed, including the sulfur content, from literature (e.g., ASTM 2007).

Both USEPA and IPCC provide CO_2, N_2O, and CH_4 emission factors for various vehicle types including those in heavy–duty categories that could potentially be used to model GSEs (USEPA[e] 2007 and IPCC 2006). These datasets need to be carefully used so that the selected emission factors reasonably represent the actual GSEs.

AEDT/EDMS predicts emissions of criteria pollutants (PM_{10}, $PM_{2.5}$, SO_x, NO_x, CO, THC, VOC, and NMHC) for GSE, but not the primary GHG, CO_2. Similar to the use of the jet fuel SO_x emission indices for APUs, a SO_x emission index could be developed for the fuel(s) used by GSEs (again, assuming the fuel sulfur content is known) to derive fuel consumption which could in turn allow for the determination of CO_2, H_2O, and SO_x emissions.

With no other data specifically available for GSEs, the USEPA's NONROAD2005 (USEPA[c] 2005) and the California Air Resource Board's (CARB) OFFROAD2007 (CARB[a] 2007) model can be employed to provide approximate emission factors for GSEs based on similar power ratings and functionalities of the equipment. These models provide emission factors for CO_2, NO_x, CO, SO_x, TOG, NMOG, NMHC, VOC, PM_{10}, and $PM_{2.5}$. In addition to exhaust emissions, various evaporative (fugitive) emissions of VOCs can be modeled including those related to the following modes: diurnal, refueling spillage, vapor displacement, etc. If the fuel composition is known, the CO_2 emission index can be readily determined and used to calculate fuel consumption which would then allow calculation of H_2O emissions as well. The inventory for Sea-Tac used the NONROAD2005 model to estimate GSE emissions based on an actual inventory of GSE at the airport. The San Diego and Sacramento GHG inventories used CARBs OFFROAD2007 model.

Currently, there are no GSE-specific emissions data for fugitive emissions of SF_6, HFC, and PFC. However, based on the use of mobile refrigeration and air conditioning systems, the USEPA's Climate Leaders have developed an approximate method for predicting emissions of HFC and PFC assuming the type of refrigerant is known (USEPA[c] 2004). This method applies to cars and light trucks and is currently employed as part of the protocols of The Climate Registry (TCR[a] 2007). Without any other data available, this may be a reasonable method for use with GSEs that have air conditioning units.

C.4.4 Ground Access Vehicles (GAV)

For GAVs, many potential sources of data exist for calculation of GHG emissions. CO_2 emissions could potentially be determined through the use of representative or average vehicle mileage rates (USEPA[e] 2007) and typical fuel composition such as those specified in the Code of Federal Regulations (CFR 2003):

- Gasoline = 2421 g C/gal of fuel
- Diesel = 2778 g C/gal of fuel

Similarly, the EIA, WRI, and other parties have published average fuel consumption rates for the national fleet, as well as the CO_2 rates for gas and diesel vehicles. This information allows for general conversion of vehicle miles traveled (VMT) for ground access vehicles into CO_2 emissions.

Similarly, H_2O and SO_x emissions can potentially be determined through typical fuel composition information from which a mass balance of reactants and products can be conducted to determine emission factors. Specifications for gasoline can be found in literature including those from SAE (1994) and ASTM (1994).

Emission factors for CO_2, CH_4, and N_2O are available from IPCC (2006) by both heat content and distance traveled. Heating values provided by IPCC as well as other sources (e.g., EIA 2007) can be used to support any unit conversions. When using these tables, care must be taken to properly account for the use of exhaust catalytic converters. As incorporated in The Climate Registry's protocols (TCR[a] 2008), USEPA also provides tabulated emission factors for CO_2, CH_4, and N_2O (USEPA[e] 2007).

Both MOBILE6.2 (USEPA 2002) and EMFAC2007 (CARB[b] 2007) provide emission predictions of the following pollutants: CO_2, CO, NO_x, SO_x, THC (and various components), PM_{10}, and $PM_{2.5}$. In addition to exhaust emissions, various evaporative emissions (e.g., running losses, vapor displacement, etc.) are also included. Although MOBILE6.2 has been implemented within AEDT/EDMS, it is often run externally to provide greater fidelity results and in its present form, AEDT/EDMS does not report either fuel or CO_2.

NMVOC is not directly provided by either model, but it can be easily derived from MOBILE6.2 hydrocarbon components. MOBILE6.2's CO_2 predictions are based on the USEPA's fuel economy trends data (USEPA[e] 2007).

USEPA's next generation Motor Vehicle Emissions Simulator (MOVES), Version 2004, can also potentially be used to predict CH_4 and N_2O emissions along with energy consumption (and hence, CO_2, H_2O, and SO_x). However, since the current incarnation of this model (MOVES2004) is limited to macroscale analyses (i.e., regional), it becomes awkward to derive the appropriate emissions or emission factors. Also, updates to the emission factors used in MOVES2004 have already been published by USEPA (USEPA[b] 2004). Due to the awkwardness of using MOVES2004 for local analyses, the emission factors from this USEPA document should be used.

Similar to the other sources, there are no specific emission factors for SF_6, HFC, and PFC. The only available data appears to be the aforementioned generic factors from EPA's Climate Leaders for air conditioning systems in vehicles. They provide methods to predict fugitive emissions of HFC and PFC from cars and light trucks (USEPA[c] 2004)

It is within this data set that a large variability likely exists as to data collected and retained by airport operators. The local metropolitan planning organization (MPO) has

responsibility under federal regulations to analyze and collect surface transportation data. However, such data is most often limited to regionally significant roadways, which may or may not include the airport roadway system. Further only the airports that have conducted passenger survey and tenant survey data may have information concerning passenger, cargo, and employee surface movement. Thus, the ability to accurately quantify GHG emissions associated with on-airport and/or off-airport GAV may be substantially constrained by the availability of any data or data sufficient to use the various methods identified to-date. To the degree that models such as MOBILE and MOVES produce the highest fidelity emission rates based on knowledge of the volume of surface traffic, but also the types of vehicle (autos, motorcycles, light duty trucks to heavy duty diesels, etc), may limit the utility of these models for some airport applications.

The San Diego and Sacramento GHG inventories focused on the on-airport roadways and parking, and relied on CARB's EMFAC2007 models (the California equivalent of MOBILE6.2). The Sea-Tac 2006 GHG inventory quantified on and off-airprot surface travel, using passenger survey data coupled with average fuel economy. It is not clear precisely how Denver evaluated surface traffic emissions, but relied on their local metropolitan planning organization (Denver Regional Council of Governments) surface traffic movements, and may have also relied on an average fuel economy.

C.4.5 Stationary Sources

To calculate direct emissions from airport combustion activities such as those involving boilers/heaters and power generation, knowledge of the fuel type and its properties are necessary. Data from the equipment manufacturer or from appropriate databases on the USEPA's Technology Transfer Network (TTN) could be used to calculate emissions associated with these sources (USEPA[d] 2008). Composition of the fuel would provide information for the carbon balance required to develop emission factors for CO_2 while fuel heating values may be necessary to quantify the amount of fuel consumed (i.e., if the energy consumed is known but not the amount of fuel). In addition to CO_2, the data would allow determination of emissions for H_2O and SO_x (assuming sulfur fuel content is known). Both USEPA and IPCC provide tabulated values of emission factors for various fuels and combustion activities (USEPA[b] 2008 and IPCC 2006).

In addition to direct emissions, indirect emissions also need to be taken into account. Most of the indirect emissions come from electricity use where the corresponding fuel consumption occurs at local power plants. Similar to the direct emissions, the fuel type and properties need to be known to properly estimate the GHG emissions. Such data could be obtained from the power plants or estimates can be made such as from average fuel properties from literature. This would be the case if the readily available emission factors from sources such as USEPA and IPCC are not appropriate (i.e., not representative of the fuel). As an alternative, pre-developed emission factors specific to U.S. regional electricity use can be employed. Such data are available from the USEPA's Emissions & Generation Resource Integrated Database (eGRID) (USEPA[f] 2007) which are also implemented as part of The Climate Registry's protocols (TCR[a] 2008).

The electrical usage-related emissions for Denver and Sea-Tac were evaluated using data either from eGRID or local utility providers. In each of these cases the electrical power demands in kWh were reported. Electrical usage was not included in the Sacramento or San Diego GHG inventories.

AEDT/EDMS allows the modeling of a fairly comprehensive list of stationary source types for CO, THC, NMHC, VOC, NO_x, SO_x, and total PM (PM_{10} = $PM_{2.5}$). For each of these source types, the fuel or associated substance (e.g., acetone for degreasing operations)

needs to be specified. This is important for predicting emissions from both combustion and volatilization processes. For some of the sources involving volatilization processes, AEDT/EDMS allows specifications for controlling portions of the emissions (e.g., through pollution control equipment), thus inherently taking into account both fugitive and non-fugitive emissions.

For HFC and PFC emissions, the USEPA's Climate Leaders provides methods for modeling fugitive emissions from commercial and industrial refrigeration and air conditioning systems (USEPA[c] 2004). The method would need to be carefully applied to make sure the appropriate is data is used to model the refrigeration systems used at the airport. For stationary sources, IPCC and USEPA provide several methods to account for fugitive-type emissions of HFCs and PFCs from refrigeration and air conditioning, aerosol propellant use, solvents for cleaning, fire extinguishers, etc. (IPCC 2006 and USEPA[a] 2007).

For SF_6 emissions, IPCC provides methods for calculating emissions from electronics etching, cleaning, and temperature control applications (IPCC 2006). However, such applications are likely to be rare used at airports. The more likely emission of SF_6 will occur indirectly from equipment used to transmit and distribute electricity. USEPA recommends the use of data from USEPA's SF_6 Emissions Reduction Partnership for Electric Power Systems (USEPA[g] 2007). If this data cannot be used, estimates can be made based empirical equations and electricity transmission distances (USEPA[a] 2007).

Denver also quantified emissions associated with incinerating airline waste as well as that associated with its recycling program. The specific methods for such quantification are not documented in their reports. Methods available to quantify these emissions appear to be associated with the USEPA's WARM model (WAste Reduction Model) (USEPA[b] 2007). As noted on the USEPA web site, this model "WARM calculates GHG emissions for baseline and alternative waste management practices, including source reduction, recycling, combustion, composting, and land-filling. The model calculates emissions in metric tons of carbon equivalent (MTCE) and metric tons of CO_2 equivalent ($MTCO_2E$) across a wide range of material types commonly found in municipal solid waste (MSW). In addition, the model calculates energy use for each of the options, and the Microsoft Excel© version allows users to report results by year, by gas, and by year and gas."

C.4.6 Training Fires

As with any combustion process, knowledge of the fuel type and composition can be used to predict GHG emissions. While this will allow predictions of CO_2, H_2O, and SO_x emissions (assuming the fuel sulfur content is known), there are currently no data available to support the modeling of N_2O and CH_4 emissions from training fires.

As modeled in AEDT/EDMS, training fires produce emissions of CO, NO_x, THC, NMHC, VOC, SO_x, and total PM (PM10 = $PM_{2.5}$). The emissions depend on both the quantity of fuel used and the type of fuel (e.g., JP-4, JP-5, etc.).

As a combustion process, there are no emissions of SF_6, HFC, and PFC from the fires. However, any use of materials containing these fluorinated compounds need to be accounted for including any fire extinguishers. Both IPCC and USEPA provide methods to estimate emissions of HFC and PFC from fire extinguishers (IPCC 2006 and USEPA[a] 2007).

None of the GHG inventories prepared to date have included training fire-related emissions.

C.4.7 Construction Activities

Assessing the emissions from these off-road activities is similar to the determination of emissions from GSEs. Although GHG emissions can be determined from fuel composition and equipment mileage information, the preferred method is to use either NONROAD2005 or OFFROAD2007 as these models implicitly include the capability to model construction equipment. The models predict emissions for CO_2, NO_x, CO, SO_x, TOG, NMOG, NMHC, VOC, PM_{10}, and $PM_{2.5}$.

Both USEPA and IPCC provide CO_2, N_2O, and CH_4 EFs for various vehicle types including those in heavy–duty categories that could potentially be used to model GSEs (USEPA[e] 2007 and IPCC 2006). These datasets need to be carefully used so that the selected EFs reasonably represent the construction equipment.

PM emissions from construction activities and from construction equipment traveling on both paved and unpaved roadways can be estimated using the appropriate methods and data from USEPA's AP-42 documents (USEPA[c] 2008).

Currently, there are no construction-specific emissions data for fugitive emissions of SF_6, HFC, and PFC. However, based on the use of mobile refrigeration and air conditioning systems, the USEPA's Climate Leaders have developed an approximate method for predicting emissions of HFC and PFC assuming the type of refrigerant is known (USEPA[c] 2004). This method applies to cars and light trucks and is currently employed as part of the protocols of The Climate Registry (TCR[a] 2008). Without any other data available, this may be a reasonable method for use with construction equipment that have air conditioning units.

Of the inventories reviewed as part of this project, only the Sacramento inventory presented GHG emissions associated with construction. The specific approach used is not documented, but it is presumed that the analysis was prepared using either CARB's OFFROAD or URBEMIS model.

C.4.8 Waste Management Activities

Few methodologies exist to capture the emissions benefits associated with waste management activities. It is recommended that airport inventories not attempt to capture the emissions benefits associated with waste management activity, especially waste reduction processes since a life-cycle analysis would be required to fully capture the ramifications of those activities. Rather, the direct emissions from waste handling should be assessed (e.g., incineration, waste hauling, etc.).

For airports that are required to consider the greenhouse gas consequence of various waste management strategies, the USEPA's Waste Reduction Model (WARM) (USEPA[b] 2007) is recommended. However, the USEPA's web site specifically notes the following with regards to this model, which reflects a life-cycle approach to considering such emissions: "This life-cycle 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." WARM provides the net effect of the upstream and downstream implications of these activities.

As indicated by USEPA, WARM models source reduction, recycling, combustion, composting, and land-filling. Some examples of materials covered by the model include aluminum cans, glass, plastic, paper, etc. 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 web site for information about this model, data requirements and reporting (USEPA[b] 2007).

Appendix D: Methods for Calculating CO_2 Equivalencies

D.1 Introduction

In this section, CO_2 equivalency methods are discussed in more detail. The current scientific understanding of CO_2 equivalency methods and their appropriateness for use as metrics to compare impacts of different pollutants is presented, but detailed descriptions of the complex physics and chemistry involved in climate change are outside the scope of this project. For clarity, the terms, "climate change agents" and "radiative forcing agents" are used interchangeably to encompass all of the primary, precursor, and secondary pollutants as well as contrails, clouds, etc. that can exert GHG effects.

In Section D.2, the effects of CO_2 on climate are discussed. Understanding the behavior of CO_2 impacts, particularly as a function of time, is critical for understanding assumptions underlying different equivalency methods. Then, in Section D.3, we present several alternative metrics for assessing the impacts of CO_2 – these metrics form the basis for different equivalency methods. However, before proceeding to a discussion of the equivalency methods, we describe in Section D.4 the physical effects of non-CO_2 climate agents. Knowledge of the differences between the effects of non-CO_2 climate agents, and the effects of CO_2 is a prerequisite for understanding the limitations of the different equivalency methods. Finally, in Section D.5 we describe the equivalency methods themselves, including the Radiative Forcing Index (RFI) in Section D.5.1, the recommended method of Global Warming Potentials (GWP) in Section D.5.2, and lesser-used alternatives in Section D.5.3, including the Linear Damage Potential (LDP), and the Global Temperature Potential (GTP). Within Section D.5.2 we provide GWP values and also a detailed review of criticisms and limitations of GWP equivalencies.

D.2 The Effect of CO_2 on Climate Change

There is a natural exchange of carbon among the atmosphere, oceans, geological formations, and plants and other life forms. This is known as the carbon-cycle. When fossil fuels (containing predominantly carbon and hydrogen) are combusted in air, H_2O and CO_2 are the primary products. The CO_2 emitted to the atmosphere is in excess of that associated with the natural carbon exchange processes. The IPCC (2007) finds that the concentration of CO_2 in the atmosphere is increasing predominantly because of human use of fossil fuels. Each kilogram of CO_2 emitted has a long lifetime in the atmosphere (hundreds of years) before it is captured in the oceans, landmasses, and various life forms (and some of the CO_2 is expected to permanently remain in the atmosphere). Thus, the change in concentration due to a new emission of CO_2 is like that shown in Figure D-1, a gradual decay over time.

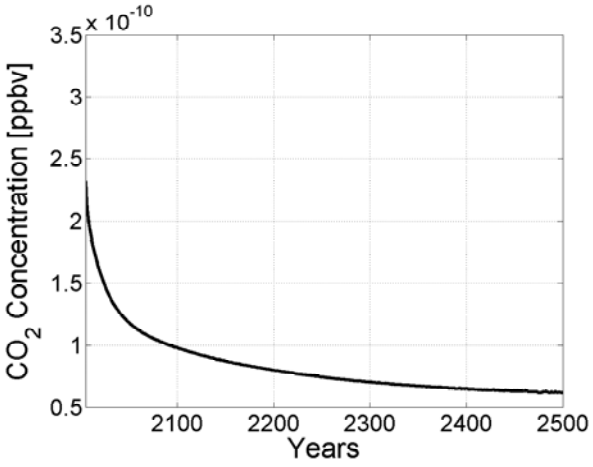


Figure D-1. Change of atmospheric concentration of CO_2 over time for the emission of one new ton of CO_2 (assuming IPCC 2007 SRES A1B background emissions scenario); only 500 years are plotted although the effect extends beyond that time period

The CO_2 in the atmosphere changes the radiative balance of the Earth. It absorbs outgoing infrared radiation, changing the balance between incoming solar energy and outgoing infrared energy. When more energy is incident on the Earth than is radiated from the Earth, the energy of the Earth increases, acting to increase the temperature. The temperature increases by different amounts and at different rates depending on the properties of the material being heated (e.g. air, water, soil, etc.) and various physical phenomena (e.g. circulation of the atmosphere and oceans). The imbalance in incident and outgoing energy as caused by human activities is called radiative forcing. Formally, the radiative forcing is "the change in net (down minus up) irradiance (solar plus longwave; in W/m^2) at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at the unperturbed values" (IPCC 2007, Chapter 2, p.133). The amount that the radiative balance of the Earth is changed by a new emission of CO_2 depends on the total concentration of CO_2 in the atmosphere (not just the new amount emitted). The response is non-linear with each new unit of CO_2 being less active as the background concentration increases. Indeed, one of the criticisms of equivalency methods is that they are sensitive to the assumptions about future background emissions. It must be understood that this is a feature of *all* equivalency methods (it is related to the physics and chemistry of the atmospheric response to CO_2 and other chemical species). Nonetheless, it is sometimes overlooked that the calculation of equivalency values requires a projection for changes in concentrations of greenhouse gases over hundreds of years. Therefore, GWPs and other equivalency metrics will in general be less accurate if the world follows a different path than that assumed in deriving them. GWP and other equivalency values should be viewed as 'what-if?' estimates: if worldwide emissions follow a certain path, then what is the equivalency among emissions? The radiative forcing due to a new unit of CO_2 being added to the atmosphere is shown in Figure D-2.

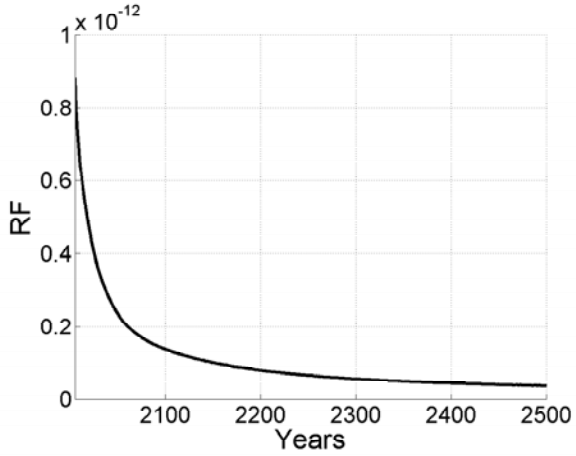


Figure D-2. Radiative forcing (W/m^2) as a function of time due to a new ton of CO_2 emitted into the atmosphere (assuming IPCC 2007 SRES A1B background emissions scenario). Only 500 years are plotted although the effect extends beyond that time period

Changing the radiative balance of the Earth does not immediately lead to a surface temperature change. It takes time for the atmosphere, oceans and landmasses to warm because they have finite (indeed, quite large) thermal inertia. The overall response to a new unit of CO_2 emitted to the atmosphere is shown in Figure D-3.

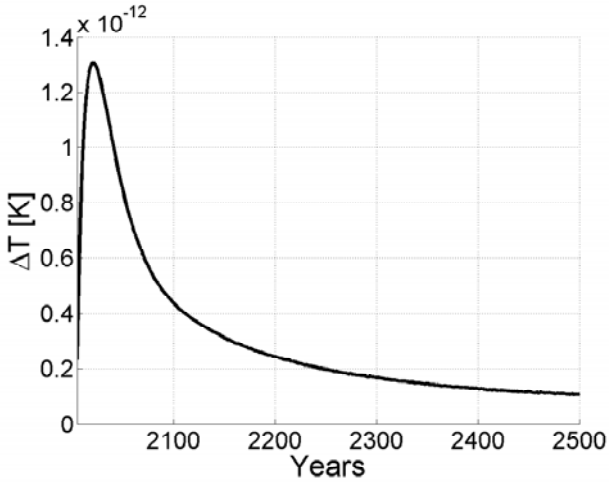


Figure D-3. Temperature response as a function of time due to a new ton of CO_2 emitted into the atmosphere. (assuming IPCC 2007 SRES A1B background emissions scenario). Only 500 years are plotted although the effect extends beyond that time period.

As shown in Figure D-3, there is a gradual warming as the change in radiative forcing warms the earth-atmospheric layer. However, over a longer time, the new unit of CO_2 is gradually removed from the atmosphere to the oceans, landmasses and biomass, so that at

some point hundreds of years in the future, it no longer significantly changes the radiative balance, and thus no longer acts to change the temperature of the Earth. A simplified mental model is to think of each new unit of CO_2 as adding a thin blanket to a body; the blanket traps heat leading to a gradual warming. Since each unit of CO_2 is slowly removed to the oceans, biomass, and landmasses, the blanket gets thinner over time. The relationship between the lifetime of the CO_2 (how quickly the blanket becomes thinner) and the time it takes to change the temperature of the Earth-atmospheric layer determines the shape of the curve shown in Figure D-3.

Because of the long lifetime of CO_2 in the atmosphere (hundreds of years), there is sufficient time for it to be transported by winds and atmospheric circulation. Therefore, no matter where on Earth the new unit of CO_2 is emitted, the radiative forcing is very uniformly distributed around the globe. Note that the effect of this radiative forcing on surface temperature may differ at different locations on the globe. Nonetheless, a change in globally-averaged surface temperature is a common and useful metric for judging the impacts of CO_2 on climate change.

Because humans are adding CO_2 to the atmosphere faster than it is being removed to the oceans, landmasses, and biological matter, the overall trend is for warming of the Earth. That is, the overall blanket is getting thicker (atmospheric concentrations of CO_2 are increasing) even though each new emission of CO_2 is added and then removed (over time), and even though each new unit of CO_2 has a smaller net effect given the growing atmospheric concentration of CO_2.

D.3 Metrics for assessing the impact of CO_2 on Climate

If one wishes to understand the impacts of a new unit of CO_2, one typically considers its effects over a time period of hundreds of years and integrates these effects over time. For example, one may consider the area under the curve in Figure D-3 as some measure of integrated effect of a new unit of emissions on changes in surface temperature. This is the basis for one equivalency method, called the linear damage potential, as will be described later. Alternatively, one may consider the integrated area under the radiative forcing curve (shown in Figure D-2) as a surrogate measure for the impact on surface temperature. This is the basis for the most popular equivalency metric, the Global Warming Potential, as will be described later. Or one may estimate the economic damage as a function of changes in surface temperature and use this as a basis for estimating the impact of a new unit of CO_2 emissions. Such economic methods may be used because it is understood that the impact of a new unit of temperature change may be more or less damaging depending on overall temperature level. For example, some coupled environmental-economics models (Nordhaus 2007) estimate that as the Earth warms, each new unit of temperature change will be more damaging (e.g., damage proportional to ΔT^2).

Each of the above examples is the basis for a different equivalency metric. It should therefore be recognized that there is no single "best" equivalency metric. For different purposes, one may wish to compare things based on changes in radiative forcing, or changes in surface temperature, or changes in economic damage. Further, one may wish to do this at a point in time (as is done for the Global Temperature Potential, GTP, as discussed later), or for the total integrated effect of a pollutant emission, or for some limited time period (e.g. the effects over only the first 20 years, 100 years, or 500 years, as is used for the GWP_{20}, GWP_{100}, and GWP_{500} equivalency methods). It should be recognized that as one moves from estimating radiative forcing, to estimating the effect on surface temperature, to estimating the economic damages, more and more assumptions and estimates about the behavior of the Earth-atmosphere system, and projections regarding the future, must be brought to bear.

The various metrics that may be used to assess even the impact of CO_2 can be confusing. However, the reason that equivalency methods are required is because the behavior of other pollutant emissions is different from that of CO_2. Due to the differing behavior of these different pollutant emissions, the metrics may carry different implicit assumptions depending on the pollutant to which they are applied. For example, as described below, some gases have significantly shorter lifetimes than CO_2, so a GWP_{100} metric may capture all of the future impacts of CH_4, but only a portion of the future impacts of CO_2. Before discussing the implications of the various assumptions more fully, it is necessary to return briefly to physics and chemistry to describe the behavior of some of the short-lived non-CO_2 climate change agents.

D.4 Behavior of Short-Lived non-CO2 Climate Change Agents

In general it is useful to consider three aspects of non-CO_2 climate change impacts (some of which were discussed in previous sections):

- Is the effect of the emission direct or indirect? For example, CO_2 acts directly to change the radiative balance. However, NO_x indirectly influences the radiative balance through three different pathways: it indirectly leads to the production and removal O_3, a greenhouse gas, on two different time-scales respectively, and it accelerates the removal of CH_4. Likewise, contrails or aviation-induced cirrus cloudiness act through a different physical pathway than do the other effects (clouds act to reflect incoming solar radiation and also to trap out-going infrared radiation; the net impact is a function of the thickness of the cloud among other properties, with thin clouds tending to warm the planet, and thick clouds tending to cool the planet).

- What is the lifetime of the effect of the emission? For example, as noted above, emissions of NO_x indirectly produce O_3, which has a dominant atmospheric lifetime of weeks, but NO_x emissions also accelerate the removal of CH_4 which has a dominant atmospheric lifetime of decades, and the chemistry related to the accelerated removal of CH_4 also reduces O_3 over the same time-scale (decades). The lifetime of the effect has a strong influence on whether the effect is felt regionally or globally. Short-lived effects such as the production of O_3, or the impact of contrails, produce regional forcing. Long-lived effects, such as those due to CH_4, CO_2, and CFC's produce changes in radiative forcing that are largely uniform around the globe. Since equivalency metrics are typically based on globally-averaged quantities, it is important to remember their limitations when applied to short-lived effects that are largely felt regionally. Some CFC's, hydroflourinated compounds, and perflourinated compounds have estimated atmospheric lifetimes of 1000s of years, whereas contrails may last only a few hours.

- How potent is the effect in terms of changing the climate? Some gases and particles have more potent influences on climate than others. Identical changes in atmospheric concentrations (as measured in parts per billion, ppb, for example) of CH_4, CO_2, O_3, SF_6, etc., will all produce different radiative forcing. For example, CO_2 has an estimated radiative efficiency of 1.4×10^{-5} W/m^2 per ppb whereas SF_6 has an estimated radiative efficiency of 0.52 W/m^2 per ppb; SF_6 is 40,000 times more potent.

In Table D-1, with direct reference to text from IPCC (2007), we list some important representative climate change agents and describe the mechanisms by which they impact climate.

Table D-1. Characteristics of important representative climate change agents

Climate change source	**Direct or indirect impact pathway**	**Time-scale of impact**	**Potency**
CO_2	CO_2 emissions directly change the Earth's radiative balance through their absorption and reemission of infrared radiation.	100s of years; the radiative forcing is global; each new unit of emission produces a gradual increase warming over the first 30 years as the effects of the sustained radiative forcing accumulate over time; after approximately 30 years the natural removal of CO2 to the oceans, biomass and landmass leads to a diminution of the effect. See Figure D-3.	As the dominant greenhouse gas, CO_2 is typically used as the reference against which other climate change impacts are compared. Radiative efficiency is 1.4×10^{-5} W/m^2 per ppb
CH_4	"Four indirect radiative effects of CH4 emissions have been identified. CH_4 enhances its own lifetime through changes in OH concentration: it leads to changes in tropospheric O_3, enhances stratospheric H_2O levels, and produces CO2." (IPCC 2007, p. 214)	10s of years; the radiative forcing is global; each new unit of emission produces a gradual increase warming over the first 10 years as the effects of the sustained radiative forcing accumulate over time; after approximately 10-15 years the removal of CH_4 leads to a diminution of the effect.	Radiative efficiency is 3.7×10^{-4} W/m^2 per ppb, about 25 times that of CO_2.
Aerosols	"Aerosol particles influence radiative forcing directly through reflection and absorption of solar and infrared radiation in the atmosphere. Some aerosols cause a positive forcing while others cause a negative forcing. The direct radiative forcing summed over all aerosol types is negative. Aerosols also cause a negative	Hours to days; the radiative forcing is regional.	Not applicable.

	radiative forcing indirectly through the changes they cause in cloud properties." IPCC 2007, chapter 2, p. 136		
CO	IPCC: 214 "The indirect effects of CO occur through reduced OH levels (leading to enhanced concentrations of CH4) and enhancement of O_3.	10s of years; the radiative forcing is global	Approximately 2 times that of CO_2 based on a 100 year GWP
NMVOCs	Non-methane volatile organic compounds have indirect impacts on radiative forcing through effects on tropospheric O_3, CH_4 (through changes in OH) and CO_2 (IPCC 2007, p 215)	10s of years; the radiative forcing is global	Approximately 0.5 to 5.5 times that of CO_2 based on 100 year GWP calculations
NO_x	The short lifetime of NO_x, and complex nonlinear chemistry, cause two opposing indirect effects through O_3 enhancements and CH4 reductions, and make calculations of the relative impacts of NO_x emissions very uncertain. Due to the nonlinear chemistry, the net radiative forcing of NO_x emissions will depend strongly on the location of emission and also on timing (daily, seasonal) of the emissions. (paraphrased from IPCC 2007, p 215)	Days to 10s of years; the radiative forcing is regional and global, depending on the pathway of impact	There is lack of agreement even on the sign of the global mean GWP for NO_x among the different studies. The IPCC provides results from a range of studies but does not provide a central estimate noting the uncertainty and the omission of the potentially important nitrate aerosol effect in GWP calculations of NO_x
CFCs, HFCs, HCFCs and PFCs	These are long-lived gases that impact climate predominantly through direct effects on absorption and reemission of infrared radiation (although there are also indirect effects on climate through changes in O_3)	The life span of these gases ranges from a year to thousands of years; the radiative forcing is global	The radiative efficiency of these gases ranges from thousands to tens of thousands of times that of CO_2
Contrails and	"Aircraft produce	Hours; the radiative	Not applicable

aviation induced cirrus cloudiness	persistent linear trails of condensation ('contrails') in regions that have suitably low temperatures and high humidity. Contrails are a form of cirrus cloud that reflect solar radiation and absorb infrared radiation. Linear contrails from global aircraft operations have increased Earth's cloudiness and are estimated to cause a small positive radiative forcing." (IPCC 2007, p. 137)	forcing is regional	
N_2O	N_2O is a long-lived greenhouse gas that directly changes the Earth's radiative balance through absorption and reemission of infrared radiation	One hundred years	Radiative efficiency is 3.03×10^{-3} W/m^2 per ppb approximately 200 times that of CO_2

Graphically, we can visualize the changes in surface temperature due to new emissions of some of these climate change agents as shown in Figure D-4. Our purpose here is to qualitatively show the different behaviors with respect to time for later reference when equivalency methods with different integration periods are discussed. CH_4 (and impacts of NO_x on CH_4) behaves similar to CO_2, but on a shorter timescale. For effects due to aviation contrails and induced cirrus, the radiative forcing is applied for a short period, producing a change in temperature that rapidly decays (over 10s of years). To use the simplified mental model described earlier, this is like adding a blanket for a short period of time, then instantaneously removing it. There is an initial warming, but then a gradual reduction in this warming as the body cools. The blanket is not left on year-after-year as it is for a long-lived gas. The short time-scale behavior is also observed for sulfur emissions and black carbon (soot) aerosols; however, they have a general cooling influence. NO_x emissions act through three indirect pathways. The first is the production of O_3, which is short-lived and thus has an effect on temperature that looks much like that of contrails and aviation-induced cirrus. The second is the accelerated removal of atmospheric CH_4, which thus has a behavior that mirrors the behavior of CH_4 emissions, but which is negative. The third is the chemical process related to the accelerated removal of CH_4 that also act to remove O_3. This process is also a cooling influence with a shape that is similar to that of the accelerated removal of CH_4.

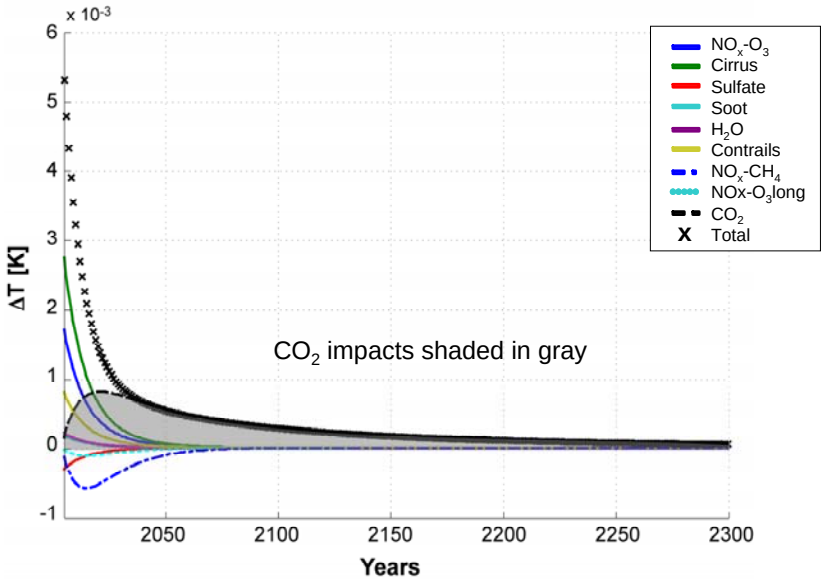


Figure D-4. Schematic showing the change in surface temperature due to different climate change agents associated with aircraft emissions

This picture alone is complex, and one can see the challenge in establishing equivalencies among these various effects that occur over different time-scales. However, above we have shown only the globally-averaged effects. The situation for some effects is even more complicated because of the different spatial scales over which the effects occur, and also because of the different effects that are estimated depending on where the emissions occur (latitude, longitude, altitude), the time of day, and the background atmospheric conditions. This is the case for the impacts of NO_x, contrails, and aviation induced-cirrus in particular, which are important climate impacts of aviation. Because of these complexities, and the evolving scientific understanding, we do not recommend inclusion of these effects in current equivalency methods as noted below. This is consistent with the recent IPCC assessment (IPCC 2007, p 215).

D.5 Emissions Equivalency Methods

With the preceding discussion of physical and chemical behavior as a foundation, we now describe methods for approximating the relative magnitude of the different climate change sources and effects. As described previously, there is no "best" equivalency method, and these methods each have explicit and implicit assumptions. Consistent with recent IPCC assessments (see e.g., IPCC 2007) we emphasize the Global Warming Potential (GWP) as the most appropriate general equivalency method, but also highlight shortcomings in the use of this method, and note climate change agents for which this method is not applicable.

We organize the discussion as follows. First, we describe why the use of radiative forcing, through the radiative forcing index (RFI), is not appropriate as an equivalency method. Next we provide a discussion of the global warming potential for both direct and indirect effects, and include a discussion of uncertainties and criticisms of the use of GWP. Finally, we conclude with a brief review of alternative methods. These are still being developed within the scientific community, and while they may be appropriate for more

advanced analyses or for more specific policy questions, they are not generally recommended for use in place of Global Warming Potentials.

D.5.1 Radiative Forcing and the Radiative Forcing Index (RFI)

It is typical in IPCC reports and many other scientific studies of climate change to find bar charts that show the relative magnitude of radiative forcing from various climate change contributors. Examples are the chart from IPCC (2007), shown in Figure D-5, and that specific to aviation from Sausen et al. (2005) shown in Figure D-6. These depict the relative contributions of various climate change agents to radiative forcing. The estimates are for the integrated effect of emissions from 1750 to 2005 (in Figure D-5) and for aviation emissions from 1940 to 2000 (in Figure D-6).

Radiative forcing is a useful surrogate for climate change, because it has been shown in many large computer simulations that for long-lived greenhouse gases, the equilibrium change in globally-averaged surface temperature is approximately linearly related to the radiative forcing:

$$\Delta T_s \approx \Delta_i \, RF$$

where Δ_i is the climate sensitivity parameter for a given agent (i), with units of Kelvin per W/m^2. From (IPCC 2007, p 133): "This equation, developed from … early climate studies, represents a linear view of global mean climate change between two equilibrium climate states. Radiative forcing is a simple measure for both quantifying and ranking the many different influences on climate change; it provides a limited measure of climate change as it does not attempt to represent the overall climate response. However, as climate sensitivity and other aspects of the climate response to external forcings remain inadequately quantified, it has the advantage of being more readily calculable and comparable than estimates of the climate response."

A radiative forcing index (RFI) is formed by taking the ratio of the radiative forcing of one contributor divided by the radiative forcing for CO_2. So, taking aviation as an example, if one were to seek a multiplier to put all of aviation's effects in CO_2-equivalent terms, one might take the ratio of the total radiative forcing to the radiative forcing for CO_2 alone (e.g., RFI = $47 mW/m^2 \div 24 \, mW/m^2 \approx 2.0$, for the most recent estimates given by the red bars in Figure D-5). However, this is an incorrect application of the radiative forcing estimates if one is trying to understand the future impacts of new emissions. The figures show the instantaneous radiative forcing at a point in time (2005 and 2000, respectively for Figure D-5 and Figure D-6), reflecting the accumulated effects of CO_2 and other emissions up to that time. They do not take account of the future impacts of those same emissions. Recall, much of the O_3 impact, the contrails, induced cirrus, sulfate, soot, and water, produce changes in radiative forcing that are contemporaneous with the aviation activity (time scales of days to weeks). The impact on surface temperature then decays over a period of a few decades and is gone (as shown in Figure D-3). CH_4 has an impact on radiative forcing of a couple of decades, thereafter the impact on surface temperature decays. CO_2 has an impact on radiative forcing for centuries (and therefore an impact on temperature for this same time scale). So for a unit of aircraft activity in 1940, the first 60 years of the CO_2 impact on radiative forcing are captured, as are nearly all of the NO_x impacts on O_3 and CH_4, and the short-lived effects of soot, sulfate aerosols, contrails and aviation-induced cirrus. For a unit of aircraft activity in 1970, the first 30 years of the CO_2 impact on radiative forcing are captured, most of the NO_x impacts on O_3 and CH_4 effects are represented, and all of the short-lived effects are captured. For a unit of aircraft activity in 2000, the short-lived impacts including the impacts of NO_x on O_3 are captured in the radiative forcing, but not the impacts of NO_x on CH_4, or the impacts of the CO_2. Thus, by forming a radiative forcing

index, one is comparing the full impacts of some emissions, to the partial impacts of other emissions, and not accounting for future impacts of any emissions. RFI has thus been identified by the IPCC (2007) and several other authors as an inappropriate means of establishing equivalency among effects that have very different time-scales (see e.g., Fuglestvedt, forthcoming, and the article by Sausen and Schumann in ICAO[b] 2007). It is most appropriate for judging the relative equilibrium globally-averaged surface temperature change due to different long-lived greenhouse gases. Because the RFI has been inappropriately used for weighting the short-lived impacts of aviation (see for example the use by carbon offsetting firms as described in (Kollmus 2006), we highlight it here. These passages from the (IPCC 2007) are included to underscore this point:

> "Current RF depends on present-day concentrations of a forcing agent, which in turn depend on the past history of emissions. Some climate response to these RFs is expected to have already occurred. Additionally, as RF is a comparative measure of equilibrium climate change and the Earth's climate is not in an equilibrium state, additional climate change in the future is also expected from present-day RFs (see Sections 2.2 and 10.7). As previously stated in Section 2.2, RF alone is not a suitable metric for weighting emissions; for this purpose, the lifetime of the forcing agent also needs to be considered." (p. 199)

And from (p. 215):

> "…the RF index (RFI) introduced by IPCC (1999), should not be used as an emission metric since it does not account for the different residence times of different forcing agents."

There are additional complexities associated with the response of the climate to these different long- and short-lived forcing agents. Due to the different time-scales over which the agents act, each has a unique spatial pattern. Thus, when combining or comparing the different effects, the global mean radiative forcing may not be an effective measure. For example, in the case of forcing from aircraft NO_x, the impacts on O_3 and CH_4 nearly offset one another when a global average is taken. However, there are nonetheless significant regional effects. There is positive radiative forcing in the northern hemisphere where there is more aircraft activity, and the O_3 effect is larger than the CH_4 effect, and negative radiative forcing in the southern hemisphere where there is less aviation activity and the CH_4 effect is larger than the O_3 effect. These spatial patterns of radiative forcing also impact the climate response, and this can be important for attributing climate change to particular agents and also for prediction of the regional patterns of future climate change (IPCC 2007, p 196).

Further, the climate is more sensitive to some radiative forcing agents that others. This is typically represented with a parameter called efficacy (E). Efficacy is the ratio of the climate sensitivity of a given forcing agent, to that of CO_2. The relative impact of different RF agents (with subscript i denoting a particular agent) on climate can be estimated to first order using

$$\Delta Ts = \Delta_{CO2} \times E_i \times RF_i$$

(see, for example, Sausen and Schumann 2000, and Marais 2008 for applications within simplified climate models for assessing aviation impacts). The range of efficacy values as reported in the literature falls between 0.6 and 1.6 as shown in Figure D-7 which is reproduced from IPCC 2007.

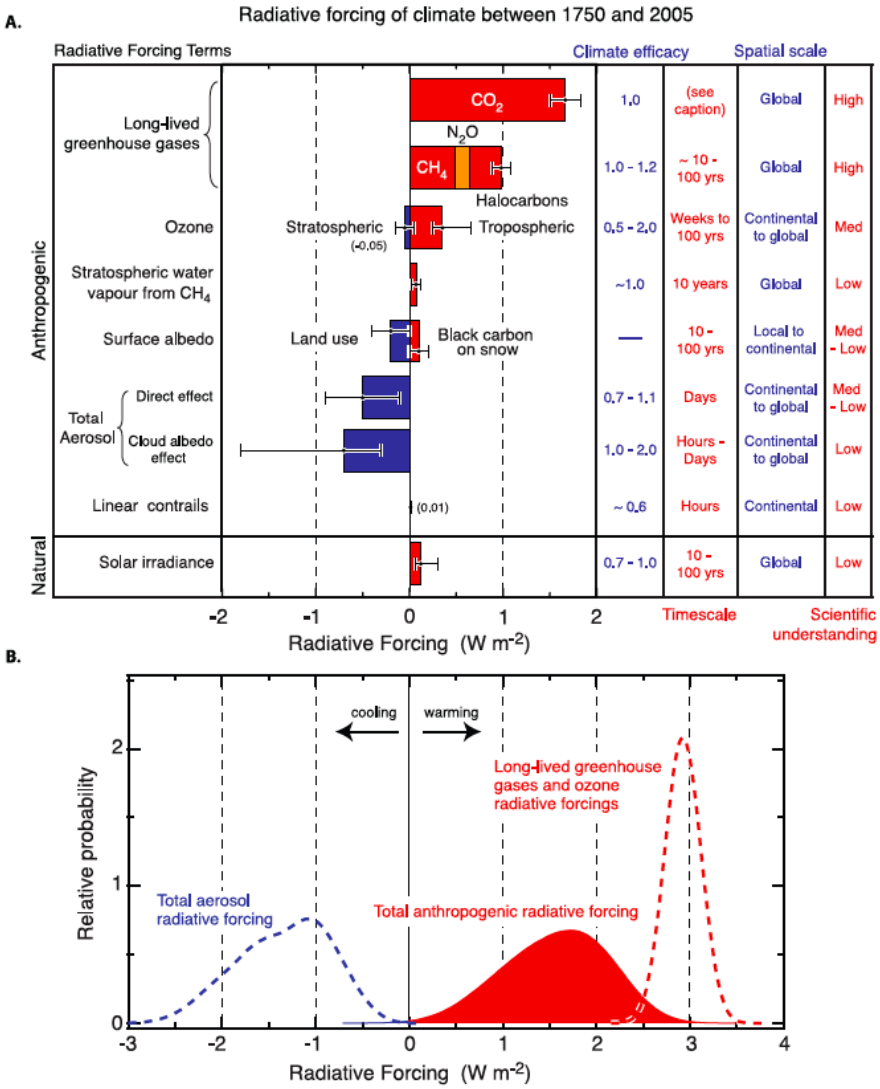


Figure 2.20. *(A) Global mean RFs from the agents and mechanisms discussed in this chapter, grouped by agent type. Anthropogenic RFs and the natural direct solar RF are shown. The plotted RF values correspond to the bold values in Table 2.12. Columns indicate other characteristics of the RF; efficacies are not used to modify the RFs shown. Time scales represent the length of time that a given RF term would persist in the atmosphere after the associated emissions and changes ceased. No CO_2 time scale is given, as its removal from the atmosphere involves a range of processes that can span long time scales, and thus cannot be expressed accurately with a narrow range of lifetime values. The scientific understanding shown for each term is described in Table 2.11. (B) Probability distribution functions (PDFs) from combining anthropogenic RFs in (A). Three cases are shown: the total of all anthropogenic RF terms (black filled red curve; see also Table 2.12); LLGHGs and ozone RFs only (dashed red curve); and aerosol direct and cloud albedo RFs only (dashed blue curve). Surface albedo, contrails and stratospheric water vapour RFs are included in the total curve but not in the others. For all of the contributing forcing agents, the uncertainty is assumed to be represented by a normal distribution (and 90% confidence intervals) with the following exceptions: contrails, for which a lognormal distribution is assumed to account for the fact that the uncertainty is quoted as a factor of three; and tropospheric ozone, the direct aerosol RF (sulphate, fossil fuel organic and black carbon, biomass burning aerosols) and the cloud albedo RF, for which discrete values based on Figure 2.9, Table 2.6 and Table 2.7 are randomly sampled. Additional normal distributions are included in the direct aerosol effect for nitrate and mineral dust, as these are not explicitly accounted for in Table 2.6. A one-million point Monte Carlo simulation was performed to derive the PDFs (Boucher and Haywood, 2001). Natural RFs (solar and volcanic) are not included in these three PDFs. Climate efficacies are not accounted for in forming the PDFs.*

Figure D-5. Contributors of different climate change agents to radiative forcing in 2005. The integrated effects of emissions occurring between 1750 and 2005 are shown (reprinted from IPCC, 2007, p.203)

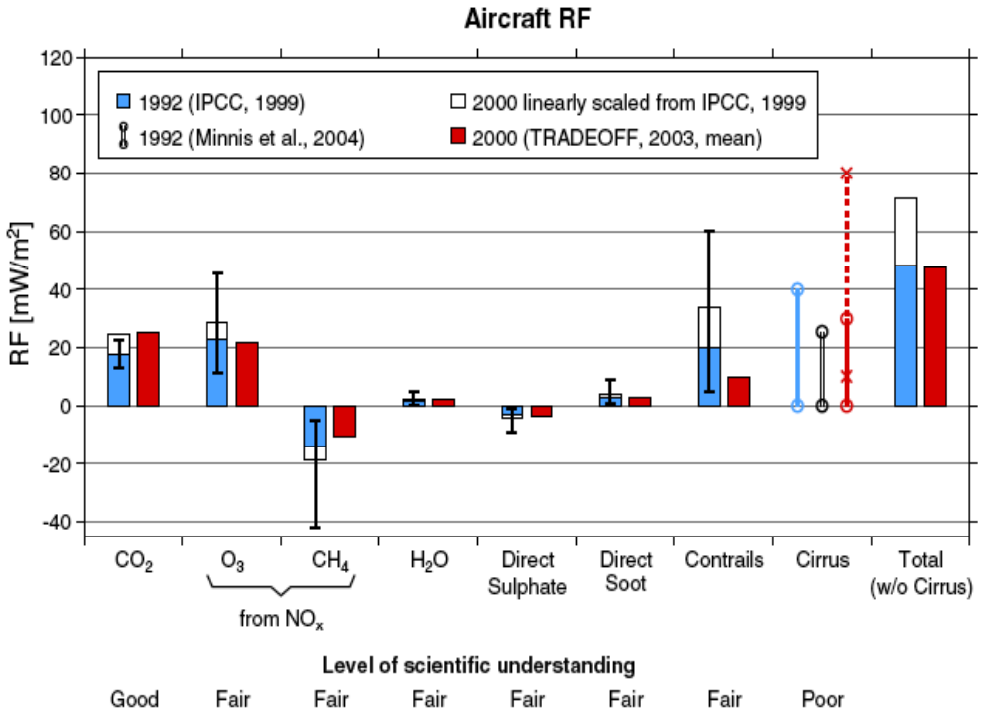


Figure D-6. Contributors to radiative forcing in 1992 and 2000 from climate change agents related to aircraft activity. The integrated effect of emissions between 1940 and 2000 is shown (reprinted from Sausen 2005)

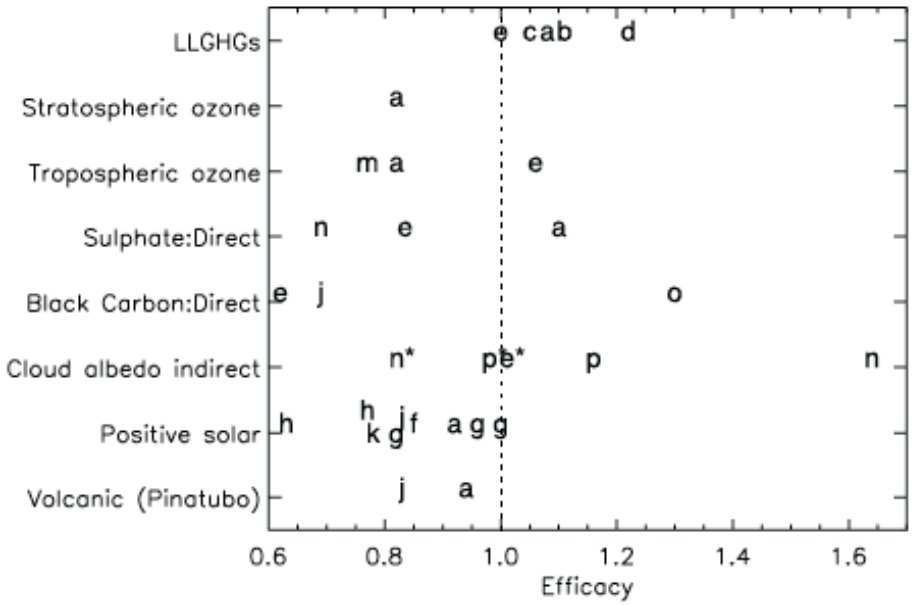


Figure 2.19. *Efficacies as calculated by several GCM models for realistic changes in RF agents. Letters are centred on efficacy value and refer to the literature study that the value is taken from (see text of Section 2.8.5 for details and further discussion). In each RF category, only one result is taken per model or model formulation. Cloud-albedo efficacies are evaluated in two ways: the standard letters include cloud lifetime effects in the efficacy term and the letters with asterisks exclude these effects. Studies assessed in the figure are: a) Hansen et al. (2005); b) Wang et al. (1991); c) Wang et al. (1992); d) Govindasamy et al. (2001b); e) Lohmann and Feichter (2005); f) Forster et al. (2000); g) Joshi et al. (2003; see also Stuber et al., 2001a); h) Gregory et al. (2004); j) Sokolov (2006); k) Cook and Highwood (2004); m) Mickley et al. (2004); n) Rotstayn and Penner (2001); o) Roberts and Jones (2004) and p) Williams et al. (2001a).*

Figure D-7. Efficacies of different climate forcing agents (reproduced from IPCC 2007, p. 197).

D.5.2 Global Warming Potential

The global warming potential is the most commonly used equivalency method. The global warming potential is formed by comparing the area under the radiative forcing curve for a unit emission of one type of gas (i), to the area under the radiative forcing curve for CO_2 (as shown in Figure D-8):

$$GWP_i \equiv \frac{\int_0^{TH} RF_i(t)dt}{\int_0^{TH} RF_{CO_2}(t)dt}$$

where TH is the time horizon over which the integration is performed. The use of the GWP in comparing emissions of different agents involves multiplying the mass emissions of a non-CO_2 agent with its GWP to obtain CO_2-equivalent (CO_{2e}) mass emissions. The GWPs from the latest IPCC report (i.e., Fourth Assessment Report) (IPCC 2007) are recommended

unless consistency is required with prior inventories or protocols that require GWPs from other assessment reports (such as those of ICLEI or TCR that require earlier assessments)..

It is common to report global warming potentials for different periods of time. For example, GWP_{20}, GWP_{100}, and GWP_{500}, reflecting 20-year, 100-year and 500-year integration periods, respectively. Restricting the comparison to a finite time period, is the same as not counting effects that occur after that period. This is an implicit value assumption regarding the importance of long-term effects relative to short-term effects. The consequences are shown in Figure D-8 for an example case of comparing CH_4 to CO_2. Here the GWP_{500} captures more than 90% of the CO_2 radiative forcing integrated over time, and all of the CH_4 integrated radiative forcing. The GWP_{100} captures about 30% of the CO_2 integrated RF and all of the CH_4 integrated RF. The GWP_{20} captures about 50% of the CH_4 integrated RF and about 5% of the CO_2 integrated RF. For CH_4 the GWP values are GWP_{20} = 72, GWP_{100} = 25, GWP_{500} = 7.6 as shown in Table D-2.

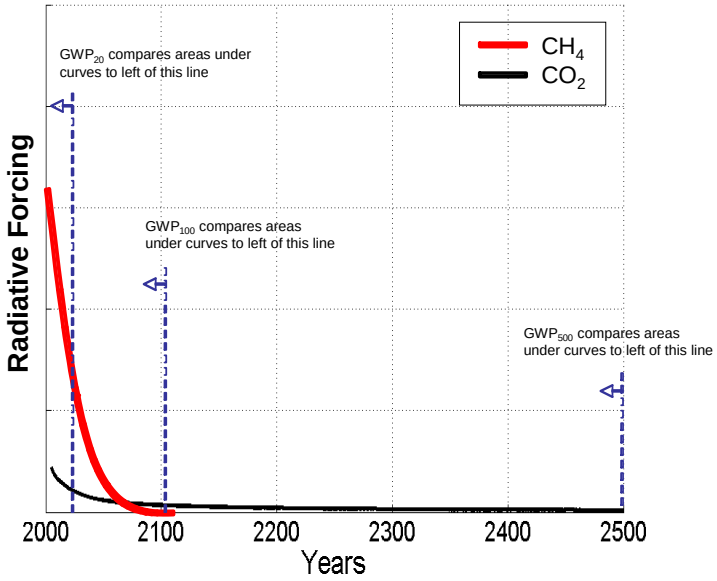


Figure D-8. Illustration of the effects of choosing different time horizons for the computation of GWPs for climate agents with different lifetimes (here the lifetimes for CO_2 and CH_4 have been used accurately, but different vertical scales have been used for the two forcing agents; the CO_2 effects have been multiplied to make them easier to see)

The impact of different time horizons is further illustrated in Figure D-9, taken from IPCC 2007. Here the marginal impacts of year 2000 emissions are integrated over two different future time periods: 20 years and 100 years. Note how significantly reduced the CO_2 effects are for the shorter time horizon. There is no universal "best" equivalency method. Depending on political and personal value-based judgments, one may seek to consider only the near term consequences of emissions (e.g., a 20-year GWP), or the long-term consequences (e.g., a 500-year GWP, or longer).

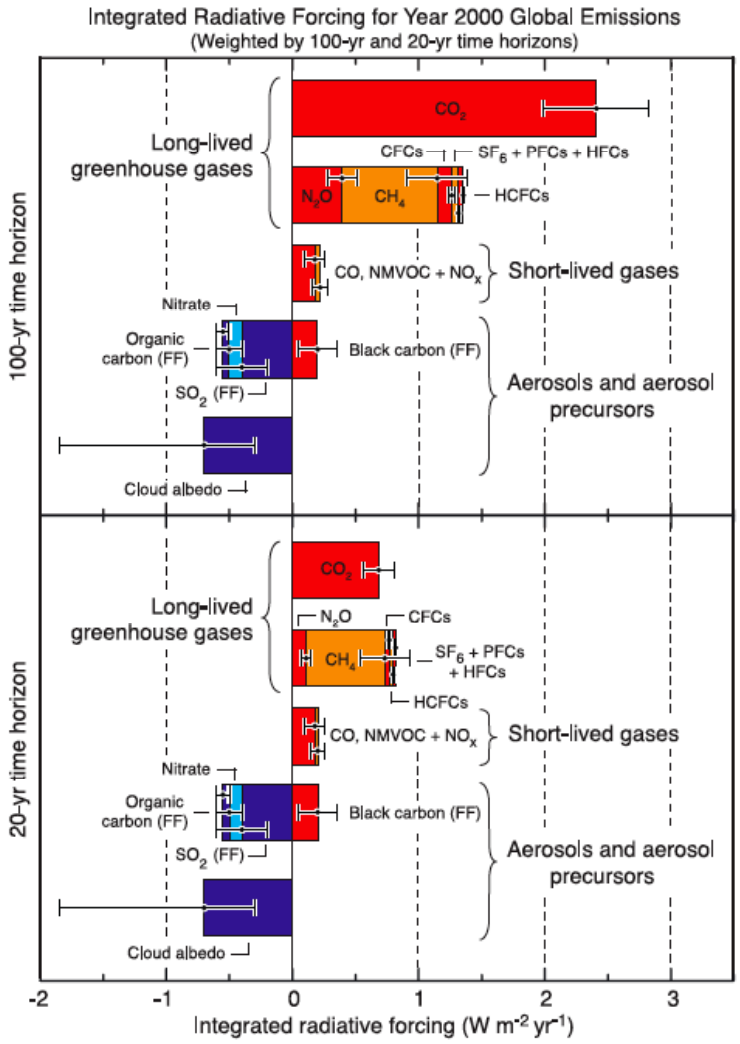


Figure 2.22. *Integrated RF of year 2000 emissions over two time horizons (20 and 100 years). The figure gives an indication of the future climate impact of current emissions. The values for aerosols and aerosol precursors are essentially equal for the two time horizons. It should be noted that the RFs of short-lived gases and aerosol depend critically on both when and where they are emitted; the values given in the figure apply only to total global annual emissions. For organic carbon and BC, both fossil fuel (FF) and biomass burning emissions are included. The uncertainty estimates are based on the uncertainties in emission sources, lifetime and radiative efficiency estimates.*

Figure D-9. Values for radiative forcing integrated over 20-year (bottom) and 100-year (top) time periods, reflecting the integrated impacts of year 2000 emissions (reprinted from IPCC 2007, p. 206)

The following criticisms and comments have been voiced about global warming potentials. We take these directly from the peer-reviewed papers in which they appeared. Our intention is not to include a comprehensive survey of the literature, but rather to select quotes that provide particularly instructive comments on the positive and negative features of GWPs. The criticisms are all well-founded: there are indeed many shortcomings related to the use of GWPs. However, this is to a large extent a function of the complex physics and chemistry of the response of climate to different forcing agents. Short of performing multi-year climate calculations for a range of alternative scenarios future scenarios, the GWP

remains as the most useful, and widely used equivalency method. Nonetheless, it should be used with caution, and with knowledge of the associated assumptions and limitations. Further, there are as yet some climate change agents that are not amenable for consideration with GWPs (e.g. the short-lived impacts of NO_x, and the impacts of contrails and aviation-induced cirrus cloudiness).

From (O'Neill 2000): "…do GWPs work? Surprisingly, despite numerous studies both critical and supportive of the GWP concept, the answer is still not clear. GWPs are well known to be subject to a number of uncertainties, but the fundamental question of whether, uncertainties aside, GWPs actually perform as expected in policy applications has remained unanswered. … GWPs can only be expected to produce equivalent integrated temperature changes, and only under a restrictive set of assumptions. … Thus GWPs have a well-defined interpretation in terms of climate response, but only under a restrictive set of assumptions. The first, controlling for the scenario dependence of GWPs, is well known but important nonetheless. If GWPs are calculated based on an assumed future concentration scenario that is not the one actually realized, pulse emissions of different greenhouse gases will not lead to equal integrated temperature change. The IPCC definition of GWPs is based on an implausible constant concentration baseline, and therefore suffers from this problem, although Smith and Wigley account for it in their exercises. The second, that emissions must not affect radiative forcing beyond the GWP time horizon, is clearly unrealistic except for time horizons much longer than the lifetime of a gas. Because a fraction of the effect of a CO2 emission is essentially permanent, this assumption is always unrealistic for CO2. The third, that temperature is linearly related to radiative forcing, is accurate for many commonly used reduced-form climate models such as one-dimensional upwelling diffusion or box diffusion in the ocean."

From (O'Neill 2003): "...there are three main views on GWPs. The first, held mainly, but not only, by economists, is that GWPs as currently formulated are the wrong tool for the job, because GWPs do not account for important economic dimensions of the problem they are intended to address (e.g., Bradford 2001). This might be called the 'GWPs are bad economics' view. As a result, economists have offered many alternative approaches (see Godal in this volume for references). The second, held mainly by a subset of natural scientists, is that GWPs are inadequate on the grounds of climate science alone – the 'GWPs are bad science' view. GWPs purport to equate climate effects between emissions of different gases, but the climate system is complex and a single number cannot adequately capture the differences in effects between ases with different dynamics. Pretending that they can is a mistake. The third view – 'GWPs are good enough' – is that the criticisms from either of the first two camps are overblown. Of course GWPs are rough approximations to equating climate effects, this argument goes, but they work reasonably well and are probably the best we are going to be able to do without becoming overly complex. Further refinements by adjusting the way the climate effects are compared, or by adding economic considerations, aren't worth the trouble.

Here I wish to discuss two specific objections often raised by those who take the 'GWPs are good enough' point of view. My goal is to help clarify the arguments, and define points of disagreement with the other two views. The first objection from this camp is that GWPs do not need improving by adding economic considerations because it is best not to mix natural

science with economics in the formulation of trace gas indexes. This line of reasoning sees separating the science and the economics to be the whole point of a GWP: it is best to let the natural scientists develop an index comparing climate effects, which can then be handed off to the economists to do the analysis of efficient reduction mixes given information on costs.

The second objection is that the costs of any inaccuracies in GWPs in terms of their ability to equate climate effects of different gases are probably small compared to the benefits they produce by facilitating a multi-gas reduction strategy. That is, the basket approach will bring potentially very large savings in mitigation costs, and the quibbling about the precise value of the exchange rate has long since passed the point of diminishing returns.

I argue here that the first objection is well founded in principle: ideally, if a purely physically-based index can perfectly equate environmental impacts, its use will produce a least-cost mix of reductions for meeting an objective based on limiting those impacts. Incorporating economic considerations into the index itself is not necessary. However, in practice, there are substantial deviations from the ideal case. Under these conditions, the science cannot be separated from the economics, and the problem of deriving the optimal value of the index must be solved by treating the economics and the science simultaneously. Regarding the second objection, there are some indications that the cost of using GWPs, even if they are the 'wrong' index, could be relatively small, but there are others that it might be large. By the 'cost of using GWPs' I mean that the total abatement costs associated with a least cost mix of emissions reductions leading to a particular climate change outcome will be greater if GWPs are used as the exchange rate in a multi-gas emissions reduction market than if a theoretically ideal index is used. This extra cost, originating from the fact that GWPs are im- perfect indexes of relative climate change effects, is the cost of using GWPs. As Godal points out, the question of how large this cost is has not been sufficiently analysed. I present a rough estimate of the cost of using GWPs that suggests it may be small, at least under some conditions."

From (Mann and Richels 2001): "Earlier, we noted two problems with GWPs: the failure to incorporate damages and abatement costs, and the arbitrary choice of time horizon for calculating cumulative radiative forcing. Here we highlight two additional problems. GWPs assume that the trade-off ratios remain constant over time and are independent of the ultimate goal. Clearly, neither of these assumptions makes economic sense. The relative prices are a function of both the target and the proximity to the target. It is illogical to suppose that this is a case of ``one size fits all''; yet this is precisely what is suggested by the IPCC in recommending the use of 100-year GWPs. Unlike GWPs, the alternative we propose extends beyond purely physical considerations in calculating trade-offs among gases. Expectations about damages influence the choice of ceiling. Abatement costs influence the relative roles of the various gases in the portfolio of abatement actions. For example, we found that the higher the costs of abating CH_4, the larger the role of the other gases in a multi-gas reduction portfolio."

From (Smith and Wigley 2000): "The use of Global Warming Potentials (GWPs) to calculate 'equivalent' carbon dioxide emissions reductions in the climate

> change context is examined. We find that GWPs are accurate only for short time horizons. Over long time horizons their use implicitly leads to tradeoffs between near- term and long-term climate change. For one of the most policy-relevant cases, comparing reductions in methane and carbon dioxide, the long-term effect on climate of reducing methane emissions is relatively small, at variance with the common perception based on published GWP values."

From (IPCC 2007: p. 211): "Globally averaged GWPs have been calculated for short lived species, for example, O_3 precursors and absorbing aerosols (Fuglestvedt 1999; Derwent et al., 2001; Collins et al., 2002; Stevenson et al., 2004; Berntsen et al., 2005; Bond and Sun, 2005). There might be substantial co-benefits realized in mitigation actions involving short-lived species affecting climate and air pollutants (Hansen and Sato 2004); however, the effectiveness of the inclusion of short-lived forcing agents in international agreements is not clear (Rypdal 2005). To assess the possible climate impacts of short-lived species and compare those with the impacts of the LLGHGs, a metric is needed. However, there are serious limitations to the use of global mean GWPs for this purpose. While the GWPs of the LLGHGs do not depend on location and time of emissions, the GWPs for short-lived species will be regionally and temporally dependent. The different response of precipitation to an aerosol RF compared to a LLGHG RF also suggests that the GWP concept may be too simplistic when applied to aerosols."

From (Godal and Fuglestvedt 2002): "The comprehensive approach adopted in the Kyoto Protocol relies on the use of 100-year Global Warming Potentials (GWPs) to convert emissions of various gases to 'carbon dioxide (CO_2) equivalents'. This particular set of weights, or metric, has a limited capacity to handle the large variations in atmospheric adjustment times, and emissions of various gases that are equal in terms of 'CO2 equivalents' will not result in equal climatic effects."

From (Eckhaus 1992): "This paper analyses the usefulness as a policy tool of a physical index of radiative forcing of a greenhouse gas, the Global Warming Potential (GWP), as proposed by the Intergovernmental Panel on Climate Change. It is shown that the economic opportunity costs of an increment in radioative forcing will vary over time, while the GWP implicitly sets these costs equal. The GWP can, therefore, play no role in policy making."

From (Schmalensee 1993): "In order to derive optimal policies for greenhouse gas emissions control, the discounted marginal damages of emissions from different gases must be compared. The greenhouse warming potential (GWP) index, which is most often used to compare greenhouse gases, is not based on such a damage comparison."

Table D-2, reproduced from IPCC 2007 presents GWP values for 20-, 100-, and 500-year time periods for direct impacts of climate change agents. The uncertainties in these GWPs are estimated to be ±35% for the 5% to 95% confidence range. Many climate change agents act indirectly. GWP_{100} values for the indirect effects of NMVOCs and NO_x are shown Table D-3 (also reprinted for IPCC 2007). The estimated uncertainty range for the GWP values for these forcing agents is –50% to +100%. The following cautions should be noted: "The indirect effects discussed here are linked to O_3 formation or destruction, enhancement of stratospheric water vapour, changes in concentrations of the OH radical with

the main effect of changing the lifetime of CH_4, and secondary aerosol formation. Uncertainties for the indirect GWPs are generally much higher than for the direct GWPs. The indirect GWP will in many cases depend on the location and time of the emissions. For some species (e.g., NO_x) the indirect effects can be of opposite sign, further increasing the uncertainty of the net GWP. This can be because background levels of reactive species (e.g., NO_x) can affect the chemical response nonlinearly, and/or because the lifetime or the radiative effects of short-lived secondary species formed can be regionally dependent. Thus, the usefulness of the global mean GWPs to inform policy decisions can be limited. However, they are readily calculable and give an indication of the total potential of mitigating climate change by including a certain forcing agent in climate policy." (IPCC 2007, p. 214)

Table D-2. Global Warming Potentials for the direct effects of climate change agents for 20-, 100-, and 500-year time periods (reprinted from IPCC 2007, pp.212-213)

Table 2.14. *Lifetimes, radiative efficiencies and direct (except for CH_4) GWPs relative to CO_2. For ozone-depleting substances and their replacements, data are taken from IPCC/TEAP (2005) unless otherwise indicated.*

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]1.4x10^{-5}	1	1	1	1
Methane[c]	CH_4	12[c]	3.7x10^{-4}	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03x10^{-3}	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990
Halon-1301	$CBrF_3$	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	$CBrClF_2$	16	0.3		4,750	1,890	575
Halon-2402	$CBrF_2CBrF_2$	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl_4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH_3Br	0.7	0.01		17	5	1
Methyl chloroform	CH_3CCl_3	5	0.06		506	146	45
HCFC-22	$CHClF_2$	12	0.2	1,500	5,160	1,810	549
HCFC-123	$CHCl_2CF_3$	1.3	0.14	90	273	77	24
HCFC-124	$CHClFCF_3$	5.8	0.22	470	2,070	609	185
HCFC-141b	CH_3CCl_2F	9.3	0.14		2,250	725	220
HCFC-142b	CH_3CClF_2	17.9	0.2	1,800	5,490	2,310	705
HCFC-225ca	$CHCl_2CF_2CF_3$	1.9	0.2		429	122	37
HCFC-225cb	$CHClFCF_2CClF_2$	5.8	0.32		2,030	595	181
Hydrofluorocarbons							
HFC-23	CHF_3	270	0.19	11,700	12,000	14,800	12,200
HFC-32	CH_2F_2	4.9	0.11	650	2,330	675	205
HFC-125	CHF_2CF_3	29	0.23	2,800	6,350	3,500	1,100
HFC-134a	CH_2FCF_3	14	0.16	1,300	3,830	1,430	435
HFC-143a	CH_3CF_3	52	0.13	3,800	5,890	4,470	1,590
HFC-152a	CH_3CHF_2	1.4	0.09	140	437	124	38
HFC-227ea	CF_3CHFCF_3	34.2	0.26	2,900	5,310	3,220	1,040
HFC-236fa	$CF_3CH_2CF_3$	240	0.28	6,300	8,100	9,810	7,660
HFC-245fa	$CHF_2CH_2CF_3$	7.6	0.28		3,380	1030	314
HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	0.21		2,520	794	241
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15.9	0.4	1,300	4,140	1,640	500
Perfluorinated compounds							
Sulphur hexafluoride	SF_6	3,200	0.52	23,900	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	0.21		12,300	17,200	20,700
PFC-14	CF_4	50,000	0.10	6,500	5,210	7,390	11,200
PFC-116	C_2F_6	10,000	0.26	9,200	8,630	12,200	18,200

Table 2.14 (continued)

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon			
				SAR[g] (100-yr)	20-yr	100-yr	500-yr
***Perfluorinated compounds** (continued)*							
PFC-218	C_3F_8	2,600	0.26	7,000	6,310	8,830	12,500
PFC-318	c-C_4F_8	3,200	0.32	8,700	7,310	10,300	14,700
PFC-3-1-10	C_4F_{10}	2,600	0.33	7,000	6,330	8,860	12,500
PFC-4-1-12	C_5F_{12}	4,100	0.41		6,510	9,160	13,300
PFC-5-1-14	C_6F_{14}	3,200	0.49	7,400	6,600	9,300	13,300
PFC-9-1-18	$C_{10}F_{18}$	>1,000[d]	0.56		>5,500	>7,500	>9,500
trifluoromethyl sulphur pentafluoride	SF_5CF_3	800	0.57		13,200	17,700	21,200
Fluorinated ethers							
HFE-125	CHF_2OCF_3	136	0.44		13,800	14,900	8,490
HFE-134	CHF_2OCHF_2	26	0.45		12,200	6,320	1,960
HFE-143a	CH_3OCF_3	4.3	0.27		2,630	756	230
HCFE-235da2	$CHF_2OCHClCF_3$	2.6	0.38		1,230	350	106
HFE-245cb2	$CH_3OCF_2CHF_2$	5.1	0.32		2,440	708	215
HFE-245fa2	$CHF_2OCH_2CF_3$	4.9	0.31		2,280	659	200
HFE-254cb2	$CH_3OCF_2CHF_2$	2.6	0.28		1,260	359	109
HFE-347mcc3	$CH_3OCF_2CF_2CF_3$	5.2	0.34		1,980	575	175
HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$	7.1	0.25		1,900	580	175
HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$	0.33	0.93		386	110	33
HFE-449sl (HFE-7100)	$C_4F_9OCH_3$	3.8	0.31		1,040	297	90
HFE-569sf2 (HFE-7200)	$C_4F_9OC_2H_5$	0.77	0.3		207	59	18
HFE-43-10pccc124 (H-Galden 1040x)	$CHF_2OCF_2OC_2F_4OCHF_2$	6.3	1.37		6,320	1,870	569
HFE-236ca12 (HG-10)	$CHF_2OCF_2OCHF_2$	12.1	0.66		8,000	2,800	860
HFE-338pcc13 (HG-01)	$CHF_2OCF_2CF_2OCHF_2$	6.2	0.87		5,100	1,500	460
Perfluoropolyethers							
PFPMIE	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$	800	0.65		7,620	10,300	12,400
Hydrocarbons and other compounds – Direct Effects							
Dimethylether	CH_3OCH_3	0.015	0.02		1	1	<<1
Methylene chloride	CH_2Cl_2	0.38	0.03		31	8.7	2.7
Methyl chloride	CH_3Cl	1.0	0.01		45	13	4

Notes:

[a] The CO_2 response function used in this report is based on the revised version of the Bern Carbon cycle model used in Chapter 10 of this report (Bern2.5CC; Joos et al. 2001) using a background CO_2 concentration value of 378 ppm. The decay of a pulse of CO_2 with time t is given by

$$a_0 + \sum_{i=1}^{3} a_i \cdot e^{-t/\tau_i}$$

Where $a_0 = 0.217$, $a_1 = 0.259$, $a_2 = 0.338$, $a_3 = 0.186$, $\tau_1 = 172.9$ years, $\tau_2 = 18.51$ years, and $\tau_3 = 1.186$ years.

[b] The radiative efficiency of CO_2 is calculated using the IPCC (1990) simplified expression as revised in the TAR, with an updated background concentration value of 378 ppm and a perturbation of +1 ppm (see Section 2.10.2).

[c] The perturbation lifetime for methane is 12 years as in the TAR (see also Section 7.4). The GWP for methane includes indirect effects from enhancements of ozone and stratospheric water vapour (see Section 2.10.3.1).

[d] Shine et al. (2005c), updated by the revised AGWP for CO_2. The assumed lifetime of 1,000 years is a lower limit.

[e] Hurley et al. (2005)

[f] Robson et al. (2006)

[g] Young et al. (2006)

Table D-3. Global Warming Potentials for the indirect effects of NMVOCs and NO_x for 100-year time periods (reprinted from IPCC 2007, p. 214)

Table 2.15. *Indirect GWPs (100-year) for 10 NMVOCs from Collins et al. (2002) and for NO_x emissions (on N-basis) from Derwent et al. (2001), Wild et al. (2001), Berntsen et al. (2005) and Stevenson et al. (2004). The second and third columns respectively represent the methane and ozone contribution to the net GWP and the fourth column represents the net GWP.*

Organic Compound/Study	GWP^{CH_4}	GWP^{O_3}	GWP
Ethane (C_2H_6)	2.9	2.6	5.5
Propane (C_3H_8)	2.7	0.6	3.3
Butane (C_4H_{10})	2.3	1.7	4.0
Ethylene (C_2H_4)	1.5	2.2	3.7
Propylene (C_3H_6)	–2.0	3.8	1.8
Toluene (C_7H_8)	0.2	2.5	2.7
Isoprene (C_5H_8)	1.1	1.6	2.7
Methanol (CH_3OH)	1.6	1.2	2.8
Acetaldehyde (CH_3CHO)	–0.4	1.7	1.3
Acetone (CH_3COCH_3)	0.3	0.2	0.5
Derwent et al. NH surface NO_x[a,b]	–24	11	–12
Derwent et al. SH surface NO_x[a,b]	–64	33	–31
Wild et al., industrial NO_x	–44	32	–12
Berntsen et al., surface NO_x Asia	–31 to –42[c]	55 to 70[c]	25 to 29[c]
Berntsen et al., surface NO_x Europe	–8.6 to –11[c]	8.1 to 12.7	–2.7 to +4.1[c]
Derwent et al., Aircraft NO_x[a,b]	–145	246	100
Wild et al., Aircraft NO_x	–210	340	130
Stevenson et al. Aircraft NO_x	–159	155	–3

Notes:
[a] Corrected values as described in Stevenson et al. (2004).
[b] For January pulse emissions.
[c] Range from two three-dimensional chemistry transport models and two radiative transfer models.

D.5.3 Alternatives to the Global Warming Potential

As described in Section 4.4.2, the limitations of GWPs are well understood by the scientific and economic communities. Thus, for analysis of policies, or detailed studies of climate impacts, more complex climate and economic simulations are typically brought to bear. A range of scenarios for future emissions and economic trends is usually considered (versus the single future path that is imbedded in a GWP), and the spatial resolution goes beyond the globally-averaged change in surface temperature to include region-by-region effects. These are valuable not only for estimating the range of possible outcomes of different policies, but also for more explicitly quantifying the range of uncertainty surrounding possible outcomes. Researchers have also developed alternative methods for establishing equivalencies among climate change agents. We discuss two of these here: the Linear Damage Potential, and the Global Temperature Potential. These have merits for some applications, but are still regarded as methods to be applied for specific policy analyses rather than for wider application in understanding inventories or within emissions trading systems.

The linear damage potential assumes that damage is directly proportional to temperature change (see Shine 2005 and Marais 2008). Then the net effect of a unit of emissions is assessed by integrating the area under the globally-averaged surface temperate change curve as shown in Figure D-3. Much like the GWP, measures can be formed for fixed periods of time. As it appears in Marias et al., the full period of impacts was assumed in forming the LDP and then economic assumptions regarding discounting of future impacts were applied separately. The Marais et al. analysis focuses specifically on aviation contributions to climate change. Marais et al. connect the analyses of surface temperature changes to the economic results of Nordhaus 2007 to predict future economic damages under different

scenarios for world economic growth and discounting. Moving from radiative forcing to surface temperature changes, and from surface temperature changes to economic damages, is generally viewed as moving in a direction of increasing relevance. However, there are larger uncertainties when predicting changes economic damages versus changes in surface temperature, and changes in surface temperature versus changes in radiative forcing, respectively. The Marais et al. approach uses probabilistic analyses to explicitly represent many of these uncertainties. Marais et al. found that the single largest contributor to variations in impact estimates is the discount rate, which represents assumptions about future economic behavior and value-based assumptions about the importance of long-term versus short-term consequences. For long-lived gases such as CO_2, impact estimates can change by a factor of a 1000 or more, depending on the assumed discount rate. The second largest source for variations in impact estimates is the assumed climate sensitivity, which different complex climate models suggest ranges from 1.5K to 4.0K per doubling of atmospheric CO_2 concentrations. Scientific uncertainties in some of the short-lived impacts of aviation (particularly aviation-induced cirrus cloudiness) are noted as the next largest contributor to variation in the impact estimates. Because of the many uncertainties, assumptions, and future projections that must be incorporated in such analyses, it is most appropriate to consider a range of equivalency estimates rather than a single point value that may be used as a simple multiplier.

The Global Temperature Potential (Shine 2005) compares the global mean temperature response due to a pulse or sustained emission of a gas (*i*) to that of a reference gas (typically CO_2) at a chosen point in time (the end of a time horizon, TH):

$$GTP_i^{TH} = \frac{\Delta T_i^{TH}}{\Delta T_{CO_2}^{TH}}$$

For example, if one had a pulse of CH_4 or a pulse of CO_2 today, how much would the global mean temperature response change in 20 years, or 100 years, or 500 years? It is also possible to extend the idea to any emissions scenario (beyond a pulse or continuous emissions). Like GWPs and LDPs, assumptions about the background emissions scenario must be made, and typically globally-averaged changes in surface temperature are considered (although for all these measures one could consider deriving regionally-specific values, and some work has been done in this direction for NO_x). The GTP does not emphasize the integrated effects over time, but what the effects would be at the end of a time horizon. Thus, it may be helpful for considering policies that focus on a particular target at a set date. For example, for a climate change stabilization scenario of 2 Kelvin rise in globally-averaged surface temperature by 2100, how much do different emissions contribute to this temperature rise?

From (Shine 2007): "Multi-gas climate agreements require a metric by which emissions of gases with different lifetimes and radiative properties can be placed on a common scale. The Kyoto Protocol to the United Nations Framework Convention on Climate Change uses the global warming potential (GWP) as such a metric. The GWP has attracted particular criticism as being inappropriate in the context of climate policy which seeks to restrict warming below a given target, because it gives equal weight to emissions irrespective of the target and the proximity to the target. The use of an alternative metric, the time-dependent global temperature change potential (GTP)…retains the transparency and relative ease of use, which are attractive features of the GWP, but explicitly includes a dependence on the target of climate policy. The weighting of emissions using the GTP is found to be significantly dependent on the scenarios of future emissions and the sensitivity of the climate system.

This may indicate that the use of any GTP-based weighting in future policymaking would necessitate regular revisions, as the global-mean temperature moves towards a specified target."

Appendix E: Inventory Development Protocols

E.1 Introduction

This appendix provides background information on the protocol components used in developing the airport GHG emission inventories. The focus is on addressing the inventory development approaches minus the emissions and CO_2 equivalency calculations which are covered in Appendices C and D. The main topics covered in this appendix are related to the different approaches used to develop entity boundaries as well as aggregating and categorizing the emissions.

The appendix first provides an overview of the pertinent issues involved in developing airport-specific GHG emissions inventories. This is followed by summaries of existing protocols from various organizations (e.g., IPCC, WRI, etc.). The intention here is not to provide exhaustive coverage of these protocols, but to highlight the pertinent points, especially if they apply to the airport setting. Leveraging these protocols, a framework for developing an airport GHG emissions inventory is also discussed.

E.2 Inventory Issues

As part of the scoping process for an airport GHG emissions inventory, several issues need to be carefully considered. These include a clear understanding of the following:

- Purpose of the inventory
- Identification of Sources and Pollutants
- Corporate Boundaries
- Geographic boundaries
- Discrepancies and Inconsistencies

Addressing these issues in a methodical manner will help to ensure that the inventory is both technically sound and useful.

E.2.1 Purpose of the Inventory

The fundamental issue to be addressed as part of the scoping process is the purpose of the inventory. This will impact both the development and the presentation of the results. For example, an inventory developed as part of a NEPA-related process would differ from one developed at the corporate level. Only those sources affected by airport development plans would need to be considered under the NEPA analysis while all sources would be considered for a corporate-based inventory. In addition, a NEPA analysis would require multiple inventories to be developed for case-difference assessments while a corporate inventory would require just the magnitudes for the current situation although tracking would still occur.

E.2.2 Identification of Sources and Pollutant

Source identification. Based on the purpose of the inventory, all applicable sources should be identified even if only a few will be included in the inventory. This will allow a comprehensive starting point where issues such as data availability and airport resources can be balanced to determine the appropriate methods to employ for an airport.

Pollutant identification. Starting from the comprehensive list of all pollutants presented in Appendix B, a decision will need to made based on balancing the purpose of the inventory with several factors including resources and data availability in determining which pollutants will need to be included in the inventory.

Data and methods. The contents of the inventory will be dependent on what data are available. This includes source characterization data (e.g., emission factors) and activity information. Even when data and methods are available (or can be made available), they will still need to be balanced with resources and level of fidelity to determine the most appropriate course of action for each airport.

Resources. The resources available for each airport vary considerably, especially when comparing a major international airport to a general aviation (GA) airport. Smaller airports will generally tend not to have the level of personnel and funding available to conduct detailed assessments. They also will tend not to have the types of detailed data that may be collected at larger airports such as aircraft fleet, maintenance activities, and vehicular traffic data.

E.2.3 Corporate Boundaries

Parties involved. To address ownership and control issues, one of the first steps would be to determine all of the parties that own or influence sources at an airport. Similar to sources and pollutants, this would allow a comprehensive starting point for categorizing sources and pollutants by the owning or influencing parties. Irrespective of the purpose for developing the inventory, all emissions should be categorized by these parties. The purpose in doing this is to clarify the responsibilities of these emissions.

Ownership and control. The main criteria for party responsibility is based on ownership of a source. This will usually qualify a party as the responsible custodian of emissions since under most cases, they will have the most control.

Operational control. Unlike ownership, operational control is based on having control over a source but not having full ownership. These sources need to be properly accounted for to provide a comprehensive accounting of all airport emissions.

Levels of influence. Related to the operational control issue is the level of influence exerted irrespective of any ownership issues. Even when parties do not own a source (or have a financial stake in the source), they can still exert varying levels of influence over its use.

Allocation of Credits. Along with the ownership and influence issues are the questions of how to allocate credit for any reductions thereof for sources not owned by the airport. This is especially important for airports wishing to receive recognition for influencing emissions of sources that they do not have direct control over.

E.2.4 Geographic Boundaries

LTO versus full flight. Unlike inventories for criteria pollutants, GHGs cannot be limited to just the LTO modes of flight. Since GHG effects are global in nature, all GHG emissions must be accounted for, meaning that emissions from cruise must also be included. This issue will need to be clarified for any inventories developed, especially in the near term until the understanding of GHG inventories become commonplace. Also, the coverage of full flight emissions imply the need to shift to an origin-destination (OD) line of thinking. That is, even though inventories are sill developed for individual airports, the data associated with the inventories (at least for aircraft) is based on airport pairs.

Attribution of cruise emissions. To properly allocate aircraft emissions to each airport, a consistent method needs to be employed so that overlaps (or double-counting) do not occur. Although different possibilities exist on how this could be accomplished, the consensus among most existing protocols appear to be to attribute all of a flight's emissions (gate-to-gate emissions) to the departure airport. Although arguments could be made to split the cruise emissions, there is no basis for doing this as the effects of GHG emissions are global in nature. Also, splitting cruise emissions would be dubious at best since some overlaps are likely to occur.

Off-airport emissions. Similar to aircraft emissions, emissions of other sources that occur off airport property need to be accounted for. This mainly includes GAVs, but any mobile source that is influenced by the airport (with its origin or destination at the airport) need to be included.

E.2.5 Discrepancies and Inconsistencies

Double-counting. In developing inventories, care must be taken to prevent double counting of emissions. An example is when individual airport inventories are used to develop or compare against larger scale (e.g., national) inventories. Double counting will cause the summed airport inventories to be greater than the larger inventories. There are several ways this could happen including the aforementioned inclusion of emissions from both approach and departure flights at each airport. In this case, one airport's emissions from a departure flight would be labeled as emissions from an approach flight for another airport. Other examples include estimating fuel use for flights based on the final destination point rather than taking into account the individual legs of a flight and summing NEPA and corporate-based inventories. The former case would cause overlaps between airport inventories since the emissions from an individual leg of one flight already attributed to an airport would be included in the total flight of another airport. In the latter case, a NEPA-based inventory may include emissions from various corporate inventories. As a result, these NEPA and corporate inventories should not be rolled-up to form larger inventories. Double-counting also has the potential to be an issue when different entities develop their own inventories. For example, an airline would include the emissions from the aircraft it owns while the airport could list those same emissions as indirect (influenced) emissions under its inventory. It will depend on the purpose or usage of the inventories to make sure that overlaps do not cause problems.

Fuel Tankering. Fuel tankering is the practice of purchasing more fuel than necessary to fly an aircraft from one airport to another. It represents an economic strategy by airlines to take advantage of lower fuel costs in certain regions. As fuel cost is one of the biggest operating expenses, airlines will generally tanker fuel whenever it is feasible. That is, the advantage of lower fuel costs must be weighed against other factors including the burden to carry the additional fuel (i.e., heavier aircraft weight). This issue needs to be addressed when using either the fuel dispensed (fuel sales) data to determine GHG emissions or using aircraft performance models to predict fuel burn from individual aircraft flights. With fuel

dispensed data, the question of where the fuel was used (or resold if not loaded on an aircraft) will be relevant while performance models will require a more accurate estimate of the total aircraft weight.

Different Data and Methods. Due to the different data and methods available for calculating emissions and CO_2 equivalencies, all of the data sources and methods will need to be clearly specified as part of the inventory work. This will be particularly helpful in explaining differences between different inventories and in preparing timely inventories (e.g., for tracking trends).

E.3 Review of Existing Protocols

The following sections provide overviews of major existing protocols for GHG emissions inventory development. Two of the more well-known protocols are from the IPCC and the WRI. These protocols are generally the most established and visible guidance that currently exist. Most of the other organizations tend to borrow from IPCC and WRI in developing their own protocols. The scope of the reviews is not to provide detailed coverage but to summarize the pertinent points, especially as they may be relevant to airports. The reviews serve to provide background understanding of the protocols that can be leveraged in developing guidance for airport inventories.

E.3.1 International Panel on Climate Change (IPCC)

To address the potential for climate change impacts, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the International Panel on Climate Change (IPCC) in 1988. The IPCC is a scientific body that provides objective information to policy and decision-makers, but conducts no research of it's own. It's goal is to "assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation" (IPCC 2008).

IPCC developed its 1995 Guidelines for National Greenhouse Gas Inventories (REF) and then revised the methods and default data resulting in the Revised 1996 IPCC Guidelines. The intention of these guidelines is to provide nations with tools and data to develop national anthropogenic GHG emissions inventories for submission to the United Nations Framework Convention on Climate Change (UNFCCC). All anthropogenic sources are covered by the guidelines including sinks. This includes all GHG emissions and removals that are the direct result of humans and any natural processes affected by humans. In developing these "living" guidelines, IPCC has taken an evolutionary approach to their updates to allow time-based consistency in the inventories. Their latest 2006 Guidelines provide further updates to the methods and data while preserving the core methods to allow continuity and straightforward updates to existing inventories.

The 2006 guidelines provide coverage of all major sources to allow nations to comprehensively cover all of their anthropogenic GHG emissions. The broad categories covered include:

- Energy
- Industrial Processes and Product Use
- Agriculture, Forestry, and Other Land Use
- Waste

These categories coincide with the organization of the guideline volumes. Although all of these volumes could be applicable to airports, the most pertinent is Energy. Included in this volume are the following sections:

- Stationary Combustion
- Mobile Combustion
- Fugitive Emissions
- Carbon Dioxide Transport, Injection and Geological Storage

The Mobile Combustion section covers all major forms of transportation including motor vehicles and aircraft. Due to the specificities of each country's data and methods available, the IPPC guidelines are also not extremely specific. The guidelines provide general suggestions on what data and methods to use. For all of the sources, IPCC generally provides three tiers of methods as summarized in Table E-1.

Table E-1. General Summary of IPCC Tiered Methods.

Tier	Method Description
1	Use total fuel consumption data (e.g., fuel sales information) with aggregated emission factor(s).
2	Somewhere between Tiers 1 and 3 involving the use of more detailed emission factors and specific fuel use or activity data than Tier 1.
3	Use detailed emission factors and/or complex models to more accurately develop inventories.

As indicated by their general descriptions, the accuracy and precision should improve from Tier 1 to Tier 3. These methods provide options for methods to use in developing inventories based on resources and data available to each nation. Tier 1 is the simplest and represents the default IPCC method.

Since the IPCC guidelines are used to develop national inventories, the basic requirement is to include all emissions occurring within a country as part of its national inventory. As such, there are generally no ownership and control issues associated with these emissions.

Calculating emissions of most sources are relatively straightforward as they involve the use of activity data with the appropriate emission factors. The types of activity data can vary significantly from total fuel consumption information as in Tier 1 to vehicle miles traveled (VMT) in the other tiers. As a result, the emission factors must be specific to the activity data.

Although most of the other sources are physically bound to the airport, aircraft (as well as water-borne navigation sources) need special consideration since their modes of operation along with fuel dispenses can occur in more than one country. As such, the tiered methods also account for these geographic issues. Aircraft operational modes are also taken into account differentiating between LTO and cruise emissions. The methods and data requirements for aircraft are shown in Table E-2.

Table E-2. Summary of IPCC Tiered Methods for Aircraft Emissions

Tier	Method Description
1	If aircraft operational data is not available, total fuel consumption data can be used to determine emissions from both LTO plus cruise operations.

2	Assumes airport operations data is known. To separate LTO and cruise emissions, start with the same assessment for total emissions from Tier 1. Using the estimated LTO operations (preferably by aircraft type), LTO emissions can be directly calculated using the IPCC supplied LTO emission factors (i.e., kg/LTO). Similarly, LTO fuel consumption can be estimated using the IPCC supplied LTO fuel consumption factors (i.e., kg/LTO). Then calculate cruise emissions by subtracting LTO fuel consumption from total fuel consumption and multiplying by the appropriate fuel-based emission factor.
3a	Assumes detailed OD-pairs by aircraft type are known. Mainly based on the EMEP/CORINAIR data, emissions are calculated for both LTO and cruise by aircraft type. Using the OD-pair information, trip distance-specific emission factors are used to compute emissions.
3b	Assumes detailed movements data is known including trajectory-type data. Sophisticated computer models containing detailed performance and emissions models are employed under this tier. Emissions are calculated for each flight segment along the flight path. The results for each flight segments can be aggregated in various ways including the differentiation between LTO and cruise emissions. The FAA's AEDT/SAGE and the EU's AERO2k model are currently listed as being applicable under this tier.

Since these methods are general guidelines, variations could potentially be employed including the calculation of LTO emissions under Tier 2 through the use of the FAA's AEDT/EDMS rather than the default LTO emission factors provided by IPCC. AEDT/EDMS could provide fuel consumption results for each aircraft type that could be used with a representative fuel-based emission factor.

For each of the tiered methods, it is assumed that the data would support the differentiation of results into domestic and international ("bunker") categories. The definitions for these categories are presented in Table E-3.

Table E-3. Aircraft Domestic and International Emissions Category Definitions

Category	**Definition**
Domestic	Emissions from a flight that departs and arrives in the same country.
International	Emissions from a flight that departs from one country and arrives in another country.

Using this definition, emissions would be itemized as "Country A Domestic" or "Country A International." As such, all of the emissions are attributed to the departure country. A similar line of thinking could be applied when developing an airport inventory such that all of the emissions from a flight could be attributed to the departure airport.

The overall IPCC guidelines also provide guidance on identification of "key categories" (or sources). Essentially, if prior GHG inventories have already been established, they can be used to quantitatively identify these categories. IPCC's Approach 1 involves ranking the emissions magnitudes and identifying those that contributed to the top 95% of total emissions. Approach 2 involves assessing the uncertainties of each category and is to be used in addition to Approach 1 in refining the identification of these key categories. The Approach 2 assessments are used to identify those categories that contribute to 90% of the overall uncertainties of the total emissions.

If no prior inventories exist or are incomplete, then qualitative measures can be used to identify key categories and to augment the quantitative approaches. Qualitative measures would be appropriate for:

- sources that have experienced emissions reductions (to reflect mitigation measures);
- sources that are expected to see increased emissions in the future;
- when uncertainty estimates have not been developed for a source, but it is expected to contribute significantly to uncertainties; and
- when the intended inventory is not complete and the neglected sources are understood to be significant.

IPCC's reference approach is to use national fuel supply data to calculate total GHG emissions for each country. Hence, this reflects a top-down approach. But the aforementioned tiered methods using sectoral (e.g., transportation, industrial, etc.) data represent a bottom-up approach. For national inventories, IPCC considers it good practice for each nation to use both the reference and the sectoral approaches to compare inventories as part of the QA/QC process.

E.3.2 World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD)

The World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) started the Greenhouse Gas Protocol Initiative through a partnership with various business, government, and non-government organizations. As part of this initiative, WRI published the "Greenhouse Gas Protocol, a Corporate Accounting and Reporting Standard" (WRI 2004) among others to provide international standards and guidance to businesses in developing consistent and transparent GHG inventories. The principles promoted by WRI are:

- **Relevance**. Ensure the GHG inventory appropriately reflects the GHG emissions of the company and serves the decision-making needs of users – both internal and external to the company.
- **Completeness**. Account for and report on all GHG emission sources and activities within the chosen inventory boundary. Disclose and justify any specific exclusions.
- **Consistency**. Use consistent methodologies to allow for meaningful comparisons of emissions over time. Transparently document any changes to the data, inventory boundary, methods, or any other relevant factors in the time series.
- **Transparency**. Address all relevant issues in a factual and coherent manner, based on a clear audit trail. Disclose any relevant assumptions and make appropriate references to the accounting and calculation methodologies and data sources used.
- **Accuracy**. Ensure that the quantification of GHG emissions is systematically neither over nor under actual emissions, as far as can be judged, and that uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable users to make decisions with reasonable assurance as to the integrity of the reported information.

WRI's corporate reporting guidance is intended to provide the protocols for setting up GHG inventories. This includes addressing issues of organizational and operational boundaries regarding the influence over sources. The guidance is not intended to provide detailed instructions on emissions or equivalency calculation methods. WRI provides separate tools for those purposes (WRI 2004).

The **organizational boundary** of a company can be defined either through equity share or through control. The **equity share** refers to the monetary share of a source. So, the percent responsibility of the source's emissions is the same as the percent ownership. In contrast, boundaries defined through **control** refers to 100 percent responsibility of the emissions for a source based on either **financial** or **operational** control of the source. Per the WRI guidance, a "company has financial control over the operation if the former has the ability to direct the financial and operating policies of the latter with a view to gaining economic benefits from its activities." For operational control, "a company has operational control over an operation if the former or one of its subsidiaries has the full authority to introduce and implement its operating policies at the operation" (WRI 2004).

The **operational boundary** of a company is defined to include both owned and not-owned sources based on its operating influence. The two top-level categories of emissions are **direct** and **indirect**. Direct emissions occur from sources owned by the company while indirect emissions occur from sources not owned by the company but are considered to be within its sphere of operations. These emissions are more methodically categorized using the concept of "scope" as indicated below:

- Scope 1 (Direct): Direct emissions from sources owned and controlled by the company.
- Scope 2 (Indirect): Indirect emissions due to the generation of purchased electricity.
- Scope 3 (Indirect): Optional reporting category that includes all other indirect emissions.

Operational boundaries are determined after the organizational boundaries have been set to allow comprehensive coverage of the emissions associated with the entity. As indicated by WRI, "…setting operational boundaries that are comprehensive with respect to direct and indirect emissions will help a company better manage the full spectrum of GHG risks and opportunities that exist along its value chain" (WRI 2004).

The issue of **double-counting** can arise if, for example, one company chooses to include sources based on an equity approach while another company uses the financial control approach. Whether this causes a problem will depend on the purpose of the reporting. For reporting to the public (e.g., through a registry), it shouldn't be an issue as long as both companies adequately disclose the methods they used.

E.3.3 United States Environmental Protection Agency (USEPA)

As part of its commitments under the UNFCCC, the USEPA develops yearly anthropogenic GHG emissions inventories for the U.S. and submits to the UNFCCC secretariat by April 15 each year. The current USEPA inventories include each year from 1990 to 2006 (USEPA[b] 2008). As such, these inventory reports generally do not provide protocols for inventory development. Rather, they mostly employ the IPCC Guidelines for

inventory development. For the 1990-2006 inventories, USEPA largely used the 1996 IPCC guidelines and have begun to employ some of the methods and data in the 2006 guidelines. The USEPA inventory reports essentially discloses the methods and data that were used to develop the U.S. national inventories.

The USEPA Climate Leaders is an industry-government partnership to reduce GHG emissions (USEPA[a] 2005). The USEPA provides guidance and incentives for organizations to reduce their corporate GHG emissions. The Climate Leaders guidance is largely based on those of the WRI but with modifications to better serve the partnership members. One of the differences is in how the direct and indirect emissions are grouped as shown in Table E-4.

Table E-4. Differences Between USEPA Climate Leaders' and WRI's Categorization of Direct and Indirect GHG Emissions

USEPA Climate Leaders	WRI
Core Emissions (Direct and Indirect)	Scopes 1 and 2
Optional Emissions	Scope 3

The USEPA is also in the process of developing a mandatory GHG emissions reporting program. The purpose of the program is to collect data for future policy-related decisions including the potential for regulation under the Clean Air Act. A threshold will be set, above which reporting will be required, and the reporting will include both upstream and downstream emissions. Existing methods in each of the sectors are expected to be leveraged, and the final ruling is expected in June 2009 (USEPA[f] 2008).

E.3.4 International Council for Local Environmental Initiatives (ICLEI)

Formerly the International Council for Local Environmental Initiatives, the ICLEI-Local Governments for Sustainability was established in 1990 as a member association of local governments with the goal of "advancing climate protection and sustainable development" (ICLEI[a] 2008). As part of this goal, ICLEI has developed a GHG emissions analysis protocol to help standardize the methods and conventions used to develop GHG inventories (ICLEI[b] 2008). The intent is to leverage the common understanding and data developed through this protocol to help local governments find ways to reduce GHG emissions.

ICLEI's protocol is consistent with that of WRI borrowing various components including the Scope 1-3 categories of direct and indirect emissions. However, the boundaries of a government entity are described using two categories:

- **Organizational Boundary – The Government Operations Analysis**: "A local government's own organizational greenhouse gas emissions analysis must include emissions arising from the use of all significant assets and services. All emissions that are a consequence of the local government's operations must be included, regardless of where those emissions occur. In some cases, notably electricity use and waste disposal, emissions arising as a consequence of the operations often occur outside the geopolitical boundary of the local government. The physical location of the site where emissions occur is not relevant to the decision regarding what emissions should be included in the analysis" (ICLEI[b] 2008).

- **Geopolitical Bound – The Community Analysis**: "The community-scale emissions analysis must include all greenhouse gas emissions associated with activity occurring within the local government's geopolitical boundary. Activities that occur within the community boundary can be controlled or influenced by jurisdictional policies, educational programs and establishing a precedent. Although some local governments may have only limited influence over the level of emissions from some activities, it is important that every effort be made to compile a complete analysis of all activities that result in the emission of greenhouse gases" (ICLEI[b] 2008).

For prioritization of emissions based on resources, the ICLEI protocol recommends the use of a 5% de minimis criteria where sources that add up to less than 5% of total emissions can be excluded. This is essentially the same recommendation made by IPCC as part of its guidance in the identification of key categories.

E.3.5 The Energy Information Administration (EIA)

Each year, the EIA develops an inventory of U.S. GHG emissions to satisfy the requirements of the 1992 Energy Policy Act (EPAct). The inventories provide estimates back to 1990 to show temporal trends, and includes coverage of various sectors (e.g., industrial, commercial, transportation , etc.). Emissions are estimate using fuel usage data with appropriate emission factors. The inventory report mainly presents the inventories and does not provide inventory development protocols.

Also under the EPAct, the EIA has developed Form EIA-1605 which provides a means of voluntarily reporting GHG emissions. The purpose is to encourage both public and private entities to report their GHG emissions, thus making public their emissions data and being recognized for doing so. The hope is that this data could for form a reliable database that may be used to identify ways to curb emissions.

Along with Form EIA-1605, the EIA provides guidance on developing an inventory. As defined by EIA, a reporting entity is one "…that initiates, controls, or in some other way participates in a United States based activity that results in the emissions of greenhouse gases in the United States" (EIA 2007). EIA specifies that each entity should report at the **highest level of aggregation** (e.g., top level of a company structure). However, reporting at subentity levels is allowed in certain cases such as when different methods are used to estimate emissions reductions. Emissions resulting from foreign activities must be reported as subentity emissions. The EIA defines foreign activity as "all activities outside of the United States, its territories, and its trusts…" (EIA 2007).

Different requirements (e.g., records maintenance) also exist for the "size" of the emitter. EIA defines a large emitter as one that emits more than 10,000 metric tons of CO_2 and a small as emitter as one that emits less than 10,000 metric tons CO_2.

Similar to the WRI protocol, the EIA uses direct and indirect categories. The direct category refers to the emissions directly from the entity (e.g., through fossil fuel combustion, highway vehicles, cement production, etc.). The indirect category is further separated into indirect emissions from purchased electricity and other indirect emissions.

E.3.6 The Climate Registry (TCR)

The Climate Registry (TCR) is a non-profit organization that has developed protocols and tools for organizations to report their GHG emissions to provide a single, unified mechanism for reporting GHG emissions in North America. The registry is intended to support both voluntary and mandatory reporting requirements, and has the following goals (TCR[b] 2008):

- Create a common standard
- Standardize best practices
- Promote full and public disclosure
- Lower policy implementation costs
- Establish a common infrastructure

The principles and guidance provided by TCR are consistent with those of the WRI including the overarching principles of relevance, completeness, consistency, transparency, and accuracy. TCR uses the same definitions for organizational and operational boundaries that WRI has promoted. The same equity versus control categories are used with options to report by a combination of both approaches (Option 1) or by just the control approach (Option 2). The registry encourages reporting at the highest organizational level. TCR's operational boundary definitions also essentially use the same scope definitions (Scope 1-3) but defines Scope 2 as including emissions from electricity, steam, heating, and cooling. Also, TCR's Scope 3 covers indirect and optional emissions, but is clarified to include both upstream and downstream emissions.

For facility level reporting, TCR requires disaggregated reporting for each facility. TCR uses the same regulatory definition to describe a facility: "stationary installation or establishment located on a single site or on contiguous or adjacent sites that are owned or operated by an entity" (TCR[a] 2008). However, aggregation is still allowed for certain facility types including commercial buildings, oil and gas pipelines, electricity transmission and distribution systems, and mobile sources.

Emissions from aircraft are categorized differently from the protocol used by IPCC. TCR uses the following categories for aircraft emissions:

- National Level Reporting: Emissions from flights with both the origin and destination in either the U.S., Canada, or Mexico (emissions are assigned to one of these countries).
- North America Level Reporting: Emissions from flights with both the origin and destination in North America where at least one of the airports is not in the U.S.
- Worldwide Reporting: Optionally reported emissions from flights with origin, destination, or both not in North America.

Each of these categories are defined by individual legs of flights rather than multiple legs associated with final destination points.

E.4 Framework for Developing an Airport GHG Emissions Inventory

Based on reviewing each of the GHG inventory protocols in the previous sections, it should be clear that guidance for developing airport inventories should be mainly focused on protocols from IPCC, WRI, and TCR. These protocols appear to the ones that most other organizations' protocols adhere to or borrow from. Using them as the basis, the following sections provide a methodical framework for developing an airport GHG emissions inventory.

E.4.1 Principles

The overarching principles promulgated by WRI and also adopted by TCR help to ensure that each inventory "represents a faithful, true, and fair account of a company's GHG emissions." The five specific principles duplicated from WRI's protocols are (WRI 2004):

- Relevance
- Completeness
- Consistency
- Transparency
- Accuracy

E.4.2 Pollutants

Based on the Kyoto Protocol, the focus of an airport inventory should be the following six pollutants: CO_2, CH_4, N_2O, SF_6, HFC, and PFC. These are the primary pollutants as discussed in Appendix B. But in addition to these, other GHGs such as halogenated ethers and other halocarbons can optionally be included in the inventory. IPCC supports the reporting of these additional pollutants on a similar basis as the primary pollutants while WRI indicate these as optionally report GHGs.

Also optional are the reporting of precursor pollutants. As covered in Appendix B, the precursors suggested by IPCC include NO_x, NH_3, NMVOC, CO, and SO_2. The argument for including these is to allow a comprehensive coverage of all pollutants that can either directly or indirectly exert GHG effects. As such, H_2O and PM are also included as part of this ACRP guidance to promote the comprehensiveness of coverage.

For this guidance, judgment is left to the inventory developers on when to include the other GHGs and the precursors. The decision should be based on airport resources, availability of data, significance of sources, and the purpose of the inventory. As discussed in Section 3.7, significance of sources is based on the relative contributions to the total airport inventory.

E.4.3 Source Categories and Reporting

As indicated in Appendix B, the general source categories used in this report are: Aircraft, APUs, GSEs, GAVs, stationary sources, training fires, and construction activities.

In keeping with the WRI principles of "sufficiently disaggregated" emissions, the individual component sources within these general categories should be maintained to facilitate categorizations by organizational and operational boundaries as necessary.

For corporate-type reporting, the general airport sources could be equated to TCR's broad categories as indicated in Table E-5.

Table E-5. Relationship between Airport and TCR general source categories

This Airport Source Category…	…Would Fall into this TCR Source Category
Aircraft	Mobile
APU	Mobile or Stationary depending on where the APU is
GSE	Mobile
GAV	Mobile
Stationary Sources	Stationary, Physical and Chemical Processes, or Fugitive depending on the characteristics of the source
Training Fires	Stationary
Construction Activities	Stationary or Mobile depending on the characteristics of the
Waste Management Activities	Recycling, waste disposal, etc.

In addition to the mappings shown in Table E-5, components of all of the airport sources except training fires could potentially fall into the TCR fugitive emissions category (e.g., leakage from mobile fuel systems, refrigeration units, etc.).

E.4.4 Organizational and Operational Boundaries

For a greenhouse gas inventory to be useful, it must contain information and present results in a meaningful way. In most cases, the preparation of an inventory enables the identification of notable or key sources of greenhouse gases and the identification of measures to reduce emissions from those sources. To be useful, as noted by WRI, the inventory **requires consideration of an appropriate inventory boundary** that reflects "the substance and economic reality of the entities activities" and responsibilities (WRI 2004). For corporate entities, this often relates to the legal form of the business. For governmental parties, this can become less clear, but typically focuses on emissions directly from governmental activities, as well as those within its control. Thus, the choice of the inventory boundary is typically dependent on the characteristics of the entity, the intended purpose of the information, and the needs of the information users.

The two fundamental inventory development approaches for an airport are corporate-based and NEPA-based. Under the corporate-based approach, inventories are developed based on ownership and control of the emissions. An inventory developed under this scheme would quantify just the emissions attributed to sources owned and controlled by the airport. In contrast, the NEPA-based approach is based on relevance to projects. The inventory would include emissions from any sources at the airport (including non-airport owned) that are affected by a project(s).

Much of the protocols from WRI are based on reporting at the corporate level through ownership and control of sources. Although protocols for projects are also provided, the inference is that the ownership and control categories still need to be spelled out. That is, an ownership categorizing-level should be included for each inventory irrespective of the

approach or purpose of the inventory. In keeping with this protocol, all airport inventories should have sources categorized by the owning/controlling entity (e.g., airport, airlines, etc.). This is implicit for an airport inventory developed under the corporate-based approach, and needs to be applied for NEPA-based approaches as well. Figure E-1 provides an example of this ownership categorization layer that needs to be added to NEPA-based inventories.

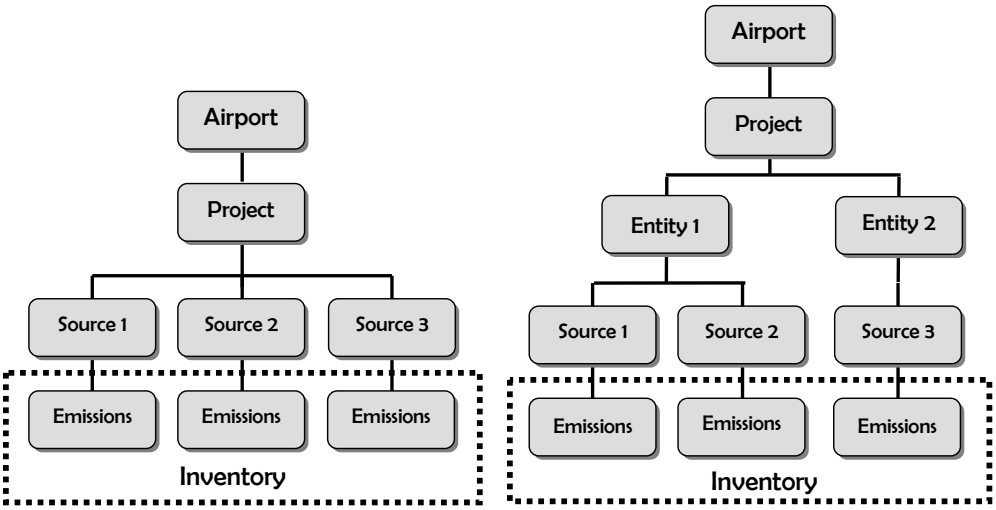


Figure E-1. Ownership Categorization Layer

This ownership categorization layer should be included for all airport inventories and will allow a clear understanding of the ownership responsibilities. This is important when including aircraft and other sources in an inventory that the airport does own. It will allow clear demarcations of source ownership.

Airports have no organizational control over aircraft, meaning that they do not own aircraft in anyway (no equity or control issues). However, aircraft emissions should still be included in airport emissions inventories even when using the corporate-based approach. Aircraft are the most visible sources at an airport and it would seem misleading if they were left out. Similarly, all of the other airport sources listed in Table E-5 should be included in the inventories irrespective of ownership as long as the ownership layer is clearly specified.

Although airports do not own aircraft, they can still influence aircraft emissions including surface movements (through runway and taxiway layouts and usage), fuel dispensing operations, etc. This also applies to other airport sources (e.g., passenger vehicles) that are not owned by the airport. The airport source ownership and control are summarized in Table E-6.

Table E-6. Airport Source Ownership and Control

Source Categories	Emissions by Ownership & Control		
	Airport Operator	Tenants (e.g., airlines, government, concessions, etc.)	General Public
Aircraft	No	Yes	No
APU	No	Yes	No
Ground	Yes (airport	Yes (aircraft and tenant	No

Support Equipment	maintenance, snow removal, fire fighting, etc.)	GSE, maintenance vehicles, etc.)	
Ground Access Vehicles	Yes (airport staff on-road travel, employee commute, all on-airport road travel, etc.)	Yes (tenant employee commute, tenant on-road travel, etc.)	Yes (public on-road travel to/away from airport)
Stationary Sources	Yes (airport owned facility power use, maintenance activities, etc.)	Yes (tenant owned facility power use, maintenance activities, etc.)	No
Construction	Yes (airport construction)	Yes (tenant construction)	No
Training Fires	Yes	Yes	No

In general, all of these airport sources are influenced by the airport to varying degrees. Some may simply use airport facilities to generate emissions (e.g., use of parking lots by passenger vehicles) while others may be significantly affected by airport rules/operations (e.g., aircraft ground movements based on taxiway/runway configurations). The Global Reporting Initiative (GRI) also recognizes the influence over emissions by entities that do not own or control the source of those emissions (GRI 2008). In addition, ICLEI (2008) provides considerations for geopolitical boundaries related to "government operations analysis" and "community-scale analysis" (Section E.3.4). Following the community-scale approach, aircraft emissions should be included as part of airport inventories to reflect the influence the airport has over the "community." The overarching influence the airport exerts is that there would be no operations of GAVs, aircraft, and other sources without the airport.

Emissions from these non-airport owned sources would be considered to be indirect emissions as defined by WRI. They are indirect in the sense that they are a "consequence of the activities of the company (airport) but occur at sources owned or controlled by another company" (WRI 2004). And under the definition of scopes used by WRI, these emissions would be categorized under Scope 3 as indirect emissions (i.e., other than due to electricity generation).

This reflects a conservative approach in accounting for all indirect emissions, which should help to better manage risks and opportunities for reduction. This issue will remain an evolving one that will need to be revisited during future revisions to this report. The current recommendation is to include all of these "airport" emissions with clear specifications of ownership and control.

E.4.5 Geographic Boundaries

The issue of geographic boundaries is related to the difference between the traditional airport boundaries used for criteria pollutant (e.g., CO, NOx, etc.) inventories and those for GHG inventories. Since the effects of GHG emissions are global in nature, there are no geographic boundaries where these emissions could be "cut off." For many airport sources (e.g., stationary sources), this may be a moot point since they occur on airport property. This issue arises only for those sources that exceed the traditional airport boundary used for local air quality assessments. GAVs and aircraft are the two prominent airport sources where this issues needs to be addressed.

Since GHGs have no local air quality effects, the emissions from GAVs would need to be tracked back to the farthest point of influence. That is, rather than cutting these emissions based on inlet/outlet roads to the airport, they need to be tracked back to the origin of travel to the airport (e.g., passenger homes). The justification is based on the airport influence factor. That is, the assumption is made that the passenger would not have driven to the location of the airport unless he/she needed to conduct some activity there (e.g., fly, pickup, etc.). Therefore, the total distance from origin to the airport (as well as airport to destination) needs to be taken into account when calculating vehicular emissions.

For aircraft, the boundaries have traditionally been placed around the LTO modes, nominally occurring at the local mixing height (about 3000 ft average). Again, since GHG effects are global, emissions from full flight (gate-to-gate movement) needs to be included (not just LTO). Unlike other sources, aircraft are unique in that its emissions for a flight can potentially be attributed to two different airports (origin or destination). Although it may be possible to attribute half of a flight's emissions to each of the origin and destination airports, this would cause difficulties in using the fuel sales data at each airport. It would be difficult or impossible to correctly apportion the fuel sales data at various origin airports to account for the emissions of the flights arriving at the airport being studied. There could also be discrepancies due to the potential for use of different methods by those developing an inventory for one airport versus another.

In part to simplify this process but also to adhere to the well-established protocols from IPCC, it is recommended that only the emissions from departing flights be attributed to the departure airport. This means that emissions from the full gate-to-gate movement for a flight be attributed to the departure airport, even if taxi-in emissions clearly occur on the arrival airport's property. This scheme is illustrated in Figure E-2.

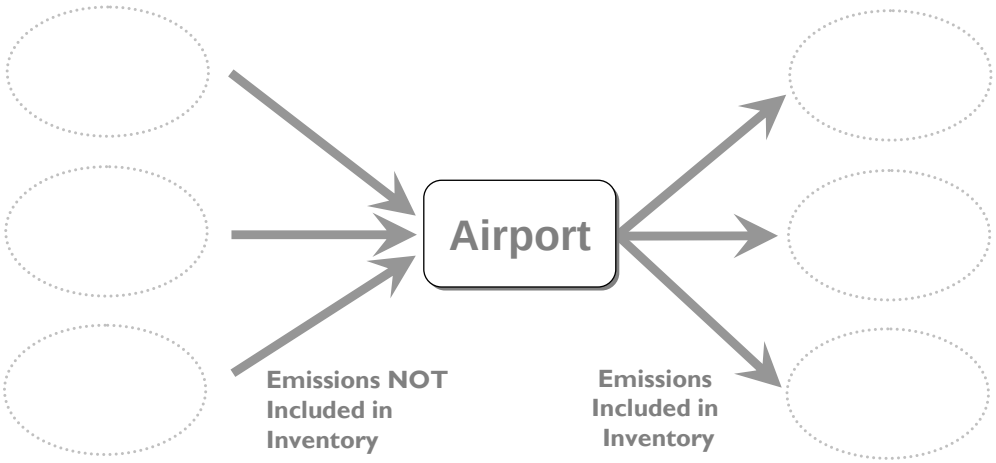


Figure E-2. Departure Aircraft GHG emissions

This method correlates well with fuel sales data which can be used directly to estimate departure flight emissions. If used uniformly by all airports, it would also prevent double counting as each airport would only account for its departure flight emissions. Indeed, as this method adheres to the IPCC protocols, emissions from all U.S. airports would equate to the total presented by USEPA as part of its national greenhouse gas inventories that it generates each year. 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 emission does 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 departure flights. These issues need to be carefully considered especially as policies are made regarding attribution of GHG emissions to airports.

Unlike the IPCC protocols for national inventories, airport departure emissions do not necessarily have to be separated into domestic and international categories as shown in Figure E-3.

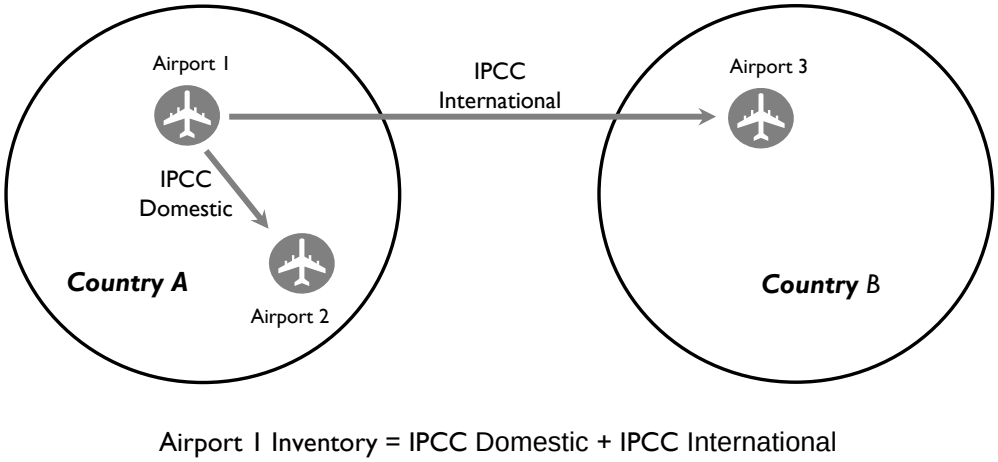


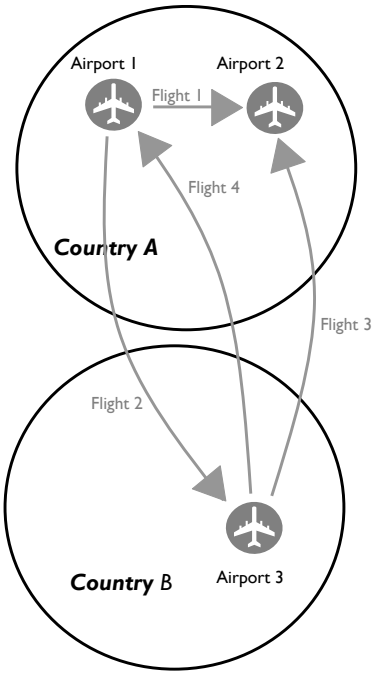
Figure E-3. Both IPCC Domestic and International Flights are Included in an Airport Inventory

A domestic flight is one in which both the origin and destination airports are located in the U.S. In contrast, an international flight starts in the U.S. but ends at an airport located in another country. These category designations are based on assessing individual flight legs rather than multi-leg trips. The use of individual legs help to prevent double-counting since it reduces misunderstandings that could occur concerning which legs should be attributed to which airport.

The aggregation of the domestic and international emissions in an airport inventory facilitates the use of fuel sales data which also represents an aggregation of these two sets of flights. Therefore, the airport emissions can only be compared to the aggregated USEPA national domestic and international value. Following the IPCC protocol provides consistency with the USEPA inventory methodology.

This aggregation method is similar to the protocol from The Climate Registry, but there are some important differences. The registry's national and North American flights are identically categorized as those for the IPCC domestic flights (i.e., departure and arrival airports are both located in the same country or region). However, the characterization of the registry's worldwide flights differ.

IPCC's definition of the domestic category is similar to the registry's National and North America categories, but the IPCC's international category differs from the registry's Worldwide category as indicated in Figure E-4.



Protocol	Country A and Airport A Related Inventory
The Climate Registry (Assume Country B is outside of North America)	Flight 1 = Country A National Flight 2 = Worldwide Flight 3 = Worldwide Flight 4 = Worldwide
IPCC	Flight 1 = Country A Domestic Flight 2 = Country A International Flight 3 = Not included as part of Country A Flight 4 = Not included as part of Country A
Airport Inventory	Flight 1 = Airport 1 Inventory Flight 2 = Airport 1 Inventory Flight 3 = Not included as part of Airport 1 Inventory Flight 4 = Not included as part of Airport 1 Inventory

Figure E-4. Difference Between an IPCC International Flight and The Climate Registry's Worldwide flight

An IPCC international flight is one in which the departure airport is always in the U.S. and the arrival airport is always in another country. In contrast, either the departure or arrival airport can be located in another country (or region) for an international flight under The Climate Registry's definition. As a result, aircraft emissions reported to The Climate Registry cannot be compared to those prepared using IPCC protocols. The "Airport Inventory" category shown in Figure E-4 follows the IPCC guidance and reflects the protocol that should be used for developing an airport GHG inventory.

E.4.6 Identification of Key Sources

In developing an airport GHG inventory, practical decisions need to be made to weigh the needs of the project versus resource availability. Organizations such as IPCC, WRI, CCAR and TCR provide guidance on how to determine the significance of smaller emitting sources.

The overarching principle in identifying the key sources is to be conservative. Using existing inventories and making estimates for various data including emission factors, source activities, etc., comparisons need to be made on a conservative basis. For example, if the emissions for lower-emitting sources are uncertain, the upper-bound of the estimates should be used. The use of upper- or lower-bound estimates will depend on the sources and scenario being assessed. This conservativeness principle is promoted by WRI.

When making decisions on which sources to include in an inventory, the 95% emissions criteria from IPCC should be adopted. Using existing data and making conservative estimates as necessary, the ranked sources that contribute to the top 95% of all airport emissions for each pollutant should be included in an inventory. Any source exclusions within this top 95% will need to be clearly articulated including those related to resource and data availability.

In addition to the 95% criteria, IPCC also recommends the additional use of the 90% uncertainty criteria. As resources allow, this technique is intended to help refine the key source identification process by adding additional details. Under this approach, the key sources are those that contribute to the top 90% of total uncertainty for each pollutant.

If the aforementioned quantitative approaches cannot be followed, qualitative measures based on experience can be employed and must be clearly articulated. As recommended by IPCC, qualitative measures include the recognition of sources that have experienced emissions reductions (e.g., due to mitigation programs), are expected to grow, that are assumed to have significant uncertainties in its emissions, and that are missing from the intended inventory but understood to be significant. In general, qualitative measures allow for the identification of key sources when the quantitative approaches are inadequate.

Appendix F: Approaches used in Airport Inventories Prepared to Date

F.1 Introduction

In order to leverage the experience that various airports have already gained through the development of their GHG inventories, several of these inventories were reviewed. These existing inventories were mainly developed by the larger airport entities. The review process was initiated through the use of an airport survey that the research team put together to inquire about the inventory purpose, methods related to boundaries and calculations, etc.

F.2 Project Survey and Inventories Identified

15 airports were surveyed to identify greenhouse gas inventories that have been prepared and the methods used in those inventories. Airport organizations included in the survey were:

1. Port Authority of New York and New Jersey
2. Massachusetts Port Authority
3. City of Los Angeles - Los Angeles World Airports
4. City of San Francisco - San Francisco International Airport
5. Port of Seattle - Seattle-Tacoma International Airport
6. Aspen-Pitkin County Airport
7. City/County of Denver - Denver International Airport
8. City of Chicago - Chicago O'Hare International Airport and Midway Airport
9. Dallas-Fort Worth International Airport Board
10. City of Philadelphia - Philadelphia International Airport
11. Port of Oakland - Oakland International Airport
12. City of Atlanta - Hartsfield-Jackson Atlanta International Airport
13. Salt Lake City - Salt Lake City International Airport
14. City of Austin - Austin Bergstrom International Airport
15. Port of Portland - Portland International Airport and Hillsboro Airport

The list of questions from the actual survey are:

1. How does your airport fit into the local/regional political structure?
   My airport is owned by the State of:_____; County of: ___; City of:_____ or
   Authority of:_____

2. Has a Greenhouse Gas (GHG) emissions inventory been prepared for your political structure (i.e., if you are owned by the city, has the city prepared an inventory that includes the city owned activities at the airport)? If so, please answer the following questions (the following questions DO NOT need to be answered if a copy of the inventory is provided in response to the survey):
    a. What was the purpose of the inventory?
    b. What years were considered in the inventory?
    c. How were the sources identified that were considered in the inventory?
    d. Who prepared the inventory (airport, city, county, state)?
    e. Can you tell us some of the specifics about the inventory? Such as:
        i. What sources were included? (i.e., did the inventory include airport tenants' activities and/or public on-road travel?)
        ii. What methods (emissions calculations, computer models and spreadsheets, CO_2 equivalencies, etc.) were used to develop the inventories?
        iii. What were the boundaries of the inventory?
        iv. If aircraft were included - were the emissions limited to the LTO? Or did they include full flight operation?

    If not the airport, then

        v. Please provide us with a contact person with the office preparing the inventory.
3. Has the Airport prepared a greenhouse gas inventory for its airport activities and those of the tenants? If so, please answer the following questions (the following questions DO NOT need to be answered if a copy of the inventory is provided in response to the survey):
    a. What was the purpose of the inventory?
    b. What years were considered in the inventory?
    c. Who prepared the inventory (airport staff, its consultants, others)?
    d. How were the sources identified that were considered in the inventory?
    e. Can you tell us some of the specifics about the inventory? Such as:
        i. What sources were included? (i.e., did the inventory include airport tenants' activities and/or public on-road travel?)
        ii. What methods (emissions calculations, computer models and spreadsheets, CO_2 equivalencies, etc.) were used to develop the inventories?
        iii. What were the boundaries of the inventory?
        iv. If aircraft were included - were the emissions limited to the LTO? Or did they include full flight operation?

    If not the airport, then

        v. Please provide us with a contact person with the office preparing the inventory.

4. Are there local or state programs that require your airport to consider greenhouse gases? If so, what are they?
5. If the airport has not prepared a GHG emissions inventory,…
    a. Do you plan to develop one? If so, what would be the purpose?
    b. Does the airport have any opinions, concerns, etc. about preparing a GHG emissions inventory?
6. Has your mayor(s) signed the U.S. Mayor's Climate Protection Agreement?
7. Has your state chosen to participate in a Climate Action Program?
8. Has your airport prepared a Climate Action Plan?
9. Has the airport initiated sustainability programs? If so,…
    a. Were GHG emissions (if any) considered part of those programs?
    b. Were GHG emissions quantified from one of these actions? If so, how were they quantified?
10. What concerns, questions, etc. do you have regarding possible effects of local GHG emissions on the environment?

Of the 15 entities that were directly surveyed, 7 responses were received. Those responding, as well as those that did not respond, were directly contacted by the research team to identify all greenhouse gas inventories that have been prepared. In addition, coordination occurred with ACI-NA concerning survey work that they were performing concerning environmental initiatives.

Based on the survey work as well as an internet search, the following inventories were identified:

- City of Seattle inventory (2000) that included Sea-Tac Airport and Boeing Field
- City of Aspen Canary Initiative (2004) that included Aspen Pitkin County Airport
- California Environmental Quality Act (CEQA) project-related evaluations at Sacramento International Airport and San Diego International Airports
- City and County of Denver GreenPrint Denver Climate Initiative that included Denver International Airport
- Port of Seattle Aviation Division Greenhouse Gas Inventory
- Vancouver International Airport Inventory
- Zurich International Airport Inventory

F.3 Reviews of Existing Airport Inventories

The results from the existing inventories are summarized in Table F-1, and discussed individually in the following sections. It is important to note that few of the inventories prepared to date have followed a common methodology or presentation format. Therefore, the information presented in Table F-1 reflects an attempt by the research team to present the

results in a comparative fashion. Many of the other parties surveyed indicated that they are in the process of preparing a greenhouse gas inventory.

Table F-1. Summary of Existing Airport GHG Inventory Results

	City of Seattle (2000)	Aspen Canary Initiative (2004)	Sacramento CEQA EIR (2004)	Vancouver Airport BC (2004)	San Diego CEQA EIR (2005)	Zurich Airport (2006)	City and County of Denver (2005)	Port of Seattle Aviation (2006)	Aspen-Pitkin County Airport (2006)	Port Authority of New York, New Jersey (2006)	City of San Francisco SFO (2005)
Airport Owned	SEA/BFI	ASE	SMF	YVR	SAN	ZRH	DEN	SEA	ASE	JFK, EWR, LGA, TEB,Heliport	SFO
Facilities	nr	1,103	nr	nr	nr	37,586	211,000	40,636	80	115,862	22,061
GSE	nr	nr	10	nr	nr	nr	14,051	2,730	155	2,511	2,004
GAV	nr	nr	nr	nr	nr	nr	nr	199,837	104		1,877
Other	nr	nr	nr	nr	nr	nr	nr	nr	nr	106,172	nr
Total	nr	1,103	10	-	-	37,586	225,051	243,203	339	224,545	25,942
Tenant Owned											
Aircraft											
LTO	nr	nr	177,307	149,044	nr	255,322	nr	348,195	10,422	1,963,358	nr
APU	nr	nr	nr	21,872	nr	nr	nr	in cruise	in cruise	In total aircraft	nr
Cruise	nr	nr	nr	nr	nr	2,561,585	nr	3,871,903	38,560	Nr	nr
Total	nr	344,487	177,307	170,916	-	2,816,907	4,569,696	4,220,098	48,982	23,830,000	nr
GSE	nr	nr	nr	28,452	nr	27,229	nr	42,708	5,924	74,416	nr
GAV	nr	nr	nr	nr	nr	nr	nr	7,196	25	Nr	nr
Facilities	nr	nr	nr	nr	nr	nr	nr	nr	nr	163,496	6,270
Other	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr	nr
Total	nr	344,487	177,307	199,368	-	2,844,136	4,569,696	4,270,002	54,931	24,067,912	6,270
Public Owned											
GAV	nr	nr	39,723	33,521	nr	13,021	21,968	580,783	1,152	834,823	nr
Other	nr	nr	nr	nr	nr	nr	nr	nr	nr	Nr	nr
Total	nr	nr	39,723	33,521	-	13,021	21,968	580,783	1,152	834,823	-
Total											
Aircraft	1,040,000	344,487	177,307	170,916	nr	2,816,907	4,569,696	4,220,098	48,982	23,830,000	-
GSE	nr	nr	10	28,452	nr	27,229	14,051	45,438	6,079	76,927	8,274
GAV	nr	nr	39,723	33,521	nr	13,021	21,968	787,816	1,281	834,823	1,877
Facilities		1,103	nr	nr	nr	37,586	211,000	40,636	80	279,358	22,061
Other	nr	nr	nr	nr	nr	nr	nr	nr	nr	106,172	nr
Total	1,040,000	345,590	217,040	232,889	nr	2,894,743	4,816,715	5,093,988	56,422	25,127,745	32,212

Direct (scope 1)	nr	n	nr	nr	223,026	nr	nr	nr	nr	4,468	nr
Indirect (scope 2)	nr	nr	nr	nr	1,377,839	nr	nr	nr	nr	148,716	nr
Optional (3)	nr	nr	nr	nr	nr	nr	nr	nr	nr	24,974,561	nr
Reconstructed	reconst	reconst	reconst	reconst	reported	reconst	reconst	reconst	reconst	reported	renconst
Direct	-	-	10	-	223,026	-	14,051	202,567	259	1,017	17,907
Indirect	-	1,103	-	-	1,377,839	37,586	211,000	40,636	80	144,611	6,158
Optional	1,040,000	344,487	217,030	232,889	nr	2,857,157	4,591,664	4,850,785	56,083	24,974,561	6,270
Metric	CO2e	CO2e	CO2e	CO2	CO2e	CO2	CO2	CO2	CO2	CO2e	CO2
Annual Operations	444,630 (SEA)/ 359,626 (BFI)	43,256	164,805	270,000	209,512	268,500	566,036	340,058	44,464	Nr	350,508
Annual Enplanements	13,853,299 (SEA)/ 11,526 (BFI)	180,519	4,671,560	7,850,000	8,686,261	10,350,000	20,675,380	14,989,549	202,137	Nr	15,913,090

Reconstructed - refers to the research team extracting data that we estimate to reflect direct, indirect, and optional emissions unless specifically reported as such by the airport.
nr = not reported/not reported in this format
City of Seattle: ***Inventory and Report: Seattle's Greenhouse Gas Emissions***, City of Seattle, Office of Sustainability and Environment, April 2002
Aspen Canary Initiative: http://www.aspenglobalwarming.com/whereCO2comesfrom.cfm
Aspen-Pitkin County Airport: Pitkin County Airport Section, **Aspen-Pitkin County Airport *Greenhouse Gas Emissions Inventory 2006***, April 2008
Sacramento: Final Environmental Impact Report, Sacramento International Airport Master Plan, County of Sacramento, July 2007
Vancouver: http://www.yvr.ca/pdf/authority/annualreport/2005_Environmental_Report.pdf
San Diego: Draft Environmental Impact Report, Airport Master Plan San Diego International Airport, San DiegoCounty Regional Airport, Oct 2007
Denver: Greenprint Denver ***Greenhouse Gas Inventory for the City and County of Denver,*** May 2007
Zurich: Spreadsheet provided to ACI (Feb 6, 2008), approved by Emanuel Flueti for public release, 2006 Environmental Report
http://www.unique.ch/ZRH/?ID_site=2&le=2&d=cnt/UPUM/EN/pum__politik-umwelt.asp&sp=en&u=1&t=Politics%20and%20environment&ID_level1=13&ID_level2=119&a2=119
Port of Seattle: Port of Seattle ***Seattle-Tacoma International Airport Greenhouse Gas Emissions Inventory 2006***, Updated March 2008
PANNYNJ: *Greenhouse Gas Emission Inventory For the Port Authority of New York & New Jersey*, March 2008. Based on Table 2-11 for the Aviation Department.

F.3.1 City of Seattle Inventory for 2000

The City of Seattle 2000 emissions inventory (City of Seattle 2002) identifies a portion of the emissions associated with Sea-Tac Airport and Boeing Field. The city inventory includes one lump-sum number of emissions titled "Transportation - Airports" which reflect a portion of the travel associated with both airports. That inventory indicates that about 15% of city-wide emissions are associated with the airports. While Sea-Tac is not within the city boundaries, it was the one exception made in the city boundary definition. The documentation associated with the 2002 effort indicates the following:

> Transportation – SeaTac and King County Airport**:** The airline industry has, over the past 30 years, improved fuel economy per passenger mile by 61 percent. Growth in air travel, however, has resulted in energy use by commercial aircraft nearly doubling in the same period[3] - which accounts for this category being the third largest source of GHG emissions. Emissions in this category were based on fuel sales data from the two airports (reported to the Clean Air Agency annually) and assigning a percentage of those sales to Seattle business and residents (Port of Seattle data indicate that 29% of passengers are from Seattle.) Emissions of CO_2 from jet fuel and aviation gasoline were computed using IPCC methods. (source: page 15 - note 3b)

As a note of clarification, emissions due to non-Seattle residents were subtracted from the data.

F.3.2 City of Aspen Canary Initiative Inventory for 2004

The City of Aspen prepared a citywide emissions inventory for the 2004 Canary Initiative (Aspen 2005). Aspen-Pitkin County Airport (ASE) is located in the City of Aspen but is operated by the Pitkin County. At the time of its preparation, this inventory was the first of its kind, where a city attempted to quantify emissions associated with an airport, including an estimate of actual aircraft operational emissions. This inventory calculated aircraft emissions based on an estimated average flight distance to the destination city for roundtrip travel. While airport fuel sales were available, the fuel sales data was not used in lieu of calculating aircraft emissions using the following general steps:

- Identifying the number of domestic passenger and international passengers.
- Estimate the average domestic and average international travel distances to enable quantifying the overall passenger travel distance
- Estimate the fuel consumed for the average travel distance based on the average national aircraft fuel consumption per passenger mile traveled.
- Using known conversion factors, estimate the CO_2 equivalent

The net effect is that the emissions associated with the large assumed aircraft travel distance produced emissions substantially greater than the emissions associated with the fuel dispensed from Aspen, and if added to the emissions from air travel associated with other

[3] Rocky Mountain Institute, Colorado.

airports, would double count aircraft emissions. As a result, the Aspen approach found that over 40% of the city-wide emissions were associated with aircraft in 2004. Airport facility emissions were calculated based on reported utility consumption.

F.3.3 Sacramento International Airport Master Plan CEQA FEIR

Because of California's Global Solutions Act, a greenhouse gas emissions inventory is being prepared for environmental documents addressing public action under the California Environmental Quality Act (CEQA) for the Country of Sacramento (SC 2007). The County of Sacramento owns and operates Sacramento International Airport and has proposed improvements to the airport that have been the subject of a recent Environmental Impact Report (EIR) that included a greenhouse gas emissions inventory. The emissions inventory was prepared for the purpose of meeting CEQA and would not necessarily represent the same format that a city would prepare for purposes of quantifying city/community emissions or submitting emissions for climate registry purposes.

Section 22 of the Final EIR responds to public and agency comments on the Draft EIR. The Sacramento Metropolitan Air Quality Management District commented on the DEIR indicating that a greenhouse gas inventory should be prepared. The Final EIR contained that analysis for the year 2004 and 2020 with and without the proposed Master Plan improvements, along with a short description of methodology. That description indicates that methodologies recommended by the IPCC were used. A further discussion indicates the methods for aircraft, GSE, on-airport ground vehicles, and "airport-related motor vehicles using off-airport roads":

- Emission factors from the 2006 IPCC guidelines were used for aircraft
- GSE emissions were based on CARB's OFFROAD2007 model
- Motor vehicles emission rates (on-road and parking) were obtained from CARBs EMFAC2007 model relative to the vehicle miles traveled for ground vehicles noted in the EIR.
- Stationary sources "include only the JET A and Aviation Gasoline fuel storage tanks and have no GHG emissions"
- The CO2 equivalency was created using IPCC's third assessment

The FEIR also quantified the annual emissions associated with constructing the proposed project. These emissions ranged from 131 tons per year of CO_{2e} in 2016 to a high of 4,338 tons per year in 2018; total construction CO_{2e} emissions were estimated at 18,460 over the 13 year period of the project.

As the focus of CEQA document is to identify if a proposed action (ie, project) would have a significant adverse effect on the environment, the emissions were contrasted with worldwide, U.S., and State of California emissions. At this time, neither the federal government or the state of California has developed a method to determine if project-related emissions exceed a threshold of significance.

The conclusions of the Sacramento FEIR include:

> While the Master Plan project will result in additional local GHG emissions, it must be considered in the context of current and projected national, state, and regional transportation needs and activities. In this light the following key factors must be considered:

- The Master Plan project does not cause increased demand for air travel. Air travel demand continues to increase in response to statewide population changes and worldwide economic development.
- The Master Plan project has very limited, if any, relationship to increasing residential development in the Sacramento area. The on-going development is instead driven by statewide population increases, land availability, housing prices, employment opportunities, regional economic development, and comparative housing costs.
- The total contribution of airline passenger travel to GHG emission totals includes a combination of surface travel to and from the airport as well as the air travel itself.
- The enroute phase of aircraft operations accounts for 90 percent of total GHG emissions associated with air travel.
- Commercial aircraft require about the same amount of energy to move each passenger one mile as do the automobiles and light trucks that make up 84 percent of overall transportation energy use.
- Jet aircraft fuel efficiency has increased about 55 percent between 1965 and 2000, and an additional improvement of 25 percent is projected by 2020.

In light of the miniscule increase in GHG emissions associated with the project, the project will not have a significant cumulative impact with regard to GHG.

F.3.4 Vancouver International Airport, BC Canada Emissions from Mobile Sources

In 2005, the Vancouver International Airport Authority released its Environmental Report (Vancouver International Airport 2005) which included an emissions inventory reporting tons of greenhouse gases (as CO_2), and tonnes of ozone-forming pollutants (VOC and NO_x). The inventory noted aircraft landings and takeoffs, public vehicle traffic (including commuters), ground support equipment (non-road), aircraft auxiliary power units (APUs), and ground support equipment (on-road). The specific methodology deployed in this analysis is not disclosed.

F.3.5 San Diego International Airport Master Plan CEQA DEIR

Similar to the Sacramento FEIS discussion, the San Diego County Regional Airport Authority prepared a Draft EIR for its proposed Master Plan in 2007 (San Diego 2007). Included in that EIR was the quantification of greenhouse gas emissions in 2005 and then forecast emissions in 2010, 2015, and 2030 with three alternatives: the No Project, the Preferred Alternative, and a second build alternative.

The emissions noted in the DEIR are reported in a different format than any other airport inventory identified in the search. The methodology section of the EIR note that "For this assessment, GHGs associated with the planned projects at SDIA were estimated for aircraft, GSE/APU, motor vehicles, stationary sources, as well as construction equipment." Relative to the reporting format, the document notes:

> Direct emissions are those that occur on the airport site, through the aircraft Landing/Take-off Operation (LTO) and associated with airport-related motor vehicles traveling to and from SDIA. Indirect emissions are those that occur beyond the aircraft LTO.

The 2006 IPCC aircraft emission factors were used to quantify emissions from aircraft, whereas EMFAC2007 is identified as a resource, and is assumed to be used for motor vehicles. The document does not indicate how GSE, APU, stationary sources, or construction equipment were estimated.

F.3.6 Zurich International Airport, CO_2 Emissions

In response to European emissions issues, the airport operator of the Zurich Airport prepared a CO_2 emissions inventory (Zurich 2008). Zurich's airport is operated by a privatized corporation (Unique) which has evaluated CO_2 emissions associated with airport operations dating back to 1991. The emissions inventory identifies emissions by the following sources: Air traffic (LTO cycle), handling (GSE), infrastructure (facilities), landside roads - access roads, and global air traffic. The specific methodologies used are not identified in the 2006 *Zurich Environmental Report*.

F.3.7 City and County of Denver, Greenprint Denver

The City and County of Denver prepared a city-wide and community based greenhouse gas inventory that includes a section on emissions associated with Denver International Airport – DIA (Denver 2007). Aircraft-related greenhouse gas emissions were identified based on the IPCC Tier 1 method (fuel sales/dispensed at DIA). Similar to the City of Seattle inventory, Denver apportioned the aircraft emissions to DIA based on the passengers living in the city, and based that proportion on citywide vehicle trips. The "fleet vehicle fuel use" was based on the City and County vehicle fuel use and does not appear to include airline ground support equipment. Because of the amount of waste incinerated at DIA, a separate line item (other - 6 tons) for this emission was identified. Airport facility based emissions were determined as a combination of expended electricity and natural gas, but also based on water consumption, land filled solid waste, and recycling. Ground access vehicle emissions were computed based on data from the Denver Region Council of Governments estimates of vehicular travel in the region and fuel consumption.

F.3.8 Port of Seattle Greenhouse Gas Inventory

In 2008, the Port of Seattle released a greenhouse gas inventory (Port of Seattle 2008) for the Aviation Division activities, which includes Seattle-Tacoma International Airport (SEA). The inventory identifies emissions associated with the Port of Seattle's Aviation Division as well as tenants and users of the airport. By using the ownership and control approach, emissions from sources specifically owned by the Port were separated from those of tenants as well as the public (reflecting surface travel on off-airport roadways). The inventory focused exclusively on CO_2. Emissions from aircraft were estimated using IPCC Tier 2 with fuel dispensed, and LTO-based fuel from AEDT/EDMS. GSE emissions were calculated using USEPA's NONROAD2005, whereas ground access vehicles were estimated based on vehicle travel on or off-airport, using average vehicle fuel consumption. Facility fuel use was identified and translated into CO_2 emission.

F.3.9 Aspen-Pitkin County Airport Greenhouse Gas Inventory

In April 2008, Pitkin County issued a greenhouse gas inventory (Apen-Pitkin County Airport 2008) for its aviation section that includes Aspen-Pitkin County Airport (ASE). The inventory followed the same approach discussed for the Port of Seattle's Aviation division, focused on source emissions by ownership and control and was targeted at improving upon the understanding of emissions identified by the Canary Initiative. Emissions from aircraft were estimated using IPCC Tier 2 with fuel dispensed, and LTO-based fuel from AEDT/EDMS. GSE emissions were calculated using EPA's NONROAD2005, whereas ground access vehicles were estimated based on vehicle travel on or off-airport, using average vehicle fuel consumption. Facility fuel use was identified and translated into CO_2 emission.

F.3.10 City of San Francisco – San Francisco International Airport

The City of San Francisco joined the California Climate Action Registry (CCAR) and volunteered to register its greenhouse gas emissions (San Francisco 2006). To assist the Airport Commissions, the City Department of Environment calculated CO_2 emissions associated with City owned and controlled activities using two methods: ICLEI software and CCAR software. Sources considered reflected electrical usage by both the Airport Commission (a department of the City) and airport tenants, natural gas consumption associated with the Airport Commission, and vehicle fuel use (general fleet and SFO Shuttle).

F.3.11 Port Authority of New York and New Jersey

This inventory was prepared in response to a broader sustainability plan that calls for reducing GHG emissions by 80% by the year 2050. The 2006 inventory serves as the baseline for that emission reduction goal. Included in the Port Authority's inventory were emissions associated with: La Guardia Airport (LGA), John F Kennedy International Airport (JFK), Newark (EWR), Teterboro Airport (TEB), and Downtown Manhattan Heliport.

Aircraft were evaluated primarily in the LTO cycle using IPCC Tier 2 information. However, the inventory report also identifies emissions for four airports based on fuel dispensed; fuel dispensed for the heliport is not noted. Tenant GSE emissions were evaluated using NONROAD2005. GAV travel was evaluated as "attracted travel" based on estimates of vehicle miles traveled for various vehicle types (rental car, taxi, bus, limo, private car, other and vans) using IPCC emission factors for vehicle types. Emissions associated with the JFK cogeneration plant were included using factors from USEPA's eGrid and CCAR General Reporting Protocol (CCAR 2008).