Appendix B

Analysis of Jet Fuel Consumption in Alaska and Greenhouse Gas Emissions

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List of Abbreviations

ADEC	Alaska Department of Environmental Conservation
AIA	Ted Stevens Anchorage International Airport
CCS	Center for Climate Strategies
CH_4	Methane
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalents
DOE	Department of Energy
EI	Emission Inventory
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
GHG	Greenhouse Gas
$MMtCO_{2e}$	Million Metric Tons Carbon Dioxide Equivalents
N_2O	Nitrous Oxide
SGIT	State Greenhouse Inventory Tool

1.0 Introduction

In February 2007, the Center for Climate Strategies (CCS) completed a report for Alaska entitled "Alaska Greenhouse Gas Inventory and Reference Case Projections 1990- 2020" (Roe et al., 2007). The CCS report contained the first comprehensive inventory and forecast of Alaska's Greenhouse Gas (GHG) emissions from 1990 to 2020. The report quantified GHG emissions by the following sources in Alaska: Electricity Production; Residential & Commercial; Industrial (non-fossil fuel production); Transportation; Fossil Fuel Industry; Industrial Processes; Waste Management; and Agriculture. Six types of greenhouse gases (GHG) were quantified: carbon dioxide (CO_2), methane, (CH_4), nitrous oxide (N_20), hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. Total emissions were quantified for each of the six GHG and converted to million metric tons of CO_2 equivalent ($MMtCO_2e$) based on their respective global warming potential. Not all six GHG were quantified for each source.

Table 1 provides a summary of GHG emissions, estimated by CCS, for Alaska by source for the years 1990, 2000, 2005, 2010, and 2020 (Roe et al., 2007). The GHG emission estimates for 2010 and 2020 were based on projected energy consumption for each source and various assumptions stated in the report.

Table 1. Alaska Historical and Reference Case GHG Emissions by Source (Roe et al, 2007).

Source Group	1990	2000	2005	2010	2020
Electricity Production	2.6	3.1	3.2	3.6	3.7
Residential & Commercial	3.8	4.3	3.9	3.9	4.2
Industrial (non-fossil fuel production)*	15.7	19.6	21.6	23.5	28.5
Transportation	15.1	16.8	19.0	19.6	20.5
Fossil Fuel Industry*	4.9	3.2	3.0	2.9	2.1
Industrial Processes	0.05	0.2	0.3	0.5	0.7
Waste Management	0.6	0.9	1.0	1.2	1.7
Agriculture	0.05	0.05	0.05	0.06	0.07
Total Gross Emissions	42.8	48.3	52.1	55.2	61.5

Note: All GHG emissions are in Million Metric Tons of CO_2 equivalents ($MMtCO_2e$).

The CCS report concluded that, in 2005, activities in Alaska accounted for approximately 52.1 million metric tons (MMt) of gross GHG emissions, an amount equal to 0.7% of total United States gross GHG emissions (Roe et al., 2007). The CCS report concluded that industrial (non-fossil fuel production) and transportation sources accounted for approximately 41.5% and 36.5% of the gross GHG emissions in Alaska, respectively.

* The CCS source groups "non-fossil fuel production" and "fossil fuel" industry categories are both "industrial". One deals with emissions from the combustion of fuel (the "non-fossil fuel production" source group) while the other estimates the methane emissions released during the extraction of a fossil fuel resource from the earth (the "fossil fuel industry" source group). ADEC has combined the "fossil fuel" industry numbers with the industrial source category to provide an overall picture of industrial emissions.

The release of the CCS report in 2007 was met with much interest by industry and the public in Alaska. The report provides a foundation of information on GHG emissions in Alaska. The reports broad emission source categories did not define the relative impacts of source sub-categories; such as the contribution of international cargo flights within the transportation source group.

1.1 Aviation GHG EI Objectives

The CCS GHG EI for Alaska (Roe et al., 2007) found that aviation sources accounted for the largest share of greenhouse gas emissions originating from Alaska's transportation sources. For the aviation source group, GHG emission estimates for 1990 to 2002 were based on SGIT methods and historical jet fuel consumption data obtained from EIA (Roe et al., 2007). The CCS GHG EI results for Alaska's transportation sources are summarized in Table 1.

Table 2. CCS Greenhouse Gas Emission Estimates for Alaska's Transportation Sources ($MMtCO_{2e}$) (Roe et al., 2007)

Source Group	1990	2000	2005	2010	2020
Aviation	7.2	10.6	12.9	13.0	12.9
Marine Vessels	4.4	2.4	2.4	2.6	3.0
On-road Vehicles	3.4	3.7	3.6	3.9	4.4
Rail & Other	0.08	0.08	0.12	0.13	0.14
Totals	15.1	16.8	19.0	19.6	20.5

As shown in Table 1, CCS found that aviation fuel consumption accounts for the largest share of Alaska's transportation GHG emissions. CCS estimated that emissions from aircraft increased by about 59% from 1990-2002 and were approximately 64% of total transportation emissions in 2002 (Roe et al., 2007). CCS projected that the GHG emissions from aviation sources would increase by 15% between 2002 and 2020 (Roe et al., 2007).

A key uncertainty regarding GHG emissions from aircraft is the consumption of bunker fuels. Bunker fuel consumption is primarily associated with international air flights and should not be included in the state inventory because much of it is actually consumed out of state; however, data were not available for CCS to subtract this consumption from total aviation fuel estimates (Roe et al., 2007).

Aviation activity is commonly categorized into three types of operations: commercial, general, and military aviation. Commercial aviation includes both international and domestic flights carrying passengers, cargo, or both. General aviation includes operations by private aircraft and fleets. Military aviation include only those operations occurring on Alaska's military bases. Commercial, general, and military aviation aircraft include turbojet, piston and turboprop aircraft which use a combination of jet fuel, bunker fuel and aviation gasoline. Jet fuel includes both jet naphtha and jet kerosene fuels.

Based on the initial CCS results, ADEC was interested in gaining some perspective on the distribution of GHG emissions in Alaska for the three types of aircraft operation (commercial, general, military) and what portion of these emissions are attributable to domestic flights versus

international flights. In July 2007, ADEC had its contractor, E.H. Pechan & Associates (a member of the CCS team), conduct an analysis to attribute GHG emissions ($MMtCO_{2e}$) to Alaska's commercial, general and military aviation source groups. Further, ADEC built upon this effort using available data from the CCS report, the EIA, and the Anchorage International Airport to estimate GHG emissions (MMtCO2e) attributable to international flights into and out of the Anchorage International Airport. This information provides context for the relative contribution on domestic and international flights to overall GHG emissions. The methods and results of the E.H. Pechan and ADEC jet fuel analyses are presented and discussed in this report.

2.0 Methods and Analysis

This section describes the methods used by E.H. Pechan & Associates and ADEC staff in their respective analyses of GHG emissions from the aviation source category.

2.1 E.H. Pechan & Associates' Analysis of Jet Fuel Methods

The methods used by E.H. Pechan & Associates in allocating Alaska's aviation CO2 equivalent (CO2e) emissions among the three aviation subcategories—commercial aviation, general aviation, and military aviation are described in a memo to ADEC, dated July 23, 3007, as follows:

> *Step 1: Locate activity data for Alaska that identifies these subsectors.* Ideally, the activity data that would be used to calculate this breakdown would be fuel consumption, since the greenhouse gas emissions are calculated directly from the fuel consumption data. However, the fuel consumption data available for Alaska from the Department of Energy (DOE) Energy Information Administration (EIA) only breaks the fuel consumption down by fuel type—aviation gasoline and jet fuel. The aviation gasoline is used by aircraft with piston engines, which are almost exclusively found in the general aviation subsector. However, the general aviation sector also includes a significant number of aircraft with turbine engines. Thus, the jet fuel consumption must be split among all three aviation subsectors.
>
> The Federal Aviation Administration (FAA) provides information on aircraft operations which are broken down by the commercial, general aviation, and military sector (FAA, 2007). (Note: the current version of the data available on this site differs for some years and some operation types from the data used in the Alaska report which was also used to perform these allocations.) Each aircraft operation represents a single takeoff or landing by an aircraft. These data were totaled for Alaska by year of operation and are shown in Columns B through I of the AK Aviation Breakdown.xls spreadsheet (E.H. Pechan & Associates, July 2007). This spreadsheet is available upon request from ADEC.
>
> *Step 2: Develop an appropriate emission factor in terms of operation for the three different operation types.* These emission factors, expressed in terms of metric tons of CO2e emissions per operation, were developed separately for commercial, general

aviation, and military operations based on national fuel emissions by subsector and national operations by subsector. The CO2e emissions data were available for 1990, 1995, and 1998 through 2005 (EPA, 2006 and EPA, 2007). Emissions for the intermediate years were calculated by interpolation. The national operations data by subsector were calculated for the nation based on the same FAA operations data base as that used for Alaska in Step 1 (FAA, 2007). The resulting emission factors by year and subsector are shown in Columns K through M of the spreadsheet (E.H. Pechan & Associates, July 2007), with the emission factor calculations shown on the sheet of the spreadsheet labeled CO2equiv EV calcs.

Step 3: Estimate Alaska Aviation CO2e emissions by subsector. Columns N through Q of the spreadsheet (E.H. Pechan & Associates, July 2007) show the CO2e emissions by aviation subsector calculated by multiplying the emission factors from Columns K through M by the corresponding airport operations reported in Columns B through I. This calculation was only performed for the years with sufficient data to calculate the emission factor (i.e., 1990 through 2005).

Step 4: Calculate fraction of aviation emissions by subsector. The emissions data for each subsector in Columns N through P (E.H. Pechan & Associates, July 2007) were divided by the total estimated Alaska aviation emissions for the year from Column Q. The resulting fractions of emissions for each of the three aviation subsectors by year are shown in Columns R through T. The fractions from 2005 were then copied for all remaining years, 2006 through 2020.

Columns U through X show the actual aviation emissions calculated for Alaska's greenhouse gas inventory (Roe et al., 2007). These were calculated by fuel type with the total Alaska aviation CO2e emissions shown in Column Y.

Step 5: Allocate Alaska aviation emissions by subsector. The total Alaska aviation emissions shown in Column Y were multiplied by the fractional values by subsector from Columns R through T (E.H. Pechan & Associates, July 2007). This results in an allocation of Alaska's aviation emissions by the commercial, general aviation, and military subsectors, as shown in Columns Z through AB.

The results of the E.H. Pechan & Associates analysis for allocating greenhouse gas contributions from commercial, general and military aircraft in Alaska are presented in Table 3 for the years 1990-2005.

Table 3. Alaska's Aviation Greenhouse Gas Emissions by Source Group ($MMtCO_{2e}$), (E.H. Pechan & Associates, 2007).

Year	Commercial	Gen. Aviation	Military	Totals
1990	6.6403	0.1394	0.2982	7.077938
1991	6.5813	0.1233	0.2968	7.001441
1992	5.6815	0.0978	0.2269	6.006258
1993	5.6549	0.0854	0.2574	5.997745
1994	6.0970	0.1018	0.2632	6.461931
1995	6.5190	0.1073	0.2419	6.868201
1996	7.1662	0.1120	0.1919	7.470163
1997	8.1289	0.1609	0.2455	8.535375
1998	8.4779	0.1832	0.2260	8.887077
1999	9.4222	0.2280	0.2304	9.880595
2000	10.0342	0.1967	0.2506	10.48151
2001	9.3592	0.1961	0.2283	9.783601
2002	10.6094	0.2172	0.2237	11.05033
2003	11.1310	0.2226	0.2309	11.58445
2004	11.6539	0.2303	0.2603	12.14447
2005	12.2360	0.2479	0.2477	12.73165

2.2 ADEC Analysis of the Contribution of International Flights

ADEC staff used the following approach in analyzing the international component of commercial aviation GHG emissions in Alaska:

1. Data was gathered on the amount of fuel consumed at the Ted Stevens Anchorage International Airport (AIA) and the proportion of the fuel that is delivered for international flights. It was assumed that the vast majority of international flights would transit from AIA.
    - The AIA reports that in 2005 nearly 903,000,000 gallons of Jet fuel were consumed (AIA, 2006).
    - According to discussions with Aircraft Service International Group, the primary provider of fuel to AIA nearly 92% of the fuel delivered to the airport was for international flights (pers. comm. to J. Murphy, 2007).

2. Given these data, ADEC calculated the amount of jet fuel consumed in international flight from AIA.
    - 810,000,000 gallons of Jet fuel were consumed in international flights

3. Staff then converted the volume of jet fuel consumer into heat content. It was assumed that Jet A has a heat content of approximately 135,000 Btu per gallon.

- The Btu content of the Jet A consumed by international flights in 2005 is approximately 109.35 trillion Btus.

4. Staff then calculated the proportion of jet fuel consumed in international flights using the heat content of the fuel used in international flights from AIA to the total heat content of jet fuel statewide. The Energy Information Administration reports in 2005 that 181 trillion Btus of jet fuel were consumed in Alaska statewide (EIA 2005).
    - International flights consume 60.38% of all jet fuel sold in the state.

5. Staff then calculated an estimate of GHG emissions from international flights. The initial CCS reported GHG emission estimates were based on the Btus of fuel consumed in state. If international flights are theoretically responsible for 60.38% of the Btus of fuel consumed in state this should translate directly to the emissions.
    - CCS estimated the statewide MMtCO2e emissions from the consumption of Jet Fuel in 2005 were 12.67 MMtC02e. Thus, if 60.38% of fuel (and Btus) are consumed by international flights out of Anchorage, then 7.65 MMtCO2e were emitted from international flights in 2005.

While this analysis of international flights is cursory at best, it does provide some insight into the relative magnitude of these flights to the overall emissions from aviation sources.

Table 3 allocates greenhouse gas contributions from commercial, general and military aircraft in Alaska in 2005, including a breakdown of domestic and international commercial flights. Figure 1 shows a breakdown of the aviation emissions by operational subcategory including the domestic and international commercial flight breakdown.

Table 4. Alaska Aviation Emissions Allocated by Subcategory for 2005, Including Domestic and International Commercial Flights

GHG Emissions by Aviation Subcategory, MMtCO2e (%)				
	Commercial		General	
Year	Domestic	International	Aviation	Military
2005	4.59 (36%)	7.65 (60%)	0.25 (2%)	0.25 (2%)

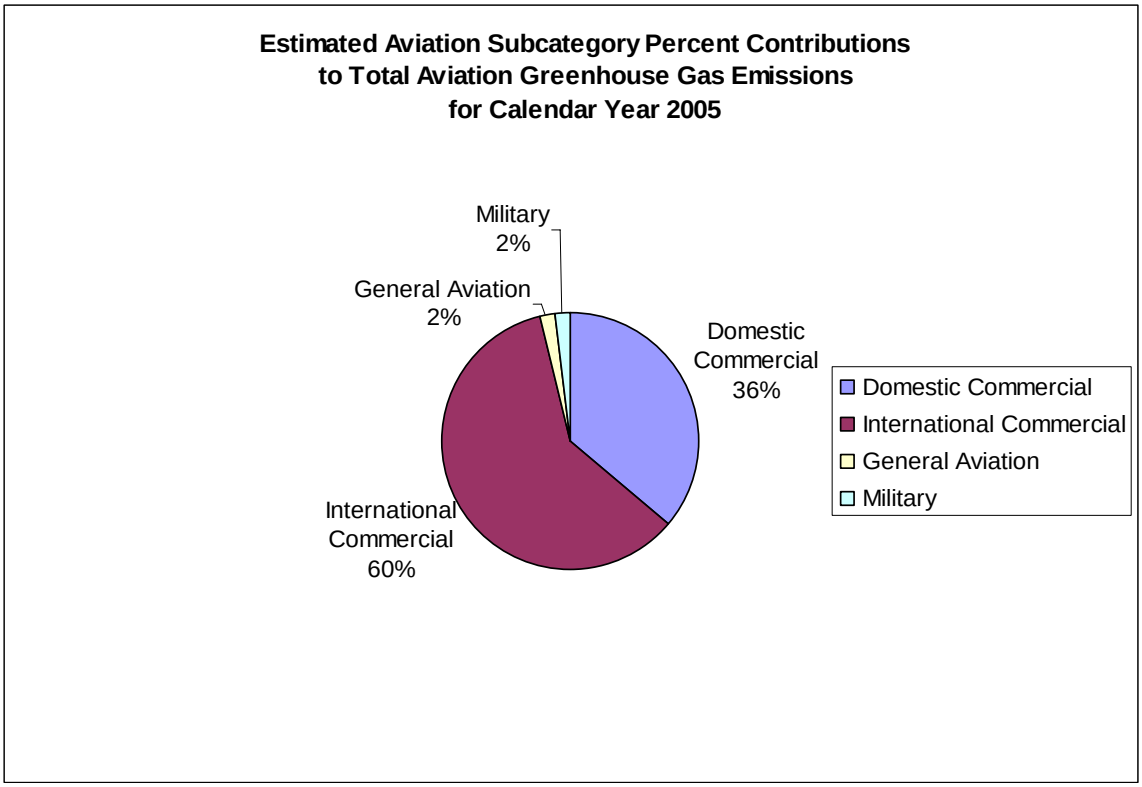

Figure 1. Aviation Subcategory Emission Percentages

3.0 Discussion of Results

The results of the E.H. Pechan & Associates' analysis of aircraft emissions in Alaska indicate that the commercial aircraft source group contributed the greatest amount of greenhouse gas emissions for the years 1990-2005. In deriving these estimates, the contractor allocated all CO_2 emissions from bunker fuels to the commercial aircraft source group. This may over allocate greenhouse gas emissions to the domestic commercial aircraft source group for Alaska because bunker fuel is used in international flights and by general and military aviation aircraft as well. The results of ADEC's additional rough estimation of the international flight contribution to the commercial aircraft sector shows that international flights are a major consumer of jet fuel sold in Alaska and thus appear to be a significant emitter of greenhouse gas emissions.

4.0 Conclusions

The greenhouse gas emission estimates for aviation source groups in Alaska, provided by E.H. Pechan & Associates, provide some additional insight about the types of aircraft operations (commercial, general, military) in Alaska that contribute to GHG emissions. The commercial aviation subcategory is by far the largest contributor to overall aviation GHG emissions.

ADEC's cursory analysis and rough estimation of the international flight contribution to the commercial aviation sector indicates that this subcategory of flights is likely a significant emitter of greenhouse gases. The air freight industry uses Anchorage as a major stopping point for global shipping to take advantage of favorable jet fuel prices to support strategic re-fueling on their international routes. While international flights commonly re-fuel in Alaska that fuel is then primarily burned outside the state. At this time, these international emissions are being included in Alaska's overall emission inventory as ADEC does not have sufficient information to determine the quantities of fuel burned within Alaskan airspace.

Additional data and improved methods would be helpful to future greenhouse gas emission estimates for Alaska's aviation sources. In particular, future efforts should ideally attempt to include:

- Alaska specific fuel data (activity data) for each airport and military base in Alaska. Alaska specific aviation fuel data are required to further define how much and what type of aviation fuels (gasoline, bunker fuel, jet fuel) are being used by the commercial, general, military aviation source groups.

- A breakdown of the number and types of planes and their engines, as well as the amount and type of each fuel used by each plane, within the commercial, general and military aircraft source group.

- A more refined method for determining how much fuel is being combusted during in-state flights versus out-of-state and international flights for each source group.

- Fuel specific emission factors for aviation fuels and documented literature references for these factors and estimation methods.

5.0 References/Data Sources:

A.I.A, 2006: Anchorage International Airport, “Airport Overview Presentation”, November 14 2006,
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